Streptococcosis

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Streptococcosis, particularly that caused by *S. iniae* and *S. agalactiae*, is a major re-emerging bacterial disease seriously affecting the global sustainability of aquaculture development.

streptococcosis phytotherapy disease resistance inhibitory activity

1. Introduction

Infections by *Streptococcus* species, *Streptococcus iniae*, *Streptococcus agalactiae*, *Streptococcus dysgalactiae, Streptococcus uberis, Streptococcus parauberis*, and *Streptococcus phocae*, are serious re-emerging bacterial diseases in humans and a wide range of terrestrial animals, fish, and marine mammals. Fish streptococcosis is one of the major infectious diseases in freshwater and marine aquaculture, affecting the sustainability of aquaculture development worldwide [1][2], and is also a zoonotic disease, with important food safety implications [3][4][5][6]. Even though vaccines have shown positive results, they are not adequately efficacious due to the wide heterogeneity of bacterial species/strains involved in the infections [7]. Consequently, fish streptococcal infections are often treated with various antibiotics, such as florfenicol, erythromycin, doxycycline and oxytetracycline [8][9][10][11]. However, due to re-infections by the pathogens, frequent treatments are required, causing major problems, including the accumulation of antibiotics in fish carcasses [12] and the release of drugs into aquatic ecosystems, increasing the likelihood of bacterial resistance [13][14][15][16][17].

Due to global demand for chemical-free aquaculture products [16][18], there is increasing interest in the use of dietary supplements or additives capable of improving fish health [19][20]. Medicinal herbs and other plants are potentially good alternatives to replace chemical substances in aquaculture due to numerous benefits, including improved growth performance, antioxidant activity, physiological conditions, and welfare status [21][22][23][24][25][26][27], antimicrobial and immune effects [28][29][30][31][32][33], and hepatoprotective effects [30][34]. Furthermore, medicinal plants are readily available, inexpensive, and more biodegradable compared to synthetic chemical compounds [35][36]. Consequently, numerous plants have been studied as treatment or preventative agents against fish streptococcosis (e.g., [20][37][38][39][40][41][42]).

2. The Disease

Species in the genus *Streptococcus* belong to the Order Lactobacillales (lactic acid bacteria) and are Gram-positive, spherical or ovoid, non-spore-forming, non-motile and facultative anaerobic bacteria. They have been

isolated from water and from the gastrointestinal (GI) tracts of various animals, such as humans, cattle, chickens, dogs, cats, hamsters, mice, monkeys, nutria, camels, horses, sheep, goat, bottlenose dolphins, fish, frogs and seals [43][44][45][46]. Streptococcosis is the general term for a variety of diseases caused by members of the genus *Streptococcus*. In fish, streptococcosis is mostly reported for infections with *S. iniae*, *S. agalactiae* and *S. dysgalactiae* [47][48][49]. *S. iniae* is one of the leading fish pathogens in freshwater and saltwater aquaculture species, especially in warmer regions. The bacterium is β-hemolytic on 5% sheep blood agar, but it cannot be grouped by the Lancefield antigen method typically used to categorize *Streptococcus* species. *S. agalactiae* is β-hemolytic and carries the Lancefield group B antigen. *S. dysgalactiae* is mostly non-beta hemolytic, with the Lancefield group C antigen.

Lethargy, loss of appetite, skin discoloration, exophthalmia/corneal opacity, abdominal distention and abnormal behavioral swimming are the most common clinical signs of streptococcosis in infected fish [9][47][50][51][52][53][54][55][56][57][58]. These clinical signs are not pathognomonic because they are not distinct from lactococcosis caused by *Lactococcus garvieae,* at least in some high susceptible species such as rainbow trout (*Oncorhynchus mykiss*) [59]. Other occasional macroscopical findings such as skin and fin hemorrhage, dorsal rigidity, vertebral deformity, tachypnoea and subcutaneous edema with ulceration are also reported in various degrees, but mostly in fish infected with *S. iniae*, *S. agalactiae* and *S. dysgalactiae*. The size and severity of the clinical signs are, however, varied and are dependent on a range of factors including fish species and size, bacterial virulence and health management criteria, particularly water temperature and dissolved oxygen (e.g., [9][47][60]). Internally, affected fish may show ascitic fluid in the abdominal cavity; the enlargement of liver and spleen; fibrinous pericarditis and peritonitis, hemorrhages in tissues of the brain, retrobulbar region, intestines and liver; and the congestion of the spleen and kidney in various degrees [50][56][58][61][62]. The clinical presentations are, however, known to be more severe in fish infected with capsulated strains of *S. iniae* and *S. agalactiae,* particularly in susceptible fish species such as rainbow trout and tilapia (*Oreochromis niloticus*).

The observation of intracellular bacteria in various external and internal organs are a clear sign of generalized bacterial septicemia in infected fish, and the most common histopathological findings due to *S. iniae, S. agalactiae* and *S. dysgalactiae* have been reported in tissues of the brain, heart and eyes of affected fish with marked pericarditis, choroiditis and meningitis [47][52][55][56][62]. Affected fish can, however, develop various other pathological findings, including keratitis, hemorrhagic or granulomatous meningoencephalitis, interstitial nephritis, branchitis, splenitis, ophthalmitis, choroiditis, hepatitis, gastritis, enteritis, pancreatitis, peritonitis, skeletal muscle myositis and fasciitis, and ulcerative and hyperemic dermatitis, as well as granulomatous reactions and inflammatory responses [47][50][56][61]. In addition, other tissues including liver, kidney, spleen, heart and gill may be affected, showing necrosis and hemorrhage [9][52][55][56][62][63]. Little information is available, however, on the pathology of other streptococcal infections in fish. Macrophage infiltration in kidney, liver and muscle, focal necrosis in muscle fibers in freshwater fish infected with *S. parauberis* [57] and large numbers of vacuoles in the brain matrix of fish infected with *S. uberis* have been reported [58], but no microscopic pathology data are available for *S. phocae* infections in fish [53][64].

2.1. Pathogenesis

The mechanism of pathogenesis and virulence factors involved in the disease caused by streptococcal species in affected fish is not yet fully understood. After the colonization and multiplication of the external (skin, fin, gills or nares) or gastrointestinal tissues, the bacteria invade internal tissues and blood, causing a generalized bacteremia followed by a septicemic condition induced by bacterial toxins. In fish infected with *S. iniae*, infection of the central nervous system (CNS) causing meningitis can occur through the entrance of bacteria via the blood circulation system or by contaminated monocytes/phagocytes with bacterial cells, and the incidence of CNS infection was correlated with the bacterial concentration in the blood and the duration of the bacteremia [65]. As some fish infected with *S. iniae* can carry the pathogen asymptomatically with no clinical signs [66], further research required to understand the mechanism of pathogenesis in more detail.

Several virulence factors are reported in *Streptococcus* species, but these are mostly detected in strains isolated from terrestrial animals. In fish, most virulence factors have been reported for *S. iniae*, *S. agalactiae* and *S. dysgalactiae*, and scarce data are available for other streptococcal species. The capsular polysaccharides are thought to be one of the most important virulence factors, inducing resistance to phagocytosis and the host humoral immune responses [10][47][67][68][69]. The survival of pathogens at the intracellular stage can facilitate the progression from a local to a systemic infection [70][71], and virulent isolates expressing a completed polysaccharide capsule are more resistant to phagocytosis than other strains [69]. Some non-capsulated strains [67] are more virulent to fish, however, suggesting that intra-phagocytic survival may not be a primary mechanism of disease establishment in fish; thus, further investigations are required.

