



## A review on the application of *Bacillus* as probiotics in aquaculture

Felix K.A. Kuebutornye<sup>a,b,c,1</sup>, Emmanuel Delwin Abarike<sup>a,b,c,d,1</sup>, Yishan Lu<sup>a,b,c,\*</sup>

<sup>a</sup> College of Fishery, Guangdong Ocean University, Zhanjiang, 524088, China

<sup>b</sup> Guangdong Provincial Key Laboratory of Pathogenic Biology and Epidemiology for Aquatic Animals, Zhanjiang, 524088, China

<sup>c</sup> Guangdong Key Laboratory of Control for Diseases of Aquatic Economic Animals, Zhanjiang, 524088, China

<sup>d</sup> Department of Fisheries and Aquatic Resources Management, University for Development Studies, Tamale, Ghana



### ARTICLE INFO

#### Keywords:

Probiotics  
Immune response  
Aquaculture  
Water quality  
Stress response

### ABSTRACT

Probiotics use in aquaculture has gained attention as microbial candidates to maintain the health and the well-being of many aquaculture animals. Among the many microbial candidates, probiotic *Bacillus* has sporulation capacity that makes them survive harsh environmental conditions, are non-pathogenic and non-toxic when fed to fish, and can produce antimicrobial substances making them more suitable candidates compared to other probiotics. In this review, we discussed the necessity of using the probiotic *Bacillus* in sustainable aquaculture as a good alternative to improve feed utilization, stress response, immune response and disease resistance, maintenance of tissue integrity, and as well improvement of water quality for sustainable aquaculture. Therefore the findings of current researches about the effects of *Bacillus* application to improve the culture of aquatic animals for future research and development of *Bacillus* application in aquaculture have been summarised.

### 1. Introduction

The occurrence of diseases in aquaculture species as a result of high stocking densities to meet the high demand of fish is a major blow to the aquaculture industry [1]. Researchers are keen to finding lasting environmentally friendly solutions to fish diseases where probiotics emerged as a good alternative to antibiotics due to the shortfalls of antibiotics such as changes in the microbiota of the aquaculture systems resulting in bacterial resistance to frequently used antimicrobials which in turn affects the natural beneficial bacteria flora [2–4]. As a result various probiotics such as *Arthrobacter*, *Bacillus*, *Enterococcus*, *Lactobacillus*, *Lactococcus*, *Micrococcus*, *Pediococcus*, *Aeromonas*, *Burkholderia*, *Enterobacter*, *Vibrio*, *Pseudomonas*, *Rhodopseudomonas*, *Roseobacter* and *Shewanella* have been discovered and used to enhance growth and immunity of aquaculture species over the years [5,6]. In Reda and Selim [13], probiotics are used in aquaculture as safe additive to enhance the health of the host by enhancing growth, providing nutrients, modulating microbial colonization, improving immune responses, improving feed utilization, increasing digestive enzyme activities and digestibility, improving water quality and controlling diseases.

Among the many probiotic species discovered, *Bacillus* species have been proven to possess better probiotic properties attributable to their ability to produce antimicrobial substances that are active against many microbes and are non-pathogenic and non-toxic, together with their

sporulation capacity (i.e., which extend their period of effectiveness), gives them double advantage in terms of survival (heat-tolerance and longer shelf-life) in diverse environments compared to other probiotics such as *Lactobacillus* spp. [2,7–10]. *Bacillus* species are documented to enhance the digestive enzyme activity, antioxidant enzyme activity, expression of immune related genes as well as stress related genes and above all improving the ability of the fish to be resistant against pathogenic microbes [5,10,11]. *Bacillus* species also enhances better feed utilization in fish leading to better growth rate [11,12]. Therefore as shown in Fig. 1, this review seeks to bring together data on the role of *Bacillus* species in modulating digestive enzymes, antioxidant enzymes, expression of immune, stress and other related genes, hepatic indexes, disease resistance, feed utilization and growth as well as prospects of *Bacillus* species in aquaculture.

### 2. Characteristics and morphology of *Bacillus* species

Shown in Fig. 2 are the characteristic of *Bacillus* species that makes them suitable probiotic candidates for sustainable aquaculture.

*Bacillus* species are Gram-positive, chemoheterotrophic rod-shaped bacteria which are usually motile by peritrichous flagella and has no capsules; they are aerobic or facultative anaerobic and catalase positive [14]. *Bacillus* produce spores which may be cylindrical, oval or round, or kidney shaped and are more resistant to disinfectant, drying, and

\* Corresponding author. College of Fisheries, Guangdong Ocean University, Huguang Yan East, Zhanjiang, 524088, Guangdong Province, China.

