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Enteric redmouth disease: Past, present and future: A review

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Abstract

Enteric red mouth disease (also known as Yersiniosis) is one of the most significant bacterial infections in coldwater fish farms that cause significant mortalities and economical losses in the salmonids fish farms, especially in rainbow trout (Oncorhynchus mykiss). ERM is caused by the gram negative pathogen bacteria Yersinia ruckeri that has five O-serotypes (O1, O2, O5, O6 and O7), five outer membrane protein types (OMP types 1–5) and two biotypes 1 and 2. The disease has a wide geographical distribution in various fresh or sea water fish. More than twenty species mainly of Salmonide origin have been affected and this number is likely to rise in the future following the introduction of new species and the increase of aquaculture trade. The disease can affect fish of all age classes but is most acute in small fish up to fingerling size. Affected fish may reveal different clinical symptoms depending on species, age and temperature. The most characteristic and common clinical signs of the disease include lethargic behavior and inactivity, swimming near the surface, anorexia, and darkening of the skin. The reddening of the throat and mouth, caused by subcutaneous haemorrhaging and exophthalmos are commonly present. Different diagnostic methods have been used for Y. ruckeri, including culturing, serological, biochemical tests, histopathological studies and molecular techniques. This review summarizes the past, present and future state of yersiniosis with emphasis on status of this disese in Iran. Also, some criteria in diagnosis, control and prevention of ERM were discussed.

Keywords: Enteric redmouth disease, *Yersinia ruckeri*, Diagnosis, Control and preventation

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Introduction

Enteric redmouth disease (ERM) or Yersiniosis is a systemic bacterial infection and one of the significant diseases in farmed fish. especially salmonids (Gregory et al., 2010). Yersiniosis is caused by Gramnegative bacteria that belonged to a member of the family Enterobacteriaceae with the name of Yersinia ruckeri (Argenton et al., 1996; Soltani et al., 2014). The pathogen was first isolated from rainbow trout Oncorhynchus mykiss, in the Hagerman Valley of Idaho, USA, in the 1950s (Rucker, 1966). At present, Yersiniosis been isolated from different continent including the USA (Arias et al., 2007; Bastardo et al., 2011; Haig et al., 2011), Europe (Austin et al., 2003; Fouz et al., 2006; Tobback et al., 2007; Wheeler et al., 2009; Welch et al., 2011; Chettri et al., 2013), Australia (Carson and Wilson, 2002; Keeling et al., 2012), Africa (Hussein et al., 1997; Eissa et al., 2008) and (Zorriehzahra et al., 2002; Akhlaghi and Sharifi, 2008; Adel et al., 2013; Soltani et al., 2014; Fadaeifard et al., Yersiniosis is the second 2014). bacterial disease in coldwater fish farms in Iran and 15 epidemic outbreaks of this bacterial disease were reported in the country's provinces especially from Mazandaran, Tehran, Lorestan and Chaharmal Bakhtiari provinces during 2012-2013 (Zorriehzahra et al., 2012; Soltani et al., 2014). The bacterium responsible for economic losses is numerous in salmonid and nonsalmonid fish species, reared in both fresh and marine waters, especially rainbow trout (Austin and Austin, 2003; Fadaeifard *et al.*, 2011).

Aetiology

Morphological and genomic characteristics

Y. ruckeri is a gram-negative rod with rounded ends of 0.5- 0.8×1.0 - $3.0 \, \mu m$ in size (Gregory et al., 2010). This bacterium does not form endospores, a capsule is not present, but often has flagella and Y. ruckeri strains show variable motility (Bastardo et al., 2011). It was demonstrated that Y. ruckeri isolates had a G + C ratio of 47.5-48.5% (Ewing et al., 1978).

Several studies showed that Y. ruckeri is a highly clonal and biochemically homogeneous species (Wheeler et al., 2009). At present, five O-serotypes (O1, O2, O5, O6 and O7), five outer membrane protein types (OMP types 1-5) and two biotypes of Y. ruckeri are recognized. Romalde et al. (1993) proposed that serovar O1 can be subdivided into two subgroups O1a (previously serovar I) and O1b (serovar III) and serovar O2 (serovar II) into three subgroups O2a, O2b and O2c. Biotype 1 strains are positive for motility and lipase activity, whereas biotype 2 strains are negative for both tests (Strom-Bestor et al., 2010; Kumar et al., 2015).