The enhancement of the apoptosis of infected cells may also assist disease establishment, as it can cause cell death without the release of cellular components, resulting in the suppression of the host inflammation responses [47]. Some strains of *S. iniae,* such as serotype II, have capsules with more surface antigens, which can present additional anti-phagocytic properties [67][72]. A cell surface Fc binding factor, which blocks the binding and activation of complement cascade, has also been demonstrated to be part of *S. iniae* pathogenesis [73]. Further, M-like protein for cell adhesion, phosphoglucomutase for sugar metabolism, streptolysin S (SLS) for the synthesis of the SLS structural peptide and the SLS modification protein, peptidoglycan deacetylase for peptidoglycan acetyl modification, cell envelope proteinase for the synthesis of IL-8-cleaving cysteine protease and SivR/S for the two-component transcriptional regulation system encoded by different genes (i.e., *simA*, *pgmA*, sagA–sagI, *agA, agB, PDI*, *cepI* and *SivR*/*S*) have been confirmed as virulence factors of *S. iniae* strains [67][69][74][75][76][77][78][79][80]. Furthermore, the C5a peptidase [78] and fibrinogen binding protein [81], and recently two novel virulence factors, an extracellular nuclease and a secreted nucleotidase, probably with enzymatic activities, have been identified in strains of *S. iniae* that were involved in the experimental infection of zebrafish [80].

Several virulence factors have been identified in pathogenic *S. agalactiae* strains, including pore-forming toxins [β-hemolysin/cytolysin, CAMP factor (a protein B that enlarges the area of hemolysis formed by the β-hemolysin elaborated from the bacterium)], factors for immune evasion (sialic acid capsular polysaccharide, C5a peptidase, serine protease), superoxide dismutase, D-alanylated lipoteichoic acid, adhesins, hyaluronate lyase, and methionine transport regulator [82][83][84]. Most of these factors, however, have been studied in strains recovered from infected terrestrial animals, and thus virulence factors in strains infecting fish require further research. Despite

the transmission of the pathogen from mother to newborn being an important risk factor of infection and disease progression for *S. agalactiae* in humans [85], no data are available on the vertical transmission of this pathogen in susceptible oviparous or viviparous fish species.

In *S. dysgalactiae,* the M-like protein is the most extensively studied virulence factor. This protein can opsonize both adherence to and entrance into host cells [86][87] and aids in immune evasion by inhibiting phagocytic activity and inactivating the complement cascade [87]. Adhesins encoded by different bacterial genes (*gfba*, *fnB*, *fbBA*, *fnBB*, *lmb* and *gapC*) are known to mediate binding to fibronectin [88][89][90][91], and the *gfba* gene can also assist bacterial entry into host endothelial cells and intracellular persistence [92][93]. Most adhesins, however, are recognized in strains of *S. dysgalactiae* isolated from affected human and other warm-blooded animals. In addition, protein G, a known virulent factor in *S. dysgalactiae* strains, can bind with circulating immunoglobulins and, hence, interfere with the host humoral immune response [94]. Furthermore, several toxins and secreted enzymes, including the hemolysins, streptolysin O and SLS [95][96] and superantigen *speG* [97], the streptokinase enzyme that enables the hydrolysis of fibrin and aids in bacterial spreading through tissues [87], have been identified in virulent isolates of *S. dysgalactiae*.

Several potential virulence factors, including hyaluronic acid capsule, hyaluronidase, uberis factor, antiphagocytic factors (capsule, neutrophil toxin, M-like protein and R-like protein), plasminogen activator/streptokinase factor, surface dehydrogenase protein, CAMP factor, lactoferrin binding protein and surface adhesion molecule, have been identified in both *S. uberis* and *S. parauberis* in warm-blooded animals [98][99][100], but these factors have never been studied in strains isolated from diseased fish. Some strains of *S. parauberis* carrying capsuled polysaccharide genes have recovered from diseased fish [101], but the role of other virulent factors in the pathogenicity of these species needs further study.

The capacity to form biofilms has been reported for *S. iniae*, *S. dysgalactiae, S. uberis* and *S. parauberis.* Biofilms can facilitate the survival and proliferation of bacteria in hostile environments, such as aquaculture recirculation bio-filtration systems [99][102][103], probably due to the bacterial extracellular production.

Virulence factors of *S. phocae* are mostly studied in marine mammals and rarely in fish species. Strains of *S. phocae* with antiphagocytic capsule ability are identified in experimental infections of Atlantic salmon (*Salmo salar*) [53][104][105]. In another study by González-Contreras et al. [106], cell-surface-related properties, including capsule detection, adhesion and hydrophobicity to fish mucus and cell lines, biofilm formation in skin mucus and serum resistance, were demonstrated in *S. phocae* isolates responsible for outbreaks in Atlantic salmon. More detailed studies of these properties are, however, required, as no mortalities or histopathological findings were seen in the fish injected with extracellular products. Other virulence factors, including fibronectin-binding proteins, the toxin SLS, genes encoding for a capsule [107] and the ability of the bacterium to invade fish and mammalian cell lines were also detected as part of *S. phocae* pathogenesis in aquatic animals, but these studies have mostly been in marine mammalians [104].

2.2. Disease Significance in Aquaculture

Despite the wide spread of infection in aquaculture, there are no recent estimates of annual losses by streptococcal pathogens in the industry [84]. The annual estimated losses caused by *Streptococcosis* were 150 and 250 million USD in 2000 and 2008, respectively [15][105][106]. In Iran, rainbow trout production in freshwater is remarkably high (about 180000 tons), but the annual loss through streptococcosis is estimated at around 30%, due to high water temperature in summer and poor health management [10][60][107][108]. Many fish species in freshwater, estuarine and marine environments are susceptible to *S. iniae*, and rainbow trout, yellow tail (*Seriola quinqueradiata*), Asian seabass (*Lates calcarifer*) and Nile tilapia (*Oreochromis niloticus*) are highly susceptible species (e.g., [9][47][50][105][109][110]).

Streptococcus agalactiae is a globally emerging fish pathogen causing huge economic losses in many freshwater and saltwater species [44]. The bacterium is reported in rainbow trout, seabream, tilapia, yellowtail, several species of catfish and mullet, croaker (*Micropogonius undulatus*), killfish *(Menhaden* spp.) and silver pomfret (*Pampus argenteus*) [44][51][52][111][112][113][114][115].

The first outbreak by the α-hemolytic Lancefield group C *S. dysgalactiae* subsp. *dysgalactiae* was reported in vaccinated and non-vaccinated farmed amberjack/yellowtail in Japanese fish farms [116]. Later, the pathogen was detected in kingfish (*Seriola lalandi*), grey mullet (*Mugil cephalus*), basket mullet (*Liza alata*), cobia (*Rachycentron canadum*), hybrid red tilapia (*Oreochromis* sp.), pompano (*Trachinotus blochii*), white spotted snapper (*Lutjanus stellatus*), Amur sturgeon (*Acipenser schrenckii*), golden pomfret (*Trachinotus ovatus*) and Nile tilapia from Brazil, Japan, China, Malaysia, Indonesia, Taiwan and Iran [28][54][117][118][119].

The first study reporting streptococcosis infection by *S. parauberis* (formerly known as *S. uberis* type II) [120] in fish was revealed by Domeénech et al. [121]. Subsequently, the disease was reported in several species including turbot (*Scophthalmus maximus*), olive flounder, sea bass (*Sebastes ventricosus*), striped bass (*Morone saxatilis*) and ram cichlid (*Mikrogeophagus ramirezi*) [57][122][123][124][125]. More recently, *S. parauberis* classified as serotype III has been reported as the cause of streptococcosis in different turbot farms in China, and the isolates are different from those that infect flounder (*Paralichthys olivaceus*) in Japan and South Korea but similar to strains in Spain and the USA [101].