E-mail address: [fishdis@163.com](mailto:fishdis@163.com) (Y. Lu).

<sup>1</sup> First co-authors.

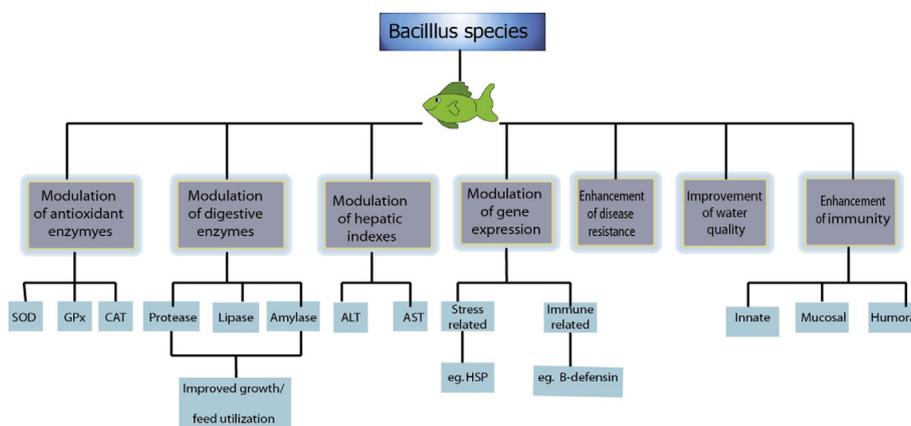


Fig. 1. Influences of probiotic *Bacillus* on aquatic organism and environment.

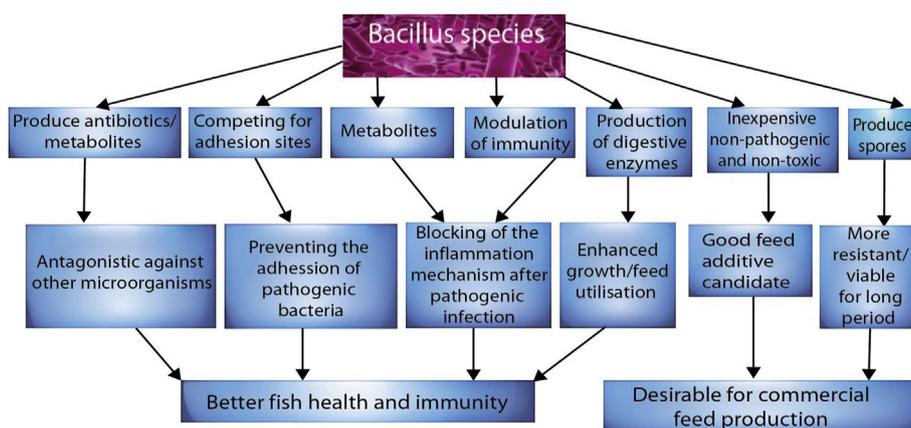


Fig. 2. Characteristics of *Bacillus* species for the improvement of fish health and immunity as well as commercial feed production.

heat compared to their vegetative cells [15] thus remain viable for a long period. There is one spore per cell and sporulation is not inhibited by exposure to air.

On non-selective media, *Bacillus* spp. typically exhibit large, flat colonies and are often beta-hemolytic. With few exceptions, the genus *Bacillus* are catalase positive and aerobic which distinguishes them from clostridia and sporolactobacillus [15]. Members of the *Bacillus* genus are usually found in soil [16] and water [17]. Those used in aquaculture are usually isolated from soil, and pond water, intestinal tract of fish, and commercial sources [16–22].

Many *Bacillus* species are important because of their ability to produce antibiotics/metabolites which have antagonistic effects against pathogenic microorganisms [23,24]. They have been used in medicine and pharmaceutical industry to control various diseases in human, animals, and plants as a biological control agent owing to their ability to synthesize a wide variety of metabolites with antimicrobial activity [25,26]. They are inexpensive, non-pathogenic and non-toxic (though not all) and more effective sources of antibiotics thus are desirable for commercial production and have been used experimentally to control pathogenic bacteria in fish over the years [1,7,8,14,23,27–29].