Results showed that, most epizootics and mortality of Yersiniosis are caused by biotype 1 strains (Garcia *et al.*, 1998; Arias *et al.*, 2007). In addition, *Y*.

ruckeri strains can be grouped into clonal types on the basis of biotype, serotype and outer membrane protein (OMP) type into 6 major clonal groups. Clonal group 5 isolates (include the Hagerman type strain) are the most prevalent cause of Yersiniosis in mainland Europe and the US, while clonal group 2 isolates are responsible for ERM in the UK (Davies, 1991; Fouz *et al.*, 2006).

It was confirmed that, clonal groups 2 and 5 are predominantly associated with rainbow trout. Strains of serotypes O1a (classic serovar I) and O2b (classic serovar II) cause most epizootic outbreaks, and serotype O1a (heatstable O1 antigen) is predominant in cultured salmonids (Arias et al., 2007). Annotated whole genome sequences of two strains of Y. ruckeri are currently available: the motile CSF007-82 strain, isolated from diseased rainbow trout and the motile O1b 37551 strain, isolated from vaccinated Atlantic salmon (Salmo salar) (Navas et al., 2014; Nelson et al., 2015). In previous studies, several virulence mechanisms of Y. ruckeri including: extra-cellular products (such as the iron-regulated Serratia-like haemolysin YhlA. azocasein protease. 47 kDa metalloprotease Yrp1), yrpA and yrpB (Secades and Guijarro, 1999) and a heat sensitive factor (HSF) have been identified (Navais et al., 2014).

Taxonomic characterization and phylogenetic analysis

The taxonomic position of Y. ruckeri has been subject to debate since its first classification in the genus Yersinia by Ewing et al. (1978). This study demonstrated that Y. ruckeri isolates had a G+C ratio of 47.5 - 48.5%, and on this basis it would be included in the genus Yersinia. Other researchers found that the biochemical characteristics of Y. ruckeri have more similarities with Serratia and Salmonella (Llewellyn, 1980). This bacterium with 47.5-48% G + C (Fouz et al., 2006) differs clearly from Serratia species (52-60% G+C) and is closer to other Yersiniae (46-50% G+C).

Kotetishvili et al. (2005) used multilocus sequence typing (MLST), and considered that Y. ruckeri was the most genetically distant species within the genus Yersinia, and that the taxonomic status possibly needs to be reassessed (Wheeler et al., 2009). From the results of many studies and the similarities with many other members of the Enterobacteriaceae, Y. ruckeri could possibly belong to its own separate genus. DNA studies based on cytosine guanine plus percentage content of total DNA initially resulted in classification of this organismas as a new species of Yersinia (Kotetishvili et al., 2005). Several studies demonstrating heterogeneity in biochemical (Daly et al., 1986) and antigenic characteristics resulted in Y. ruckeri isolates being classified (Davies

and Frerichs, 1989) into five serovars (Wheeler *et al.*, 2009).

Molecular analysis based on nucleic hybridization and sequence analysis of 16S rDNA of the Y. ruckeri genome has been conducted determine the phylogeny this organism (Ibrahim et al., 1993). Based on DNA hybridization and G 1+C ratios, Y. ruckeri was found to be only 30% related to other Yersiniae and Serratia. however. 16S rDNA similarities between Y.ruckeri and other Yersiniae was as high as 98.3% (Ibrahim et al., 1993). Dot-blot DNA hybridization assays also demonstrated a high level of genetic relatedness among Y. ruckeri serovars (Kotetishvili et al., 2005).

Hosts and geographical distribution

Yersiniosis is one of the most common diseases in salmonids, especially in juvenile rainbow trout, but it was also reported from seawater in several other fish species, and in both farmed and wild fish. Some of the host species of *Yersinia ruckeri* are shown in Table 1.

Y. ruckeri is highly contagious and has been reported in several fish species in North and South America, Australia, New Zealand, Africa, Europe and Asia especially in Iran and Turkey (Tobback et al., 2007; Keeling et al., 2012; Soltani et al., 2014).