S. uberis is an important causative agent of bovine mastitis worldwide. Although [58] documented the first report of disease outbreak by *S. uberis* in mandarin fish (*Siniperca chuatsi*) in China, the first isolation and characterization of this streptococcal species from fish was reported by [119] in Iranian commercial rainbow trout farms. *S. uberis* was isolated from the gills of healthy fish [126], and thus, the report by Pourgholam et al. [119] is in doubt because they did not assess the pathogenicity of the isolated strains.

S. phocae subsp. *salmonis* was first isolated from clinical specimens from harbor seal (*Phocae vitulina*) by Skaar et al. [127] before being isolated from diseased Atlantic salmon cage-farmed in Chile in the summer in 1999, with a reported mortality up to 25% [53][64]. In addition to fish, *S. phocae* has been recognized as an important pathogen of marine mammals, gray seal (*Halichoerus grypus*), ringed seal (*Phoca hispida*), Cape fur seal (*Arctocephalus pusillus pusillus*), southern sea otters (*Enhydra lutris nereis*), harbor porpoise (*Phocoena phocoena*) and other

cetaceans, causing pneumonia or respiratory infection [128][129][130][131]. This pathogen has also been associated with urogenital neoplasia in Steller sea lions (*Eumatopias jubatus*) and skin abscesses in southern sea otters (*Enhydra lutris nereis*) [132][133], and Taurisano et al. [46] suggested that *S. phocae* is a serious disease in marine mammals.

Some streptococci species are serious zoonotic pathogens, with *S. iniae* causing bacteremia, cellulitis, meningitis and osteomyelitis [134], neonatal meningitis, sepsis and pneumonia caused by *S. agalactiae* [135][136] and bacteremia, lower limb cellulitis and meningitis caused by both *S. dysgalactiae* subsp. *equisimilus* and *S. dysgalactiae* subsp. *dysgalactiae* [137][138][139][140][141][142]. There are also reports of *S. uberis* in humans, although the accuracy of this identification is arguable [143]. A problem with streptococcal infections in aquaculture is that, in some outbreaks, the infected fish exhibit no clinical signs prior to death, and the mortalities are mostly due to bacterial septicemia that can involve the brain and nervous system [47][144]. In these cases, the consumption of infected fish, which appear clinically normal, can seriously affect public health.

The immune system of aquatic animals can inevitably be suppressed by various stressors, which increases the animal's susceptibility to pathogenic agents [47][145]. Stress and stressors, therefore play a significant role in the initiation and development of streptococcal infections. Streptococcal infections are highly stress-dependent and occur in farmed fish exposed to sub-optimal water quality parameters such as sudden fluctuations in temperature or salinity, high alkalinity (pH > 8), low dissolved oxygen concentration and increases in NH_3 and NO_2. Overfeeding, overstocking and overhandling can also cause outbreaks of streptococcosis with high cumulative mortality [108][146][147][148][149][150]. Mortality caused by streptococcal infections can be reduced by pathogen-free stock/larvae, separate water supplies for culture systems, reducing over-manipulation or transportation, the quarantining of newly arrived fish, reducing overcrowding, avoiding overfeeding, frequently removing dying and dead fish, and keeping excellent sanitary conditions [105]. These preventive precautions can, however, be exceedingly difficult and expensive to implement, as streptococcal agents are quite common in aquatic environments. Due to the formation of granulomatous reactions in different organs of affected fish [151], antibiotic therapy of streptococcal infections is unsuccessful [152]. Treatment by antibiotics may also increase water pollution through frequent drug administration and the release of excess chemical substances into the farm environments, causing further stress of fish. Additionally, frequent antibiotic therapy can increase the withholding period for fish carcasses, and this may interfere with the farm production scheme.

References

1. Pradeep, P.J.; Suebsing, R.; Sirthammajak, S.; Kampeera, J.; Jitrakorn, S.; Saksmerprome, V.; Turner, W.; Palang, I.; Vanichviriyakit, R.; Senapin, S.; et al. Evidence of vertical transmission and tissue tropism of Streptococcosis from naturally infected red tilapia (Oreochromis spp.). Aquac. Rep. 2016, 3, 58–66.

2. Austin, B.; Austin, D.A. Bacterial Fish Pathogens: Disease of Farmed and Wild Fish; Springer International Publishing: Cham, Switzerland, 2016; pp. 48–66.
3. Pereira, U.P.; Mian, G.F.; Oliveira, I.C.M.; Benchetrit, L.C.; Costa, G.M.; Figueiredo, H.C.P. Genotyping of Streptococcus agalactiae strains isolated from fish, human and cattle and their virulence potential in Nile tilapia. Vet. Microbiol. 2010, 140, 186–192.
4. Delannoy, C.M.; Crumlish, M.; Fontaine, M.C.; Pollock, J.; Foster, G.; Dagleish, M.P.; Turnbull, J.F.; Zadoks, R.N. Human Streptococcus agalactiae strains in aquatic mammals and fish. BMC Microbiol. 2013, 13, 41.
5. Ma, Y.P.; Ke, H.; Liang, Z.L.; Liu, Z.X.; Hao, L.; Ma, J.Y.; Li, Y.G. Multiple evolutionary selections involved in synonymous codon usages in the Streptococcus agalactiae genome. Int. J. Mol. Sci. 2016, 17, 277.
6. Gauthier, D.T. Bacterial zoonoses of fishes: A review and appraisal of evidence for linkages between fish and human infections. Vet. J. 2015, 203, 27–35.
7. Caipang, C.M.A.; Lucanas, J.B.; Lay-yag, C.M. Updates on the vaccination against bacterial diseases in tilapia, Oreochromis spp. and Asian seabass, Lates calcarifer. Aquac. Aquar. Conserv. Legis. 2014, 7, 184–193.
8. Darwish, A.M.; Hobbs, M.S. Laboratory efficacy of amoxicillin for the control of Streptococcus iniae infection in blue tilapia. J. Aquat. Anim. Health 2005, 17, 197–202.
9. Soltani, M.; Jamshidi, S.; Sharifpour, I. Streptococcosis caused by Streptococcus iniae in farmed rainbow trout (Oncorhynchys mykiss) in Iran: Biophysical characteristics and pathogenesis. Bull. Eur. Assoc. Fish Pathol. 2005, 25, 95–106.
10. Soltani, M.; Pirali, E.; Rasoli, A.; Shams, G.; Shafiei, S. Antibiotic residuals in some farmed rainbow trout (Oncorhynchus mykiss) of market size in Iran. Iran. J. Aquat. Anim. Health 2014, 1, 71–77.
11. Miranda, C.D.; Godoy, F.A.; Lee, M.R. Current status of the use of antibiotics and the antimicrobial resistance in the Chilean salmon farms. Front. Microbiol. 2018, 9, 1284.
12. Heuer, O.E.; Kruse, H.; Grave, K.; Collignon, P.; Karunasagar, I.; Angulo, F.J. Human health consequences of use of antimicrobial agents in aquaculture. Clin. Infec. Dis. 2009, 49, 1248–1253.
13. Smith, P.; Hiney, M.P.; Samuelsen, O.B. Bacterial resistance to antimicrobial agents used in fish farming: A critical evaluation of method and meaning. Ann. Rev. Fish Dis. 1994, 4, 273–313.
14. Cabello, F.C. Heavy use of prophylactic antibiotics in aquaculture: A growing problem for human and animal health and for the environment. Environ. Microbiol. 2006, 8, 1137–1144.