Like any other probiotics, *Bacillus* species possess characteristics such as inhibition of pathogens by competing for adhesion sites with pathogenic microbes to inhibit their growth as well as production of antibiotics [30,31] and bacteriocins [32,33], inhibition of virulence gene expression (quorum quenching) [34,35] and the production of lytic enzymes such as proteases, chitinases, cellulases, and  $\beta$ -1,3-glucanases which lyse the cell wall of pathogenic microbes [32,36]. Another characteristic of *Bacillus* is the provision of nutrients and enzymatic digestion that enhances growth through the secretion of digestive enzymes [6]. *Bacillus* species are also known for their

immunostimulatory effects and stimulation of beneficial gut microflora thus enhancing the host's innate and adaptive immunity [6,37]. The majority of *Bacillus* species used as probiotics in fish include *B. subtilis*, *B. licheniformis*, *B. pumilus* and *B. amyloliquefaciens* [38].

### 3. Modulation of antioxidant enzymes by *Bacillus* species

Phagocytic process as well as cellular metabolism eventually results in the production of reactive oxygen species (ROS), such as hydrogen peroxide ( $H_2O_2$ ), superoxide anion ( $O_2^{\cdot-}$ ), and hydroxyl radical ( $\cdot OH$ ) [29,39,40]. Oxidative stress occurs when oxidants such as ROS, nitrogen species (RNS), and lipid peroxidation (LPO) production, surpasses the antioxidant capacity of cells or tissues [41,42]. The damages induced by these ROS are known to be counteracted by antioxidant enzymes [43] hence antioxidants enzymes protect the host from oxidative stress [29]. Antioxidant enzymes indicate the antioxidant status of an aquatic organism and they reflect the oxidative anxiety [44]. The common antioxidant enzymes found in fish are superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx) [45]. For instance SOD decomposes of  $O_2^{\cdot-}$  to  $H_2O_2$  [46,47] while CAT catalyses the dismutation of  $H_2O_2$  into  $H_2O$  and  $O_2$  [48].

As mentioned by Li et al. [49] and Hindu et al. [44], *Bacillus* species as probiotics can produce antioxidant enzymes for example SOD and glutathione to eliminate the free radicals effectively. Whether in the serum or in the mucus, *Bacillus* are able to modulate antioxidant activities. For example, *B. licheniformis* Dabhl was mentioned to increase the antioxidant response of Asian catfish *Pangasius hypophthalmus* [50] and also in the serum and mucus of *O. mossambicus* [40]. Esteban et al. [51], also discovered that the expressions of GPx and SOD in the mucus of gilthead seabream *Sparus aurata* were up-regulated after dietary

supplementation of *Shewanella putrefaciens* and *Bacillus* species. The antioxidant capability of gibel carp (*Carassius auratus gibelio*) [52] and Nile tilapia [29] were enhanced after *B. coagulans* and *B. subtilis* and *B. licheniformis* supplementation respectively.

#### 4. Stress mitigation by the application of *Bacillus* species

Stress renders fish susceptible to diseases by modifying the innate immune responses, which are important defense mechanisms [53] thus stress is a factor that contributes to the high mortality and diseases in aquaculture and fisheries stock enhancement [54]. Stress response occurs at the cellular level in fish, which includes various heat shock proteins (HSP), which have a defensive role in maintaining the homeostasis [54]. HSP play an important role in the survival and health of stressed fish due to their increased levels in correspondence to exposure to stressors [55]. Other indicators of stress are glucose and cortisol [56]. Various factors such as handling, vaccination, water quality, transport, salinity, feeding, and high stocking densities as well as ammonia and nitrite in aquaculture are stressors that affect the physiology and health of fish [56–61].

Stressors are unavoidable in commercial fish farming and probiotics have been reported to improve the stress tolerance of fish [62,63]. For example in shrimps, *Litopenaeus vannamei* subjected to various chemicals and environmental stressors, those treated with *B. subtilis* and *B. licheniformis* were more resistant relative to the control [56]. Telli et al. [64] reported that the inclusion *B. subtilis* in the diet of Nile tilapia decreased the stress associated with high stocking density. Also low mortality was recorded in striped catfish (*P. hypophthalmus*) subjected to ammonia stress after *B. amyloliquefaciens* 54A, and *B. pumilus* 47B diet supplementation [60]. An experiment by Eissa et al. [53] revealed that mixed *Bacillus* species (*B. subtilis*, *B. pumilus*, *Bacillus amyloliquefaciens* and *B. licheniformis*) improved yellow perch's stress tolerance to hypoxia and air-exposure.