Clinical signs

Redmouth disease takes place as acute to chronic forms (Woo and Bruno, 2011; Kumar *et al.*, 2015). Yersiniosis

is most acute in small fish up to fingerling size (Tobback, 2009; Şeker et al., 2011). Pre-acute to acute infection usually occurs in the spring and in the beginning of summer, during periods of rising water temperatures (Eissa et al., 2008; Seker et al., 2011). Acute to subacute infections usually appear in yearling fish in the fall and early winter with declining water temperatures (Eissa et al.. 2008). The acute epizootics can result in severe mortalities (30-70%) depending on the size of fish, stress condition, water temperature and individual susceptibility and are also assiocaited with strain virulence (Furones et al., 1993; Noga, 2010).

Like other bacterial septicaemia there are no specific early signs of disease for ERM except in small fry, where mortality may be seen without clinical signs (Altinok et al., 2001). Observable signs (Fig. 1) of the disease lethargic include behavior inactivity (Tobback et al., 2007; Austin and Austin, 2012), swimming near the surface (Keeling et al., 2012), anorexia (Carson and Wilson, 2002), darkening of the skin (Woo and Bruno, 2011). Prolapse and hemorrhages in the anus has been observed in many cases and could be counted as a specific sign for ERM (Seker et al., 2011). Fish infected with Y. ruckeri are often jadish and found in areas of low flow.

Table 1: Some of the host species of Yersinia ruckeri.

| Common name | Scientific name | Reference |
|-------------------|------------------------|--------------------------------------------|
| Rainbow trout | Oncorhynchus mykiss | (Chettri et al., 2013; Fadaeifard et al., |
| | | 2014; Soltani et al., 2014, etc.) |
| Arctic charr | Salvelinus alpines | (Tinsley, 2010) |
| Atlantic salmon | Salmo salar | (Rintamäki et al., 1986; Valtonen et al., |
| | | 1992; Bastardo et al., 2011) |
| Cod | Gadus morhua | (Tinsley, 2010) |
| Coalfish | Pollachius virens | (Michel et al., 1986) |
| Sturgeon | Acipenser sturio | Vuillaume et al., 1987 |
| Amur Sturgeon | Acipenser schrencki | (Shaowu <i>et al.</i> , 2013) |
| Sole | Soleidae sp. | (Michel et al., 1986) |
| Nile tilapia | Oreochromis niloticus | (Eissa <i>et al.</i> , 2008) |
| Brown trout | Salmo trutta | Mc Daniel, 1971) |
| Gudgeon | Gobio gobio | (McDaniel, 1971) |
| Turbot | Scophthalmus maximus | (Michel et al., 1986) |
| Goldfish | Carassius auratus | (McArdle and Dooley-Martyn, 1985) |
| Common carp | Cyprinus carpio | (Fuhrmann et al., 1983; Berc et al., 1999) |
| Indian major carp | Cirrhinus mrigala | (Manna <i>et al.</i> , 2003) |
| Eel | Anguilla Anguilla | (Fuhrmann <i>et al.</i> , 1983) |
| Pike | Esox lucius | (McDaniel, 1971) |
| African catfish | Clarias gariepinus | (Abd-El Latief, 2001) |
| Minnows | Pimephales promelas | (Michel et al., 1986) |
| Channel catfish | Ictalurus punctatus | (Danley et al., 1999) |
| Sea bass | Dicentrarchus labrax | (Savas and Ture, 2007) |
| Char | Salvelinus leucomaenis | (Sakai <i>et al.</i> , 2012) |
| Whitespotted char | Salvelinus leucomaenis | (Sakai <i>et al.</i> , 2012) |



Figure 1: Hemorrhage and red spots in mouth cavity (A), darkening and exophtalmia (B), hemorrhage and abdominal distention (C, d) of naturally *Yersinia ruckeri* infected rainbow trout (Zorriehzahra *et al.*, 2002; Adel *et al.*, 2015).

Also, fish with chronic Yersiniosis may display dark pigmentation (Fig. 1) or depigmentation in the skin (Tobback *et al.*, 2007).