15. Amal, M.N.A.; Zamri-Saad, M. Streptococcosis in tilapia (Oreochromis niloticus): A review. Pertanika J. Trop. Agri. Sci. 2011, 34, 195–206.
16. Bulfon, C.; Volpatti, D.; Galeotti, M. Current research on the use of plant-derived products in farmed fish. Aquac. Res. 2015, 46, 513–551.
17. Okocha, R.C.; Olatoye, I.O.; Adedeji, O.B. Food safety impacts of antimicrobial use and their residues in aquaculture. Publ. Health Rev. 2018, 39, 21.
18. Ji, S.C.; Jeong, G.S.; Gwang-Soon, I.M.; Lee, S.W.; Yoo, J.H.; Takii, K. Dietary medicinal herbs improve growth performance, fatty acid utilization, and stress recovery of Japanese flounder. Fish. Sci. 2007, 73, 70–76.
19. Gabriel, N.N. Review on the progress in the role of herbal extracts in tilapia culture. Cogent Food Agric. 2019, 5, 1619651.
20. Elumalai, P.; Kurian, A.; Lakshmi, S.; Faggio, C.; Esteban, M.Á.; Ringø, E. Herbal immunomodulators in aquaculture. Rev. Fish. Sci. Aquacul. 2020, 29, 33–57.
21. Yılmaz, S.; Ergün, S. Effects of garlic and ginger oils on hematological and biochemical variables of sea bass (Dicentrarchus labrax). J. Aquat. Anim. Health 2012, 24, 219–224.
22. Yılmaz, S.; Ergün, S.; Celik, E.Ş. Effects of herbal supplements on growth performance of sea bass (Dicentrarchus labrax): Change in body composition and some blood parameters. J. BioSci. Biotech. 2012, 1, 217–222.
23. Yılmaz, S.; Ergün, S.; Çelik, E.Ş. Effect of dietary herbal supplements on some physiological conditions of sea bass Dicentrarchus labrax. J. Aquat. Anim. Health 2013, 25, 98–103.
24. Yılmaz, S.; Ergün, S.; Çelik, E.Ş. Effect of dietary spice supplementations on welfare status of sea bass (Dicentrarchus labrax L). Proc. Natl. Acad. Sci. India Sect. B Biol. Sci. 2016, 86, 229–237.
25. Mahdavi, M.; Hajimoradloo, A.; Ghorbani, R. Effect of Aloe vera extract on growth parameters of common carp (Cyprinus carpio). World J.Med. Sci. 2013, 9, 55–60.
26. Gabriel, N.N.; Qiang, J.; He, J.; Ma, X.Y.; Kpundeh, M.D.; Xu, P. Dietary Aloe vera supplementation on growth performance, some haemato-biochemical parameters and disease resistance against Streptococcus iniae in tilapia (GIFT). Fish Shellfish Immunoo. 2015, 44, 504–514.
27. Gabriel, N.N.; Qiang, J.; Ma, X.Y.; He, J.; Xu, P.; Liu, K. Dietary Aloe vera improves plasma lipid profile, antioxidant, and hepatoprotective enzyme activities in GIFT-tilapia (Oreochromis niloticus) after Streptococcus iniae challenge. Fish Physiolo. Biochem. 2015, 41, 1321–1332.
28. Yang, W.; Li, A. Isolation and characterization of Streptococcus dysgalactiae from diseased Acipenser schrenckii. Aquaculture 2009, 294, 14–17.

29. Soltani, M.; Lymbery, A.; Song, S.K.; Hosseini Shekarabi, P. Adjuvant effects of medicinal herbs and probiotics for fish vaccines. Rev. Aquac. 2019, 11, 1325–1341.
30. Yılmaz, S.; Ergün, S. Dietary supplementation with allspice Pimenta dioica reduces the occurrence of streptococcal disease during first feeding of Mozambique Tilapia Fry. J. Aquat. Anim. Health 2014, 26, 144–148.
31. Yilmaz, S.; Ergün, S.; Kaya, H.; Gürkan, M. Influence of Tribulus terrestris extract on the survival and histopathology of Oreochromis mossambicus (Peters, 1852) fry before and after Streptococcus iniae infection. J. Appl. Ichthyol. 2014, 30, 994–1000.
32. Yilmaz, S. Effects of dietary blackberry syrup supplement on growth performance, antioxidant, and immunological responses, and resistance of Nile tilapia, Oreochromis niloticus to Plesiomonas shigelloides. Fish Shellfish Immunol. 2019, 84, 1125–1133.
33. Yilmaz, S. Effects of dietary caffeic acid supplement on antioxidant, immunological and liver gene expression responses, and resistance of Nile tilapia, Oreochromis niloticus to Aeromonas veronii. Fish Shellfish Immunol. 2019, 86, 384–392.
34. Gurkan, M.; Yilmaz, S.; Hasan, K.A.Y.A.; Ergun, S.; Alkan, S. Influence of three spice powders on the survival and histopathology of Oreochromis mossambicus before and after Streptococcus iniae infection. Mar. Sci. Technol. Bull. 2015, 4, 1–5.
35. Olusola, S.E.; Emikpe, B.O.; Olaifa, F.E. The potentials of medicinal plant extracts as bio-antimicrobials in aquaculture. Int. Medic. Aromat. Plants 2013, 3, 404–412.
36. Reverter, M.; Bontemps, N.; Lecchini, D.; Banaigs, B.; Sasal, P. Use of plant extracts in fish aquaculture as an alternative to chemotherapy: Current status and future perspectives. Aquaculture 2014, 433, 50–61.
37. Acar, Ü.; Kesbiç, O.S.; Yılmaz, S.; Gültepe, N.; Türker, A. Evaluation of the effects of essential oil extracted from sweet orange peel (Citrus sinensis) on growth rate of tilapia (Oreochromis mossambicus) and possible disease resistance against Streptococcus iniae. Aquaculture 2015, 437, 282–286.
38. Brum, A.; Pereira, S.A.; Owatari, M.S.; Chagas, E.C.; Chaves, F.C.M.; Mouriño, J.L.P.; Martins, M.L. Effect of dietary essential oils of clove basil and ginger on Nile tilapia (Oreochromis niloticus) following challenge with Streptococcus agalactiae. Aquaculture 2017, 468, 235–243.
39. Tafi, A.A.; Meshkini, S.; Tukmechi, A.; Alishahi, M.; Noori, F. Immunological and anti-streptococcal effects of Salvia officinalis and Aloe vera extracts supplemented feed in rainbow trout (Oncorhynchus mykiss). Kafkas Üniversitesi Vet. Fakültesi Derg. 2018, 24, 365–370.
40. Vazirzadeh, A.; Jalali, S.; Farhadi, A. Antibacterial activity of Oliveria decumbens against Streptococcus iniae in Nile tilapia (Oreochromis niloticus) and its effects on serum and mucosal immunity and antioxidant status. Fish Shellfish Immunol. 2019, 94, 407–416.