#### 5. *Bacillus* species can prevent tissue damage

In recent times, aquatic systems have heavily suffered from the accumulation of pollutants/toxicants which has raised the opinion that these pollutants are the possible causes of liver enlargement and gall syndrome disease in many cultured fish [65]. Aspartate transaminase (AST) and alanine transaminase (ALT) are enzymes accountable for some biochemical reactions of metabolism that interconvert amino acids with other metabolic intermediates and increase in their amount is suggestive of tissue damage e.g. chronic liver diseases [56,66]. As stated by Wala et al. [67], AST and ALT are sensitive biomarkers used in the diagnosis of hepatic damage since they are cytoplasmic in nature and are released into circulation (blood) after cellular damage. In vertebrates, AST exists in mitochondrial and cytoplasmic forms with the highest level in heart, liver, muscle, and kidney tissues respectively [56].

Analyzing the activities of AST and ALT can help detect tissue damage caused by toxicants (i.e. within feed administered or in the environment) [65] thus they are enzymes that are of vital importance to fishes. The role of *Bacillus* spp. in modulating AST and ALT in fish has been elucidated. For example lower AST, ALT were recorded in fish fed diet supplemented with probiotic *B. licheniformis* and *B. subtilis* [20]. In shrimps, AST, ALT activities were significantly lower in groups treated with *B. subtilis* and *B. licheniformis* compared with the control [56]. Similar observations were recorded in Nile tilapia fed with *B. subtilis*, *Bacillus megaterium*, and *B. licheniformis* [68,69] and in *Labeo rohita* treated with *B. amyloliquefaciens* CCF7 [70] indicating *Bacillus* to be responsible for removing the toxic factors and improved liver functions demonstrating their hepatoprotective potential. However there are very few reports on their ability to ameliorate the emerging liver associated problems in fish culture.

#### 6. *Bacillus* species increases disease resistance in aquatic organism

The most common causes of disease problems in aquaculture is bacterial infections [71]. Among the bacterial pathogens, *Streptococcus agalactiae* [72] and *Aeromonas hydrophila* [73] have been reported to cause substantial economic losses in fish farms. The application of antibiotics and chemotherapeutic to curb the situation of diseases caused by pathogenic bacteria has resulted in the emergence of drug resistant microorganisms, which has led to environmental hazards and food safety issues [11,74]. Also treatment with vaccines are only effective against specific pathogenic bacteria hence cannot be used as universal control agent [75].

As a result, probiotics have been introduced as an alternative for enhancing fish health and controlling diseases [76–80]. The proposed mechanisms used by probiotics to improve the disease resistance of fish include exclusion of pathogens by producing antimicrobial substances and competing with pathogens for nutrients and space [11] as well as causing up-regulation of the host's nonspecific or specific immune system hence enhancing defence against pathogens [74].

A growing number of studies have dealt explicitly with the use of *Bacillus* species in combating bacteria diseases in aquaculture. Evidently, increased resistance have been recorded against *S. iniae*, [11], *A. hydrophila* [75], *Acinetobacter* sp. and *Acinetobacter tandoii* [2] and *Aeromonas salmonicida*, *S. agalactiae*, *Lactococcus garvieae*, and *Vibrio parahaemolyticus* [38] after *Bacillus* diet supplementation. Furthermore, improved disease resistance through dietary *B. subtilis* administration has been as well reported in various aquatic species such as rainbow trout [81], tilapia [82], and white shrimp [83]. Therefore *Bacillus* species have been successful in their role as substitutes for antibiotics.

#### 7. *Bacillus* species improve feed utilization and growth

Intensified aquaculture to meet the growing demand of fish has led to increased stress, poor welfare and slow growth performance of aquaculture species [84]. As a result, several chemicals and food supplements have been used to improve growth and promote welfare of cultured fish [85]. One paramount of such supplements is probiotics used as simple and safe additive to improve growth of the host by providing nutrients, increasing digestive enzyme activities hence enhancing feed utilization and digestibility [85–87]. Irianto and Austin [88] also mentioned that probiotic bacteria contributes to growth of fish by increasing appetite, the production of vitamins, increasing digestive enzyme activity, breaking down indigestible components as well as improvement of intestine morphology.