The reddening of the throat and mouth cavity resulted from subcutaneous haemorrhaging and from which it has led to its present name (Carson and Wilson, 2002; Woo and Bruno, 2011). Haemorrhages are found on the external surface, at the base of the fins, at the gill tips, and around the lateral line (Bastardo et al., 2011; Huang et al., 2013). The involved fins haemorrhagic in the congestion comprise the pectoral and pelvic, anal caudal fins (Carson and Wilson, 2002; Seker et al., 2011). Shaowu et al. (2013) observed that the disease in Amur sturgeon (Acipenser schrencki) showed obvious hemorrhages around the mouth, at the lower jaw, the base of the pectoral fins, the abdomen, and the urogenital pore as the main external signs.

atypical infections of In hemorrhages are observed on the mouth gill operculum (Bullock Cipriano, 1990; Woo and Bruno, 2011); sometimes show abnormal behavior and may become dark and swim near the surface (Bullock and Cipriano, 1990) thus lack of classic 'redmouth' does not deny infection with Y. ruckeri (Tobback et al., 2007). frank There are patches haemorrhagic congestion on the iris of the eye, is a feature for the epithet salmonid blood spot disease (Carson and Wilson, 2002; Keeling et al., 2012).

Tissue tropism

Similar to other septicemic bacterial diseases, Y. ruckeri causes generalised haemorrhaging over the external and internal organs. Tissues tropism of versinosis has seen in hematopoietic organs including anterior and posterior kidney, liver and spleen. But in the chronic or acute forms of Yersiniosis, histopathological changes were observed in other organs such as cecae. stomach, intestine, pyloric pancreas, swim blader, body muscles and etc. (Zorriehzahra et al., 2009; Fadaeifard et al., 2014).

Transmission routes

Transmission is primarily horizontal from fish to fish by direct contact with infected fish or carriers. The role of carrier fish is important during Y. ruckeri infections. Diffirent studies showed that wild animals, such as birds, invertebrates and even wild fish, humans could act as vectors for Y. ruckeri (Tinsley, 2010). Hunter et al. (1980) discussed the importance of stress inducted transmission of Y. ruckeri from asymptomatic carriers to healthy fish. It was found that the organism was shed in the faeces over 36-40 day cycles. The organism may remain for up to 2 months in pond mud (Tinsley, 2010). Y. ruckeri has been recovered from the aquatic environment, including water, faeces and sewage sludge and from human bile (Farmer et al., 1985; Coquet et al., showed 2002). Results while asymptomatic fish can remain carriers for an indefinite period of time, major stressors, such as an increase in temperature, can trigger an increase of pathogen shedding and increase the probability of horizontal transmission to healthy fish (Hunter *et al.*, 1980).

Vertical transmission has not been demonstrated (Tinsley, 2010). probably does not occur. Although, Y. ruckeri from chinook salmon (Oncorhynchus tshawytscha) eggs was reported, highlighting that vertical transmission could be a possibility; further evidence of this issue has not yet been provided (Tinsley, 2010). Although, the presence of Y. ruckeri DNA in ovarian fluids and unfertilized eggs of Chinook salmon (Oncorhynchus tshawytscha) indicates that vertical transmission of the Y. ruckeri from females to their progeny is possible (Richard et al., 2014).

Diagnostic methods

Different diagnostic methods have been used for *Y. ruckeri*, including culturing, serological, biochemical tests, histopathology studies and molecular techniques (Altinok *et al.*, 2001; Kubilay and Timur, 2001; Bastardo *et al.*, 2012; Kumar *et al.*, 2015).

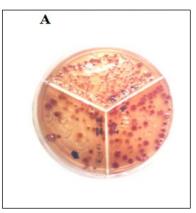
Media culture isolation

Y. ruckeri can be grown on simple culture media such as blood agar and Tryptone Soya Agar (TSA) that is are commonly media for identification of bacteria (Fig. 2). After incubation for 48 h at 25°C, off-white, opaque colonies of approximately 2-3 mm in

diameter were observed. Also, *Y. ruckeri* grows readily on MacConkey agar and Xylose Lysine Desoxycholate (XLD) agar. In addition, this bacterium can tolerate bile salts, the selective component in a number of media used for the isolation of enteropathogenic *Enterobacteriaceae*.