41. Kim, J.; Lee, K.W.; Jeong, H.S.; Ansary, M.W.R.; Kim, H.S.; Kim, T.; Kwon, M.G.; Cho, S.H. Oral administration effect of yacon, ginger and blueberry on the growth, body composition and plasma chemistry of juvenile olive flounder (Paralichthys olivaceus) and immunity test against Streptococcus iniae compared to a commercial probiotic, Lactobacillus fermentum. Aquac. Rep. 2019, 15, 100212.
42. Foysal, M.J.; Alam, M.; Momtaz, F.; Chaklader, M.R.; Siddik, M.A.; Cole, A.; Fotedar, R.; Rahman, M.M. Dietary supplementation of garlic (Allium sativum) modulates gut microbiota and health status of tilapia (Oreochromis niloticus) against Streptococcus iniae infection. Aquac. Res. 2019, 50, 2107–2116.
43. Wilkinson, H.W.; Thacker, L.G.; Facklam, R.R. Nonhemolytic group B streptococci of human, bovine, and ichthyic origin. Infect. Immun. 1973, 7, 496–498.
44. Evans, J.J.; Klesius, P.H.; Gilbert, P.M.; Shoemaker, C.A.; Al-Sarawi, M.A.; Landsberg, J.; Durendez, R.; Al-Marzouk, A.; Al-Zenki, S. Characterization of β-hemolytic group B Streptococcus agalactiae in cultured seabream, Sparus auratus and mullet, Liza klunzingeri, in Kuwait. J. Fish Dis. 2002, 25, 505–513.
45. Zappulli, V.; Mazzariol, S.; Cavicchioli, L.; Petterino, C.; Bargelloni, L.; Castagnaro, M. Fatal necrotizing fasciitis and myositis in a captive common bottlenose dolphin (Tursiops truncatus) associated with Streptococcus agalactiae. J. Vet. Diagn. Investig. 2005, 17, 617–622.
46. Taurisano, N.D.; Butler, B.P.; Stone, D.; Hariharan, H.; Fields, P.J.; Ferguson, H.W.; Haulena, M.; Cotrell, P.; Nielsen, O.; Raverty, S. Streptococcus phocae in marine mammals of northeastern Pacific and Arctic Canada: A retrospective analysis of 85 postmortem investigations. J. Wildl. Dis. 2018, 54, 101–111.
47. Agnew, W.; Barnes, A.C. Streptococcus iniae: An aquatic pathogen of global veterinary significance and a challenging candidate for reliable vaccination. Vet. Microbiol. 2007, 122, 1–15.
48. Liu, G.; Zhu, J.L.; Chen, K.M.; Gao, T.T.; Yao, H.C.; Liu, Y.J.; Zhang, W.; Lu, C.P. Development of Streptococcus agalactiae vaccines for tilapia. Dis. Aquat. Org. 2016, 122, 163–170.
49. Maekawa, S.; Wang, Y.-T.; Yoshida, T.; Wang, P.C.; Chen, S.-C. Group C Streptococcus dysgalactiae infection in fish. J. Fish Dis. 2020, 43, 963–970.
50. Eldar, A.; Bejerano, Y.; Livoff, A.; Horovitcz, A.; Bercovier, H. Experimental streptococcal meningoencephalitis in cultured fish. Vet. Microbiol. 1995, 43, 33–40.
51. Evans, J.J.; Klesius, P.H.; Shoemaker, C.A.; Pasnik, D.J. Identification and epidemiology of Streptococcus iniae and S. agalactiae in tilapias Oreochromis spp. In Proceedings of the 7th International Symposium on Tilapia in Aquaculture, American Tilapia Association, Vera Cruz, Mexico, 9 June 2006; pp. 25–42.

52. Salvador, R.; Muller, E.E.; Freitas, J.C.; Leonhadt, J.H.; Giordano, L.G.P.; Dias, J.A. Isolation and characterization of Streptococcus spp. group B in Nile Tilapia (Oreochromis niloticus) reared in hapas nets and earth nurseries in the northern region of Parana State, Brazil. Ciência Rural. 2005, 35, 1374–1378.
53. Romalde, J.L.; Ravelo, C.; Valdés, I.; Magariños, B.; de la Fuente, E.; San Martín, C.; Avendaño-Herrera, R.; Toranzo, A.E. Streptococcus phocae, an emerging pathogen for salmonid culture. Vet. Microbiol. 2008, 130, 198–207.
54. Netto, L.N.; Leal, C.A.G.; Figueiredo, H.C.P. Streptococcus dysgalactiae as an agent of septicaemia in Nile tilapia, Oreochromis niloticus (L.). J. Fish Dis. 2011, 34, 251–254.
55. Sepahi, A.; Heidarieh, M.; Mirvaghefi, A.; Rafiee, G.R.; Farid, M.; Sheikhzadeh, N. Effects of water temperature on the susceptibility of rainbow trout to Streptococcus agalactiae. Acta Sci. Vet. 2013, 41, 1097.
56. Iregui, C.A.; Comas, J.; Vasquez, G.M.; Verjan, N. Experimental early pathogenesis of Streptococcus agalactiae infection in red tilapia Oreochromis spp. J. Fish Dis. 2016, 39, 205–215.
57. Lazado, C.C.; Fridman, S.; Sinai, T.; Zilberg, D. First report of Streptococcus parauberis in a cultured freshwater ornamental fish, the ram cichlid Mikrogeophagus ramirezi (Myers & Harry, 1948). J. Fish Dis. 2017, 41, 161–164.
58. Luo, X.; Fu, X.; Liao, G.; Chang, O.; Huang, Z.; Li, N. Isolation, pathogenicity and characterization of a novel bacterial pathogen Streptococcus uberis from diseased mandarin fish (Siniperca chuatsi). Microb. Pathog. 2017, 107, 380–389.
59. Soltani, M.; Baldisserotto, B.; Hosseini Shekarabi, S.P.; Shafiei, S.; Bashiri, M. Lactococcosis a re-emerging disease in aquaculture: Disease significant and phytotherapy. Vet. Sci. 2021, 8, 181.
60. Haghighi Karsidani, S.; Soltani, M.; Nikbakhat-Brojeni, R.; Ghasemi, M.; Skall, S.F. Molecular epidemiology of zoonotic streptococcosis/lactococcosis in rainbow trout (Oncorhynchus mykiss) aquaculture in Iran. Iran. J. Microbiol. 2010, 2, 198–209.
61. Eldar, A.; Bejerano, Y.; Bercovier, H. Streptococcus shiloi and Streptococcus difficile: Two new streptococcal species causing a meningoencephalitis in fish. Curr. Microbiol. 1994, 28, 139–143.
62. Delamare-Deboutteville, J.; Bowater, R.; Condon, K.; Reynolds, A.; Fisk, A.; Aviles, F.; Barnes, A.C. Infection and pathology in Queensland grouper, Epinephelus lanceolatus, (Bloch), caused by exposure to Streptococcus agalactiae via different routes. J. Fish Dis. 2015, 38, 1021–1035.
63. Roberts, R.J. Fish Pathology, 4th ed.; John Wiley & Sons: Hoboken, NJ, USA, 2012.
64. Gibello, A.; Mata, A.I.; Blanco, M.M.; Casamayor, A.; Domínguez, L.; Fernández-Garayzabal, J.F. First identification of Streptococcus phocae isolated from Atlantic salmon (Salmo salar). J. Clin. Microbiol. 2005, 43, 526–527.