Literature has proven that *Bacillus* species as probiotics when administered to fish, increase growth and feed utilization either in solitary or in combination with other immunostimulants [89–91]. For instance Gobi et al. [50] and Aly et al. [92] reported that *B. licheniformis* Dabhl and *B. pumilus* significantly increased the growth of *P. hypophthalmus* and *Oreochromis niloticus*. Furthermore when used as water additive, *B. coagulans* B<sub>16</sub> enhanced the growth of tilapia [93] hence most *Bacillus* species are able to improve the growth of the host. An experiment conducted by Elsabagh et al. [94] to assess the impact of mixture of *Bacillus* strains (*B. subtilis*, *B. licheniformis* and *Bacillus pumilus*) on growth performance and intestinal morphology of Nile tilapia, *O. niloticus* showed a significant improvement in growth performance and feed conversion ratio likewise *B. subtilis* and *B. licheniformis* combination [95], even though the ability of *Bacillus* to improve growth is dose dependent. In combination with other immunostimulants such as *Yarrowia lipolytica* lipase 2 [96], *Astragalus membranaceus*, *Angelica sinensis*, and *Crataegus hupehensis* [1],  $\beta$ -glucan oligosaccharides [97], malic acid [69] and mannan oligosaccharide [98] *Bacillus* species are able to enhance the growth of fish.

In relation to feed utilization, feeding tiger shrimp, *Penaeus*

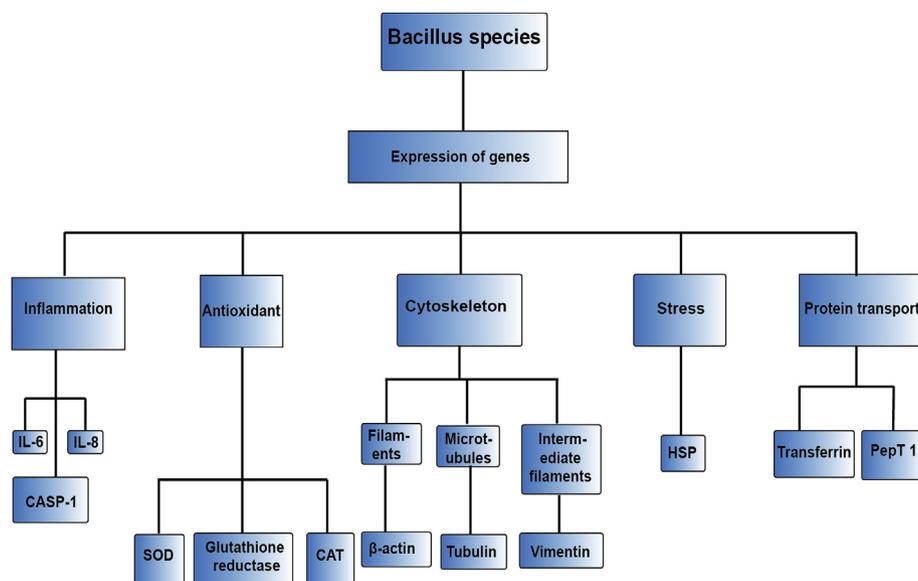


Fig. 3. Molecular action of *Bacillus* in improving health of aquatic organisms.

*monodon* with diet supplemented with *Bacillus* sp. DDKRC1 resulted in better protein efficiency ratio, lower feed conversion ratio and fast growth [99]. Same effect was observed in European seabass, *Dicentrarchus labrax* larvae and white shrimp *L. vannamei* after *Bacillus* treatment [95,100].

The assessment of the presence of digestive enzymes and their level of activity in fish is a relative indicator of the food acceptance, the digestive capacity in relation to the type of feed offered, trophic niche in natural conditions and feeding ecology of the fish [101,102]. Fish growth as well as production cost in aquaculture is directly affected by feed digestibility which can be enhanced by increasing the activity of digestive enzymes [22]. It is further stated that the level of digestive enzyme activity in fish is a relative sign of digestive capacity, food utilization rate, and growth performance of the host [101]. Enzymes produced by *Bacillus* are efficient at metabolizing a large range of lipids, proteins, and carbohydrates and this is one of the reasons for their choice as probiotics to improve digestive enzyme activities [17,103,104].