The Shotts-Waltman medium is a semi-selective indicator medium for Y. ruckeri, with inhibitory properties equivalent to MacConkey agar (Shotts, 1991). The indicator is based on the ability of Y. ruckeri to hydrolyse Tween 80, and inability to produce acid from sucrose (Shotts, 1991). In secondary infection with other bacteria, samples should also be cultured on plates of **XLD** agar (Oxoid CM469) Ribose preferably Ornithine Desoxycholate (ROD). agar moderately selective indicator medium for Y. ruckeri (Tinsley, 2010). Also, ROD can be useful for the detection of Y. ruckeri in faeces of carrier fish and can detect both biotypes 1 and 2 (Tinsley, 2010). The density of Y. ruckeri in faecal samples tends to be low in carriers and, typically, few colonies of Y. ruckeri will be evident on culture plates.

Yersinia Selective Agar is a selective and differential medium supporting good growth of *Y. ruckeri* and some *Yersinia* spp such as *Y. enterocolitica* (Fig. 2).



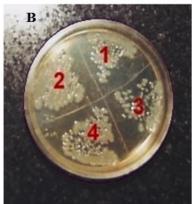


Figure 2: Pure culture of *Yersinia ruckeri* on Yersinia selective agar (CIN Agar Base/Schiemann Medium Base) (A) and Tryptic Soy Agar (B) after incubation at 25°C for 48 hours (Zorriehzahra *et al.*, 2013).

Yersinia Selective Agar was first described by Schiemann (1979) as an alternative to MacConkey Agar and other commonly used media for isolation of *Y. ruckeri*, a causative agent of Yersiniosis.

Histopathology assay

The histopathology assay could be a supportive diagnosis method regarding the lack of pathognomonic lesions in Yersiniosis. According to obtained findings in recent years, the most important histopathological changes in varied tissues could be distinguished as follows:

Skin:

Skin of infected rainbow trout shows an increase in mucus cells that has a relation with marked epidermal hyperplasia. Also, thinning of the stratum spongiosum and red muscle degradation was observed (Tobback *et al.*, 2009).

Gills:

In gill tissue often hypotrophy and hyperplasia of the epithelial cells on the filaments and lamellae were observed along with lamellae destruction that leads to fusion and clubbing (Fig. 3). Furthermore, capillary dilatation of the lamellae and diffused haemorrhages in both the lamellae and filaments could be observed (Adel *et al.*, 2014).

Kidney:

Obvious changes could be found in the posterior kidney. Pathological sections were revealing large amounts of congestion with blood suggesting loss of haemopoeitic tissue. Noticeable changes in kidney tubule structure in sample later into the infection are due slight interstitial haemopoeitic hyperplasia. So, glomerular nephritis, melanin deposits and destruction of the renal tubules could occur. Also, severe necrosis may be seen in haemopoietic tissues of anterior and posterior parts of the kidney (Tobback et al., 2009; Woo and Bruno, 2011).

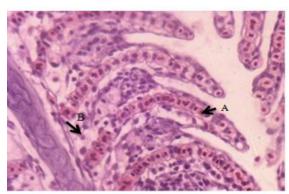


Figure 3: Hyperplasia (A) necrosis and lifting of the pilar cell (B) in gill tissue of rainbow trout infected by yersiniosis (Adel *et al.*, 2014, H&E. X40).

Furthermore, pyknotic cells in the lumen and glomerulus are observed, suggesting that the cells are going through apoptosis. Basophilic immature kidney tubules are often visible, highlighting signs of regeneration. Melano-macrophages cells in the kidney often increase throughout the course of the infection (Mahjoor and Akhlaghi, 2012).

Liver:

Heart:

Liver sections often displayed marked areas of necrosis with diffused areas lipidosis of hepatocytes. So, hyperplasia of necrotic foci and blood congestion should be anticipated (Tinsley, 2010).

Pathological observations in rainbow trout heart originated from infection procedure. So, hyperplasia of the epicardium and myocardial necrosis are observed in acute infectious cases (Avci

et al., 2005).