65. Zlotkin, A.; Chilmonczyk, S.; Eyngor, M.; Hurvitz, A.; Ghittino, C.; Eldar, A. Trojan horse effect: Phagocyte-mediated Streptococcus iniae infection of fish. Infect. Immun. 2003, 71, 2318–2325.
66. Bromage, E.S.; Thomas, A.; Owens, L. Streptococcus iniae, a bacterial infection in barramundi Lates calcarifer. Dis. Aquat. Org. 1999, 36, 177–181.
67. Buchanan, J.T.; Stannard, J.A.; Lauth, X.; Ostland, V.E.; Powell, H.C.; Westerman, M.E.; Nizet, V.S. iniae phosphoglucomutase is a virulence factor and a target for vaccine development. Infect. Immun. 2005, 73, 6935–6944.
68. Lowe, B.A.; Miller, J.D.; Neely, M.N. Analysis of the polysaccharide capsule of the systemic pathogen Streptococcus iniae and its implications in virulence. Infect. Immun. 2007, 75, 1255–1264.
69. Locke, J.B.; Colvin, K.M.; Datta, A.K.; Patel, S.K.; Naidu, N.N.; Neely, M.N.; Nizet, V.; Buchanan, J.T. Streptococcus iniae capsule impairs phagocytic clearance and contributes to virulence in fish. J. Bacteriol. 2007, 189, 1279–1287.
70. Baron, M.; Bolduc, G.; Goldberg, M.; Auperin, T.; Madoff, L. Alpha C protein of group B Streptococcus binds host cell surface glycosaminoglycan and enters cells by an action-dependent mechanism. J. Biol. Chem. 2004, 279, 24714–24723.
71. Baron, M.; Filman, D.; Prophete, G.; Hogle, J.; Madoff, L. Identification of a glycosaminoglycan binding region of the alpha C protein that mediates entry of group B Streptococci into host cells. J. Biol. Chem. 2007, 282, 10526–10536.
72. Barnes, A.C.; Young, F.M.; Horne, M.T.; Ellis, A.E. Streptococcus iniae: Serological differences, presence of capsule and resistance to immune serum killing. Dis. Aquat. Org. 2003, 53, 241–247.
73. Barnes, A.C.; Horne, M.T.; Ellis, A.E. Streptococcus iniae expresses a cell surface non-immune trout immunoglobulin binding factor when grown in normal trout serum. Fish Shellfish. Immunol. 2003, 15, 425–431.
74. Nizet, V. Streptococcal beta-hemolysins: Genetics and role in disease pathogenesis. Trends Microbiol. 2002, 10, 575–580.
75. Nizet, V.; Beall, B.; Bast, D.J.; Datta, V.; Kilburn, L.; Low, D.E.; De Azavedo, J.C. Genetic locus for streptolysin S production by group A streptococcus. Infect. Immun. 2000, 68, 4245–4254.
76. Fuller, J.D.; Camus, A.C.; Duncan, C.L.; Nizet, V.; Bast, D.J.; Thune, R.L.; Low, D.E.; de Azavedo, J.C. Identification of a streptolysin S-associated gene cluster and its role in the pathogenesis of S. iniae disease. Infect. Immun. 2002, 70, 5730–5739.
77. Locke, J.B.; Colvin, K.M.; Varki, N.; Vicknair, M.R.; Nizet, V.; Buchanan, J.T. Streptococcus iniae β-hemolysin streptolysin S is a virulence factor in fish infection. Dis. Aquat. Org. 2007, 76, 17–26.

78. Locke, J.B.; Aziz, R.K.; Vicknair, M.R.; Nizet, V.; Buchanan, J.T. Streptococcus iniae M-like protein contributes to virulence in fish and is a target for live attenuated vaccine development. PLoS ONE 2008, 3, e2824.
79. Aviles, F.; Zhang, M.M.; Chan, J.; Delamare-Deboutteville, J.; Green, T.J.; Dang, C.; Barnes, A.C. The conserved surface M-protein SiMA of Streptococcus iniae is not effective as a cross-protective vaccine against differing capsular serotypes in farmed fish. Vet. Microbiol. 2013, 162, 151–159.
80. Soh, K.Y.; Loh, J.M.S.; Hall, C.; Proft, T. Functional analysis of two novel Streptococcus iniae virulence factors using a zebrafish infection model. Microorganisms 2020, 8, 1361.
81. Baiano, J.C.; Tumbol, R.A.; Umapathy, A.; Barnes, A.C. Identification and molecular characterisation of a fibrinogen binding protein from Streptococcus iniae. BMC Microbiol. 2008, 8, 67.
82. Lang, S.; Palmer, M. Characterization of Streptococcus agalactiae CAMP factor as a pore-forming toxin. J. Biol. Chem. 2003, 278, 38167–38173.
83. Rajagopal, L. Understanding the regulation of Group B Streptococcal virulence factors. Future Microbiol. 2009, 4, 201–221.
84. Mishra, A.; Nam, G.H.; Gim, J.A.; Lee, H.E.; Jo, A.; Kim, H.S. Current challenges of Streptococcus infection and effective molecular, cellular, and environmental control methods in aquaculture. Mol. Cells 2018, 41, 495.
85. Ancona, R.J.; Ferrieri, P.; Williams, P.P. Maternal factors that enhance the acquisition of Group B streptococci by newborn infants. J. Med. Microbiol. 1980, 13, 273–280.
86. Bisno, A.L.; Craven, D.E.; McCabe, W.R. M proteins of group G streptococci isolated from bacteremic human infections. Infect. Immun. 1987, 55, 753–757.
87. Brandt, C.M.; Spellerberg, B. Human infections due to Streptococcus dysgalactiae subspecies equisimilis. Clin. Infect. Dis. 2009, 49, 766–772.
88. Lindgren, P.E.; McGavin, M.J.; Signäs, C.; Guss, B.; Gurusiddappa, S.; Höök, M.; Lindberg, M. Two different genes coding for fibronectin-binding proteins from Streptococcus dysgalactiae. The complete nucleotide sequences and characterization of the binding domains. Eur. J. Biochem. 1993, 214, 819–827.
89. Lindgren, P.E.; Signäs, C.; Rantamäki, L.; Lindberg, M. A fibronectin-binding protein from Streptococcus equisimilis: Characterization of the gene and identification of the binding domain. Vet. Microbiol. 1994, 41, 235–247.
90. Kline, J.B.; Xu, S.; Bisno, A.L.; Collins, C.M. Identification of a fibronectin-binding protein (GfbA) in pathogenic group G streptococci. Infect. Immun. 1996, 64, 2122–2129.

91. Lo, H.H.; Cheng, W.S. Distribution of virulence factors and association with emm polymorphism or isolation site among beta-hemolytic group G Streptococcus dysgalactiae subspecies equisimilis. APMIS 2015, 123, 45–52.
92. Rohde, M.; Talay, S.R.; Rasmussen, M. Molecular mechanisms of Streptococcus dysgalactiae subsp equisimilis enabling intravascular persistence. Microbes Infect. 2012, 14, 329–334.
93. Gherardi, G.; Imperi, M.; Palmieri, C.; Magi, G.; Facinelli, B.; Baldassarri, L.; Pataracchia, M.; Creti, R. Genetic diversity and virulence properties of Streptococcus dysgalactiae subsp. equisimilis from different sources". J. Med. Microbiol. 2014, 63, 90–98.
94. Sjöbring, U.; Björck, L.; Kastern, W. Streptococcal protein G. Gene structure and protein binding properties. J. Biol. Chem. 1991, 266, 399–405.
95. Watanabe, S.; Shimomura, Y.; Ubukata, K.; Krikae, T.; Tohru, M.A. Concomitant regulation of host tissue-destroying virulence factors and carbohydrate metabolism during invasive diseases induced by group g streptococci. J. Infect. Dis. 2013, 208, 1482–1493.
96. Smyth, D.; Cameron, A.; Davies, M.R.; McNeilly, C.; Hafner, L.; Sriprakash, K.S.; McMillan, D.J. DrsG from Streptococcus dysgalactiae subsp. equisimilis inhibits the antimicrobial peptide LL-37. Infect. Immun. 2014, 82, 2337–2344.
97. Sachse, S.; Seidel, P.; Gerlach, D.; Günther, E.; Rödel, J.; Straube, E.; Schmidt, K.H. Superantigen-like gene(s) in human pathogenic Streptococcus dysgalactiae, subsp equisimilis: Genomic localisation of the gene encoding streptococcal pyrogenic exotoxin G (speG(dys)). FEMS Immunol. Med. Microbiol. 2002, 34, 159–167.
98. Oliver, S.P.; Almeida, R.A.; Calvinho, L.F. Virulence factors of Streptococcus uberis isolated from cows with mastitis. Zent. Vet. B 1998, 45, 461–471.
99. Kaczorek, E.; Malaczewska, J.; Wojcik, R.; Siwicki, A.K. Biofilm production and other virulence factors in Streptococcus spp. isolated from clinical cases of bovine mastitis in Poland. BMC Vet. Res. 2017, 13, 398.
100. Reinoso, E.B.; Lasagno, M.C.; Dieser, S.A.; Odierno, L.M. Distribution of virulence-associated genes in Streptococcus uberis isolated from bovine mastitis. FEMS Microbiol. Lett. 2011, 318, 183–188.
101. Gao, Y.; Liu, Y.; Wang, P.; Mo, Z.; Li, J.; Liu, S.; Li, G.; Zhu, M.; Li, G. Isolation, identification and vaccine development of serotype III Streptococcus parauberis in turbot (Scophthalmus maximus) in China. Aquaculture 2021, 538, 736525.
102. Silayeva, O.; Engelstädter, J.; Barnes, A.C. Evolutionary epidemiology of Streptococcus iniae: Linking mutation rate dynamics with adaptation to novel immunological landscapes. Infect. Genet. Evol. J. Mol. Epidemiol. Evol. Genet. Infect. Dis. 2020, 85, 104435.