Liu et al. [103] reported that *B. subtilis* E20 fed to shrimp improved digestive protease activity which translated into excellent growth performance. Evidently dietary administration of *B. subtilis* HAINUP40 significantly increased the enzyme activities in the digestive tract of *O. niloticus* after 4 and 8 weeks [17]. *B. subtilis* ANSB060 also improved digestive enzyme activities of hepatopancreas and intestines of Yellow river carp [105]. The improvement in the digestive enzyme activities of fish after *Bacillus* administration may be attributed to enzymes synthesized by the bacteria or perhaps *Bacillus* are able to stimulate the production of endogenous enzymes in the fish [106,107]. Typically, protease, amylase, trypsin, and lipase are the major digestive enzymes modulated by *Bacillus* species [106,108–110]. For example, *B. subtilis* enhanced the digestive enzyme activity of grass carp, Yellow River carp, white shrimp and tilapia, [17,105,107,111]. *B. coagulans* was also reported to enhance the digestive enzymes activity freshwater prawn, *Macrobrachium rosenbergii* [108]. Hamza et al. [110] also recorded improvement in the digestive enzymes of sea bass, *Dicentrarchus labrax* larva after feeding with *Bacillus mojavensis*. *Bacillus clausii* DE5 and *Bacillus pumilus* SE5 improved intestinal digestive enzymes of grouper, *Epinephelus coioides* [112]. Whether administered in solitary or in combination with other probiotics and/or prebiotics, *Bacillus* species are able to modulate the digestive enzymes of fish. A typical example is the modulation of amylase in the digestive tract of sea bass after *Virgibacillus proomii* and *Bacillus mojavensis* administration [110] and

intestinal protease of triangular bream *Megalobrama terminalis* after feeding with fructooligosaccharide and *Bacillus licheniformis* [113].

## 8. *Bacillus* species enhances immune response in fish

Enhancement of host immunity is one important benefits of probiotic diet supplementation [5]. As stated by Verschuere et al. [114], probiotics can modulate innate immunity through the modulation of humoral immune responses and expression of immune-related genes.

## 9. Humoral immunity

Serum immune parameters such as lysozyme, peroxidase, superoxide dismutase (SOD), protease and antiprotease, catalase (CAT) and myeloperoxidase (MPO) have potent bactericidal activity against microbial infection [5]. An increase in the activities of the above mentioned immune parameters generally suggests an increase in immune response in the host [115,116]. Modulation of these parameters after probiotic *Bacillus* diet supplementation has been documented by many researchers. As have been reported by Cha et al. [11] and Yi et al. [38], dietary administration of *Bacillus* species enhanced both cellular and humoral immune responses in fish which reflected in increased disease resistance.

Mucus plays a vital role in the defence against infection since infectious agents affect and initiate the process of infection in the mucus [117]. Immune substances in fish mucus, contains lysozyme, almodulin, complement, interferon, lectin, immunoglobulin, agglutinin C-reactive protein, antimicrobial peptides, proteolytic enzymes, and vitellogenin are the common molecules [118,119]. In comparison with serum, only few researches have revealed the role of probiotics in modulating mucosal immunity [120,121]. Nevertheless the little literature available revealed that *Bacillus* species can enhance the mucosal immunity of fish [77,120,122].

## 10. Gene expression

Shown in Fig. 3 are some genes found in previous reports to have changed in expression following probiotic *Bacillus* feeding. *Bacillus* species are reported to enhance the expression of genes related to inflammation, growth metabolism, digestion processes, cytoskeleton, genes encoding proteins of junction complexes, antioxidant genes and genes related to transport proteins [29,51,123–126]. Unlike the role of

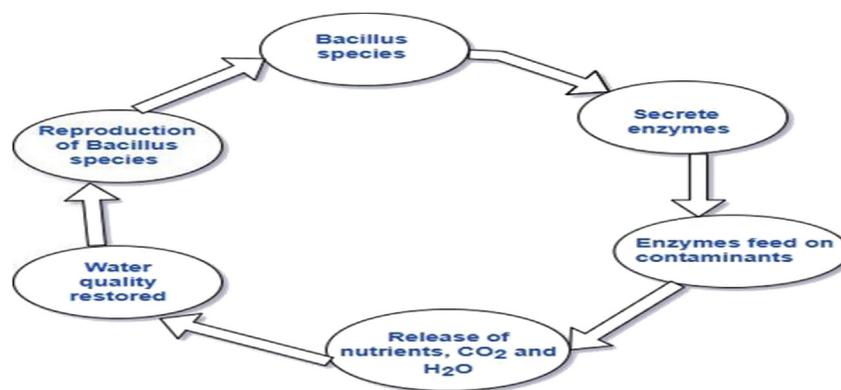


Fig. 4. *Bacillus* action in improving water quality.

*Bacillus* in modulating growth, feed utilization, and digestive enzymes activity, only few literature are available in relation to *Bacillus* and the expression of the above mentioned genes [125].