Enzyme-Linked Immunosorbent assays (ELISA)

Different diagnostic methods have been developed for *Y. ruckeri*, including

serological culturing, tests and molecular biological techniques (Tobback, 2009). Some methods may be used in detecting Y. ruckeri such as enzyme-linked immunosorbent assay (ELISA), agglutination and immunofluorescence antibody technique (IFAT), based on serological characteristics (Tobback, 2009; Woo and Bruno, 2011).

Since leukocyte phagocytosis, antibody production and lymphocyte proliferation are activated in fish infected by *Y. ruckeri* (Tobback *et al.*, 2007), ELISA can be important to detect and determine amount of specific antibodies in fish. Antigen detection has been utilised either in studies or commercially in plate using specific antibodies in ELISA formats (Romalde *et al.*, 1995).

Enzyme linked immunosorbent assays (ELISA) have been improved to detect antibodies against *Y. ruckeri* in rainbow trout. The tests have proved to be more sensitive than the agglutination test (Olesen, 1991; Furones *et al.*, 1993; Tobback *et al.*, 2007).

In a study, the quick diagnosis of cases of **ERM** clinical using antibody-based monoclonal **ELISA** indicated value of a novel approach using a dipstick-ELISA which was a method easily adaptable for field use. However, it was investigated the technique was used for the confirmation of clinical cases of ERM and didn't have usage for finding sub-clinically infected or carrier fish. Probably because of this lack of sensitivity, the ELISA method has not been greatly used in the diagnostic field (Furones et al., 1993).

Immunofluorescence antibody test (IFAT)

Immunofluorescence antibody test is an important method for screening of Y. ruckeri (Kubilay and Timur, 2001). In this method preparing by histopathological sections from the kidney or other tissues such as spleen, liver, and staining with specialized Immunofluorescence technique indicates the localized bacteria in kidney and haematopoietic tissues (Fig. 4). The binding of antibodies to target tissues, cells or organisms can be visualized if those antibodies directly coupled to a fluorochrome or indirectly bound by a fluorescent reagent. Fluorochromes emit visible light (of an 'emission' wavelength) when exposed to light of a different wavelength, usually in the ultraviolet range (Kubilay and Timur, 2001).

Molecular assays

Nowadays, Polymerase Chain Reaction (PCR) has been able to represent a widely-used alternative to traditional identification methods (Eissa et al., 2008). Many of them are based on the amplification of 16S ribosomal RNA (16S rRNA) genes (Fig. 5), to find out various bacterial fish pathogens (Bastardo et al., 2012; Fadaeifard et al., 2014). This PCR assay is able to demonstrate low amounts of Y. ruckeri and provides the possibility to find asymptomatic carrier fish, this matter is highly important in order to inhibit the transmission and release of ERM into the environment (Tobback et al., 2007).

It has been recommended that isolation in pure culture, afterwards identification, by amplification and sequencing of the 16S rRNA gene using the universal bacterial primers 27F and 1492R as the gold standard provide a very strong diagnostic method (Woo and Bruno, 2011). Also 16S rDNA PCR assay has been employed to identify or confirm the presence of *Y. ruckeri* in several studies (Akhlaghi and Sharifi, 2008; Bastardo *et al.*, 2012).

Altinok *et al.* (2001) evaluated a PCR method for detecting *Y. ruckeri*, in the blood of rainbow trout. In this study, the authors demonstrated that a non-lethal blood sample can be used with PCR to find *Y. ruckeri*. Şeker *et al.* (2011) extracted DNA from blood samples and carried out PCR amplification based upon a pair of *Y. ruckeri* specific primers, as well.

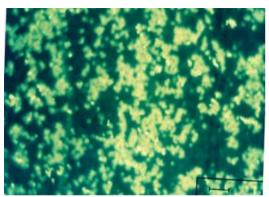


Figure 4: IFAT assay to diagnosis of *Yersinia ruckeri* isolated from rainbow trout (x 40, Zorriehzahra *et al.*, 2013).

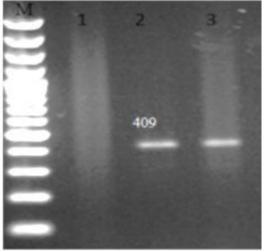


Figure 5: Electerophoretic analysis (2% agarose gel) of DNA amplified fragments from 8 isolates in this experiment. M: marker (100 bp), Lane 1: negative control, Lane 2: the isolated bacteria (409 bp), Lane 3: positive control, (Adel et al., 2013).