103. Genteluci, G.L.; Silva, L.G.; Souza, M.C.; Glatthardt, T.; de Mattos, M.C.; Ejzemberg, R.; Alviano, C.S.; Figueiredo, A.M.S.; Bernadete, T.F.C. Assessment and characterization of biofilm formation among human isolates of Streptococcus dysgalactiae subsp. equisimilis. Int. J. Med. Microbiol. 2015, 305, 937–947.

104. Martin, M.C.-S.; González-Contreras, A.; Avendaño-Herrera, R. Infectivity study of Streptococcus phocae to seven fish and mammalian cell lines by confocal microscopy. J. Fish Dis. 2012, 35, 431–436.

105. Salazar, S.; Oliver, C.; Yáñez, A.J.; Avendaño-Herrera, R. Comparative analysis of innate immune responses to Streptococcus phocae strains in Atlantic salmon (Salmo salar) and rainbow trout (Oncorhynchus mykiss). Fish Shellfish. Immunol. 2016, 51, 97–103.

106. González-Contreras, A.; Magariños, B.; Godoy, M.; Irgang, R.; Toranzo, A.E.; Avendaño-Herrera, R. Surface properties of Streptococcus phocae strains isolated from diseased Atlantic salmon, Salmo salar L. J. Fish Dis. 2011, 34, 203–215.

107. Soltani, M.; Alishahi, M.; Mirzargar, S.; Nikbakht, G. Vaccination of rainbow trout against Streptococcus iniae infection comparison of different routes of administration and different vaccine. Iran. J. Fish. Sci. 2007, 7, 129–140.

108. Soltani, M.; Pirali Kheirabadi, A.; Taherimirkahead, E.; Shafie, S.; Mohamadian, S.; Roholahi, S. Molecular study of streptococcosis/lactococcosis distribution in farmed rainbow trout in Charmahal–va-Bakhteyari and Kohgiloyeh-va-Boyerahmad provinces, Iran. Iran. J. Epidemiol. 2013, 9, 59–68.

109. Bromage, E.S.; Owens, L. Infection of barramundi Lates calcarifer with Streptococcus iniae: Effects of different routes of exposure. Dis. Aquat. Org. 2002, 52, 199–205.

110. Klesius, P.; Evans, J.; Shoemaker, C.; Yeh, H.; Goodwin, A.; Adams, A.; Thompson, K. Rapid detection and identification of Streptococcus iniae using a monoclonal antibody-based indirect fluorescent antibody technique. Aquaculture 2006, 258, 180–186.

111. Suanyuk, N.; Kong, F.; Ko, D.; Gilbert, G.; Supamattaya, K. Occurrence of rare genotypes of Streptococcus agalactiae in cultured red tilapia Oreochromis sp. and Nile tilapia O. niloticus in Thailand-relationship to human isolates? Aquaculture 2008, 284, 35–40.

112. Suanyuk, N.; Sukkasame, N.; Tanmark, N.; Yoshida, T.; Itami, T.; Thune, R.L.; Tantikitti, C.; Supamattaya, K. Streptococcus iniae infection in cultured Asian sea bass (Lates calcarifer) and red tilapia (Oreochromis sp.) in southern Thailand. Songklanakarin J. Sci. Technol. 2010, 32, 341–348.

113. Duremdez, R.; Al-Marzouk, A.; Qasem, J.A.; Al-Harbi, A.; Gharabally, H. Isolation of Streptococcus agalactiae from cultured silver pomfret, Pampus argenteus (Euphrasen), in Kuwait. J. Fish Dis. 2004, 27, 307–310.

114. Kim, J.H.; Gomez, D.K.; Choresca, C.H.; Park, S.C. Detection of major bacterial and viral pathogens in trash fish used to feed cultured flounder in Korea. Aquaculture 2007, 272, 105–110.

115. Garcia, J.C.; Klesius, P.H.; Evans, J.J.; Shoemaker, C.A. Non infectivity of cattle S. agalactiae in Nile tilapia (O. niloticus) and channel catfsh (Ictalurus ounctatus). Aquaculture 2008, 281, 151–154.

116. Nomoto, R.; Munasinghe, L.I.; Jin, D.H.; Shimahara, Y.; Yasuda, H.; Nakamura, A.; Misawa, N.; Itami, T.; Yoshida, T. Lancefield group C Streptococcus dysgalactiae infection responsible for fish mortalities in Japan. J. Fish Dis. 2004, 27, 679–686.

117. Zhou, S.M.; Li, A.X.; Ma, Y.; Liu, R.M. Isolation, identification and characteristics of 16S rDNA gene sequences of the pathogens responsible for the Streptococcicosis in cultured fish. Acta Sci. Nat. Univ. Sunyatseni 2007, 46, 68–71.

118. Abdelsalam, M.; Chen, S.C.; Yoshida, T. Phenotypic and genetic characterizations of Streptococcus dysgalactiae strains isolated from fish collected in Japan and other Asian countries. FEMS Microbiol. Lett. 2010, 302, 32–38.

119. Pourgholam, R.; Laloei, F.; Saeidi, A.A.; Ghoroghi, A.; Taghavi, M.J.; Zahedi, A.; Safari, R.; Sharifpour, E.; Sepahdari, A. Molecular identification of some causative agents of streptococcosis isolated in farmed rainbow trout (Oncorhynchus mykiss, walbaum) in Iran. Iran. J. Fish. Sci. 2011, 10, 109–122.

120. Williams, A.M.; Collins, M.D. Molecular taxonomic studies on Streptococcus uberis types I and II. Description of Streptococcus parauberis sp. nov. J. Appl. Microbiol. 1990, 68, 485–490.

121. Domeénech, A.; Derenaáandez-Garayzábal, J.F.; Pascual, C.; Garcia, J.A.; Cutuli, M.T.; Moreno, M.A.; Collins, M.D.; Dominguez, L. Streptococcosis in cultured turbot, Scopthalmus maximus (L.), associated with Streptococcus parauberis. J. Fish Dis. 1996, 19, 33–38.

122. Haines, A.N.; Gauthier, D.T.; Nebergall, E.E.; Cole, S.D.; Nguyen, K.M.; Rhodes, M.W.; Vogelbein, W.K. First report of Streptococcus parauberis in wild finfish from North America. Vet. Microbiol. 2013, 166, 270–275.

123. Haines, A.; Nebergall, E.; Besong, E.; Council, K.; Lambert, O.; Gauthier, D. Draft genome sequences for seven Streptococcus parauberis isolates from wild fish in the Chesapeake Bay. Genome Announc. 2016, 4, e00741-16.

124. Baeck, G.W.; Kim, J.H.; Gomez, D.K.; Park, S.C. Isolation and characterization of Streptococcus sp. from diseased flounder (Paralichthys olivaceus) in Jeju Island. J. Vet. Sci. 2006, 7, 53–58.

125. Oguro, K.; Yamane, J.; Yamamoto, T.; Ohnishi, K.; Oshima, S.I.; Imajoh, M. Draft genome sequence of Streptococcus parauberis strain SK-417, isolated from diseased Sebastes ventricosus in Kagoshima Japan. Genome Announc. 2014, 2, e00453-14.