A mix of *Bacillus* species was reported to reduce the severity of cellular stress in Sea bream larvae by lowering the expression of HSP70 gene thus improving tolerance of the fish to rearing conditions [126]. Two strains of *B. subtilis* strains, L10 and G1 were also reported to induce the expression of immune-related genes (prophenoloxidase (proPO), peroxinectin (PE), lipopolysaccharide and  $\beta$ -1,3-glucan-binding protein (LGBP) and serine protein (SP)) making white shrimp, *L. vannamei* more resistant against *V. harveyi* [111]. Other evidences exist such as the modulation of mucosal gene expression in gilthead Sea bream [51], the expression of immune-related genes in the head kidney of *C. auratus* [38], the expression of pro-inflammatory cytokines (IL-8 and IL-1 $\beta$ ), TLR5, and TGF- $\beta$ 1 in intestine and head kidney of *E. coioides* [127] and the expression of pro-inflammatory cytokines in the intestine of Nile tilapia [128] after probiotic *Bacillus* administration.

### 11. Application of *Bacillus* species improves water quality

The wellbeing and growth of any organism is directly reliant on its environment [129]. Optimal condition and the physico-chemical status of the rearing water is an essential concern in aquaculture and most infections may be as a result of poor water quality [130]. Extracellular enzymes and antimicrobial peptides produced by *Bacillus* species not only control pathogenic bacteria but also improve the rearing water quality [130–134]. It is documented that the addition of probiotic bacteria to the water or diet of fish can improve the water quality [135] thus probiotic bacteria detoxify water making it suitable for culture organisms [129,136].

The addition of *B. subtilis* ( $10^8$  CFU ml $^{-1}$ ) directly to the rearing water was reported to maintain the concentration of nitrite, ammonia, and nitrate ions within the tolerable ranges for shrimp culture [130]. An experiment conducted by Nimrat et al. [132] revealed that the addition of *Bacillus* probiotics in diverse forms and methods of application to shrimp larvae results in significant reduction of ammonia and nitrite levels. Many researchers have reported the mineralization of nitrogenous wastes through nitrification and/or denitrification leading to reduced ammonia and nitrite levels thus improving water quality by *Bacillus* genera [137–143]. Nitrification as a result of the addition of *Bacillus* probiotics discharges hydrogen ions which results in the reduction of pH [144]. Modulation of dissolved oxygen, ammonia, BOD, TDS, COD, alkalinity and pH was recorded after *B. megaterium* treatment but temperature and transparency were not affected [129]. *Bacillus* are also useful in removing organic matter from culture systems [145]. However Liu et al. [103] reported that *B. subtilis* E20 did not improve water quality for shrimp culture. Regardless, the above documentations ascertain that *Bacillus* species can be used for bioremediation hence maintaining water quality leading to better growth of

aquaculture species. In Fig. 4 is a summary of the water purification process by *Bacillus* species.

### 12. Conclusion and future perspectives

The role of probiotics, specifically *Bacillus* in aquaculture is overwhelming. In this review, it is obvious that *Bacillus* have a great potential in contributing to the continuity of farming of fish by maintaining the total wellbeing of cultured fish ranging from enhancement of growth, feed utilization, immune response, protection against diseases infections especially against bacterial infections as well as improvement of water quality. However, we suggest the following to help improve research and the application of probiotic *Bacillus* in fish culture.

With the recent emergence of viral infections in tilapia resulting in massive economic losses [146,147]; to our knowledge, there are no reports on probiotic use in conferring protection against viral diseases in cultured fish. Therefore, there is the need for researchers to further elucidate the mechanism of action of probiotic *Bacillus* against viral infection.

Also, we advocate for studies that are geared towards elucidating the effects of probiotic *Bacillus* on; nutrient utilization and molecular (gene expression) responses to help in understanding the mechanism of action of *Bacillus* in preventing and controlling diseases.

### Acknowledgment

Shenzhen strategic emerging and future industrial development funds (20170426231005389).