However, the quantitative PCR (qPCR) method is speedily replacing other molecular techniques for detecting the nucleic acids of pathogens (Purcell et al., 2011). This method is abe to detect and quantify DNA targets by scanning PCR product accumulation in the beginning of exponential phase of amplification, shown by increased fluorescence (Bastardo et al., 2012). QPCR assays can be used to detect the pathogen within fish tissues, which can be useful to investigate a continuous carrier state or the beginning of an epizootic by comparison with threshold levels of pathogen load prior to significant losses (Taylor *et al.*, 2009). Thus, real-time qPCR methods would be used for the detection of several fish pathogens such as *Y. ruckeri* (Glenn *et al.*, 2011; Bastardo *et al.*, 2012). Several researchers have developed, a real-time primer/probe set for detecting and quantifying the amount of *Y. ruckeri* DNA found in various samples of fish exposed to *Y. ruckeri* (Glenn *et al.*, 2011; Zorriehzahra *et al.*, 2013).

Intraspecific genetic diversity among Chilean *Y. ruckeri* strains can be indicated using genotyping analyses by

enterobacterial repetitive intergenic (ERIC-) repetitive consensus and extragenic palindromic (REP-) PCR methods (Bastardo et al., 2011). Huang (2013) in another study, al.characterized Y. ruckeri originated from rainbow trout by biochemical profiling, rDNA sequencing, repetitive sequence-based PCRs, including (GTG) 5 -PCR, BOX-PCR, ERIC-PCR and REP-PCR.

Treatment, control and prevention methods

Antimicrobial compounds

The use of antimicrobial compounds has been implemented in the treatment of Y. ruckeri infections in fish since several years ago (Gudding and Van Muiswinkel, 2013). Rucker (1966) described treatment with sulphamethazine for 5 days, followed by three days of chloramphenicol or oxytetracycline administration. Indeed, sulphonamide therapy has been of great in the treatment of both experimental and natural cases (Bullock et al., 1983). Furthermore, Rodgers and Austin (1983) used oxolinic acid for prophylaxis and treatment Yersiniosis in rainbow trout. Although Y. ruckeri is susceptible to various antibiotics, there is acquired resistance Y.ruckeri strains to many antimicrobial compounds. Post (1987) reported the absolute resistance of some isolates of Y.ruckeri in the USA to therapeutic levels of both sulphamerazine and oxytetracycline. By exposing bacteria to inadequate or variable dosage, failure to complete the recommended course or by repeated short term treatment, will probably lead to selection for drug resistance (Rodgers, 2001).

Vaccination

Vaccines against ERM are one of the success scenarios of disease control in aquaculture, with the first commercial product released in 1976 and are composed of formalin-killed whole bacterial cells. Soltani *et al.* (2013) expressed to establish a new native vaccine against *Y. ruckeri* that could protect sensitive rainbow trout in Iran. The level of mortality in immunized groups was in the range of 10-20% within 10 weeks after vaccination, in contrast to those of control group was in range 56.7-73.3% (*p*<0.05).

Tinsley et al. (2011) and Deshmukh et al. (2012) developed a bivalent vaccine using formalin inactivated biotypes 1 and biotype 2 Y. ruckeri strains that provides good protection against the biotype 2 strains in rainbow New vaccines have trout. been developed that are based on the Y. ruckeri Yrp1 protease, aroA gene, extracellular product lipopolysaccharide and these provide good protection against Y. ruckeri biotype strains which 1 administered by several routes such as immersion, injection and oral (Deshmukh et al., 2014; Ispir and Dorucu, 2014). Nowadays, some nonmotile strains seem to be unaffected by commercial vaccines (Kim and Austin, 2006; Fouz et al., 2006). Thus, novel ways based on subunits or DNA might vaccines be an additional approach to eliminate or minimize this diasease. Recently, attention to the use of live attenuated vaccines against pathogens fish bacterial increased, because they can provide effective protection. Totally, reduce a greater cell-mediated response than bacterins, although the higher immunity caused by attenuated bacteria in comparison with that provided by killed organisms is likely due to the induced expression of stress proteins (Temprano, 2005).