126. Al Bulushi, I.M.; Poole, S.E.; Barlow, R.; Deeth, H.C.; Dykes, G.A. Speciation of Gram-positive bacteria in fresh and ambient-stored sub-tropical marine fish. Int. J. Food Microbiol. 2010, 138, 32–38.

127. Skaar, I.; Gaustad, P.; Tønjum, T.; Holm, B.; Stenwig, H. Streptococcus phocae sp. nov., a new species isolated from clinical specimens from seals. Int. J. Syst. Evol. Microbiol. 1994, 44, 646–650.

128. Henton, M.M.; Zapke, O.; Basson, P.A. Streptococcus phocae infections associated with starvation in Cape fur seals: Case report. J. S. Afr. Vet. Assoc. 1999, 70, 98–99.

129. Vossen, A.; Abdulmawjood, A.; Lämmler, C.; Weiss, R.; Siebert, U. Identification and molecular characterization of beta-hemolytic streptococci isolated from harbor seals (Phoca vitulina) and grey seals (Halichoerus grypus) of the German North and Baltic seas. J. Clin. Microbiol. 2004, 42, 469–473.

130. Kuiken, T.; Kennedy, S.; Barrett, T.; Van de Bildt, M.W.G.; Borgsteede, F.H.; Brew, S.D.; Codd, G.A.; Duck, C.; Deaville, R.; Eybatov, T.; et al. The 2000 canine distemper epidemic in Caspian seals (Phoca caspica): Pathology and analysis of contributory factors. Vet. Pathol. 2006, 43, 321–338.

131. Imai, D.; Jang, S.; Miller, M.; Conrad, P.A. Characterization of beta-hemolytic streptococci isolated from southern sea otters (Enhydra lutris nereis) stranded along the California coast. Vet. Microbiol. 2009, 136, 378–381.

132. Johnson, S.; Lowenstine, L.; Gulland, F.; Jang, S.; Imai, D.; Almy, F.; DeLong, R.; Gardner, I. Aerobic bacterial flora of the vagina and prepuce of California sea lions (Zalophus californianus) and investigation of associations with urogenital carcinomas. Vet. Microbiol. 2006, 114, 94–103.

133. Bartlett, G.; Smith, W.; Dominik, C.; Batac, F.; Dodd, E.; Byrne, B.A.; Jang, S.; Jessup, D.; Chantrey, J.; Miller, M. Prevalence, pathology, and risk factors associated with Streptococcus phocae infection in southern sea otters (Enhydra lutris nereis), 2004–2010. J. Wildl. Dis. 2016, 52, 1–9.

134. Facklam, R.; Elloitt, J.; Shewmaker, L.; Reingold, A. Identification and characterization of sporadic isolates of S. iniae from human. J. Clin. Microbiol. 2005, 43, 933–937.

135. Nitzan, Y.; Maayan, M.; Wajsman, C. Streptococcus group B isolates in a regional hospital area. Med. Microbiol. Immunol. 1980, 169, 21–30.

136. Tenenbaum, T.; Spellerberg, B.; Adam, R.; Vogel, M.; Kim, K.S.; Schroten, H. Streptococcus agalactiae invasion of human brain microvascular endothelial cells are promoted by the laminin-binding protein Lmb. Microbes Infect. 2007, 9, 714–720.

137. Oppegaard, O.; Mylvaganam, H.; Skrede, S.; Langeland, N.; Kittang, B.R. Sequence diversity of sicG among group C and G Streptococcus dysgalactiae subspecies equisimilis isolates

associated with human infections in western Norway. Eur. J. Clin. Microbiol. Infect. Dis. 2014, 33, 273–277.

138. Chennapragada, S.S.; Ramphul, K.; Barnett, B.J.; Mejias, S.G.; Lohana, P. A rare case of Streptococcus dysgalactiae subsp. dysgalactiae human zoonotic infection. Cureu 2018, 10, e2901.
139. Koh, T.H.; Sng, L.H.; Yuen, S.M.; Thomas, C.K.; Tan, P.L.; Tan, S.H.; Wong, N.S. Streptococcal cellulitis following preparation of fresh raw seafood. Zoonoses Public Health 2009, 56, 206–208.
140. Bert, F.; Lambert-Zechovsky, N. A case of bacteremia caused by Streptococcus dysgalactiae. Eur. J. Clin. Microbiol. Infect. Dis. 1997, 16, 324–326.
141. Woo, P.C.; Teng, J.L.; Lau, S.K.; Lum, P.N.; Leung, K.W.; Wong, K.L.; Li, K.W.; Lam, K.C.; Yuen, K.Y. Analysis of a viridans group strain reveals a case of bacteremia due to Lancefield group G alpha-hemolytic Streptococcus dysgalactiae subsp. equisimilis in a patient with pyomyositis and reactive arthritis. J. Clin. Microbiol. 2003, 41, 613–618.
142. Fernández-Aceñero, M.J.; Fernández-López, P. Cutaneous lesions associated with bacteremia by Streptococcus dysgalactiae. J. Am. Acad. Dermatol. 2006, 55, S91–S92.
143. Di Domenico, E.G.; Toma, L.; Prignano, G.; Pelagalli, L.; Police, A.; Cavallotti, C.; Torelli, R.; Sanguinetti, M.; Ensoli, F. Misidentification of Streptococcus uberis as a human pathogen: A case report and literature review. Int. J. Infect. Dis. 2015, 33, 79–81.
144. Chen, C.-Y.; Chao, C.-B.; Bowser, P.R. Comparative histopathology of Streptococcus iniae and Streptococcus agalactiae-infected tilapia. Bull. Eur. Assoc. Fish Pathol. 2007, 27, 2–9.
145. Martos-Sitcha, J.A.; Mancera, J.M.; Prunet, P.; Magnoni, L.J. Welfare and stressors in fish: Challenges facing aquaculture. Front. Physiol. 2020, 11, 162.
146. Shoemaker, C.A.; Evans, J.J.; Klesius, P.H. Density and dose: Factors affecting mortality of Streptococcus iniae infected tilapia (Oreochromis niloticus). Aquaclture 2000, 188, 229–235.
147. Alsaid, M.; Hassan, H.M.D.; Noordin, N.M.; Khairani Bejo, S.; Mohamed, Y.; Abuseliana, A.F. Environmental factors influencing the susceptibility of red hybrid tilapia (Oreochromis sp.) to Streptococcus agalactiae infection. Adv. Sci. Lett. 2013, 19, 3600–3604.
148. Chang, P.; Plumb, J. Effects of salinity on Streptococcus infection of Nile tilapia, Oreochromis niloticus. J. Appl. Aquac. 1996, 6, 39–45.
149. Bunch, E.C.; Bajerano, Y. The effect of environmental factors on the susceptibility of hybrid tilapia Oreochromis niloticus x Oreochromis aureus to streptococcosis. Isr. J. Aquac. 1997, 49, 56–61.
150. Anshary, H.; Kurniawan, R.A.; Sriwulan, S.; Ramli, R.; Baxa, D.V. Isolation and molecular identification of the etiological agents of streptococcosis in Nile tilapia (Oreochromis niloticus) cultured in net cages in Lake Sentani, Papua, Indonesia. SpringerPlus 2014, 3, 627.

151. Chang, P.H.; Plumb, J.A. Histopathology of experimental Streptococcus sp. infection in tilapia, O. niloticus and channel catfish, Ictalarus punctatus. J. Fish Dis. 1996, 19, 235–241.

152. Hernández, E.; Figueroa, J.; Iregui, C. Streptococcosis on a red tilapia, Oreochromis sp., farm: A case study. J. Fish Dis. 2009, 32, 247–252.