Immunostimulants

Recently, interest in the use of natural immunostimulants in the protection of fish against bacterial fish pathogens has increased. In addition, resistance to bacterial pathogens can be improved by administration of immunostimulants to increase the effectiveness of vaccines. β -hydroxy- β -methylbutyrate (HMB) is a breakdown product of the amino acid leucine which is an essential building unit of proteins in all tissues and provided a positive immunostimulatory effect after in vivo immunization of rainbow trout with anti-Y. ruckeri vaccine (Raida, 2003). Immunostimulating effects against Y. ruckeri were also observed in rainbow trout using levamisole bathing (Ispir and Yonar, 2007). Nowadays, herbal plants as immunostimulant agents are used in many countries such as Iran, India, China, against fish etc.

pathogens. The findings of Adel (2014) demonstrated that the use of M. piperita extract, particularly at the rate of 3% can increase the survival rate of rainbow trout when exposed to Y. ruckeri. Some researchers have examined antibacterial activity Zataria multiflora, Nigella sativa. Scutellaria multicaulis. Punica granatum, Olea europaea, Echinacea purpurea (Alishahi, 2012) Lavandula officinalis, Melissa officinalis, Ocimum basilicum. Origanum vulgare, officinalis Rosmarinus Salvia officinalis on Y. ruckeri in in vitro condition (Bulfon, 2014).

Application of certain probiotics to reared trout enhanced their survival when exposed to *Y*. ruckeri. Administration of feeds supplemented with **Bacillus** subtilis and licheniformis (4 x 10⁴ spores g⁻¹ feed) raised resistance in rainbow trout against withering caused by Y. ruckeri 2003). Similarly, feed (Raida, supplemented with Carnobacterium maltaromaticum or C. divergens dosed at>107 cells g-1 feed also induced protection against challenge with Y. ruckeri because these cultures improved cellular and humoral immune defences (Kim and Austin, 2006). When rainbow trout fed with 108 cells Enterobacter cloacae and Bacillus mojavensis g-1 feed for 60 days, it led to a significant enhanced survival of the fish after bath challenge with Y. ruckeri (Capkin and 2009). Moreover, Altinok, (2010) showed that biotype 2 infections of Y. ruckeri could be inhibited by cellular components of certain probiotic bacteria.

Future prospects

Despite passing almost 50 years after the first report of the ERM disease (Rucker, 1966), some important issues still remain unresolved or not fully understood. particularly concerned with the mechanisms of transmission, disease spreading and the role of asymptomatic carrier fish. Furthermore, in some cases of Y. ruckeri occurrence, the possibility of vertical transmission has been suggested; nevertheless it has not yet been definitively demonstrated whether it is a real vertical transmission or, rather, a phenomenon of egg shell contamination which is more probably what will happen. If so, it would be just a matter of finding an effective disinfection procedure, which inhibit the transmission of the disease affected broodfish offspring and produced eggs (green eggs and eyed eggs).

Otherwise, in the presence of a true vertical transmission, the only choice to prevent infection in the larval and juvenile stages will be based exclusively on the identification and elimination of subclinical infected broodfish, as well as the need for disinfection of water coming into the hatchery and cultured fish farms.

Generally, good health management strategy could play the most important role in control and prevention. Furthermore, good farm management

consists of appropriate water quality, high quality feeding, quarantine requirements, reduction of stress and fish density, use of effective vaccine, probiotics, prebiotics immunostimulants that should be considered practical important parameters in the control and prevention of Yersiniosis in the fish hatchery and rearing farms.

More attention should also be addressed in the future to interactions and exchanges of pathogens, between farmed and wild populations, to assess the risk of transmission of infection from one environment to another.

Despite all attempts that can be performed and the more restrictive measures taken, it is estimated that the optimal solution can be acquired only when an effective and commercial vaccine will be available. So, more studies are needed on the molecular epidemiological sights to produce effective protection against ERM. Moreover, using suitable health strategy, besides management development of educational programs considered to should be information and awareness of fish to new developmental equipment and achievements.

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