### References

- [1] E.D. Abarike, J. Jian, J. Tang, J. Cai, H. Yu, C. Lihua, L. Jun, Influence of traditional Chinese medicine and *Bacillus* species (TCMBBS) on growth, immune response and disease resistance in Nile tilapia, *Oreochromis niloticus*, Aquacult. Res. 49 (2018) 2366–2375, <https://doi.org/10.1111/are.13691>.
- [2] M. Kavitha, M. Raja, P. Perumal, Evaluation of probiotic potential of *Bacillus* spp. isolated from the digestive tract of freshwater fish *Labeo calbasu* (Hamilton, 1822), Aquac. Reports. 11 (2018) 59–69 <https://doi.org/10.1016/j.aqrep.2018.07.001>.
- [3] B. Magnadottir, Immunological control of fish diseases, Mar. Biotechnol. 12 (2010) 361–379, <https://doi.org/10.1007/s10126-010-9279-x>.
- [4] J.A. Resende, V.L. Silva, C.O. Fontes, J.A. Souza-Filho, T.L.R.C. de Oliveira, C.M. César, D. Evangelista, Diniz, C. Galuppo, Multidrug-resistance and toxic metal tolerance of medically important bacteria isolated from an aquaculture system, Microb. Environ. 27 (2012) 449–455, <https://doi.org/10.1264/jsme2.ME12049>.
- [5] S.K. Nayak, Probiotics and immunity: a fish perspective, Fish Shellfish Immunol. 29 (2010) 2–14 <https://doi.org/10.1016/j.fsi.2010.02.017>.
- [6] N. Van Hai, Research findings from the use of probiotics in tilapia aquaculture: a review, Fish Shellfish Immunol. 45 (2015) 592–597, <https://doi.org/10.1016/j.fsi.2015.05.026>.
- [7] H. Abriouel, C.M.A.P. Franz, N. Ben Omar, A. Galvez, Diversity and applications of *Bacillus* bacteriocins, FEMS Microbiol. Rev. 35 (2011) 201–232, <https://doi.org/10.1111/j.1574-6976.2010.00244.x>.

- [8] X. Geng, X.H. Dong, B.P. Tan, Q.H. Yang, S.Y. Chi, H.Y. Liu, X.Q. Liu, Effects of dietary probiotic on the growth performance, non-specific immunity and disease resistance of cobia, *Rachycentron canadum*, *Aquac. Nutr.* 18 (2012) 46–55, <https://doi.org/10.1111/j.1365-2095.2011.00875.x>.
- [9] Y.-Z. Sun, H.-L. Yang, R.-L. Ma, W.-Y. Lin, Probiotic applications of two dominant gut *Bacillus* strains with antagonistic activity improved the growth performance and immune responses of grouper *Epinephelus coioides*, *Fish Shellfish Immunol.* 29 (2010) 803–809 <https://doi.org/10.1016/j.fsi.2010.07.018>.
- [10] C.T. Buruiană, A.G. Profir, C. Vizireanu, Effects of probiotic bacillus species in aquaculture – an overview, *Ann. Univ. Dunarea Jos Galati, Fascicle VI Food Technol.* 38 (2014) 9–17.
- [11] J.H. Cha, S. Rahimnejad, S.Y. Yang, K.W. Kim, K.J. Lee, Evaluations of *Bacillus* spp. as dietary additives on growth performance, innate immunity and disease resistance of olive flounder (*Paralichthys olivaceus*) against streptococcus iniae and as water additives, *Aquaculture* (2013) 402–403, <https://doi.org/10.1016/j.aquaculture.2013.03.030> 50–55.
- [12] H. Adineh, H. Jafaryan, J. Sahandi, M. Alizadeh, Effect of *Bacillus* spp. probiotic on growth and feeding performance of rainbow trout (*Oncorhynchus mykiss*) larvae, *Bulg. J. Vet. Med.* 16 (2013) 29–36.
- [13] K.M. Selim, R.M. Reda, Improvement of immunity and disease resistance in the Nile tilapia, *Oreochromis niloticus*, by dietary supplementation with *Bacillus amyloliquefaciens*, *Fish Shellfish Immunol.* 44 (2015) 496–503, <https://doi.org/10.1016/j.fsi.2015.03.004>.
- [14] M. Amin, Z. Rakhisi, A.Z. Ahmady, Isolation and identification of *Bacillus* species from soil and evaluation of their antibacterial properties, *Avicenna J Clin Microb Infec* 2 (2015) 10–13, <https://doi.org/10.17795/ajcimi-23233>.
- [15] R.E. Gordon, W.C. Haynes, C.H.N. Pang, N.R. Smith, *The Genus Bacillus*. US Department of Agriculture Handbook, vol. 427, 1973.
- [16] X. Zhou, Y. Wang, W. Li, Effect of probiotic on larvae shrimp (*Penaeus vannamei*) based on water quality, survival rate and digestive enzyme activities, *Aquaculture* 287 (2009) 349–353 <https://doi.org/10.1016/j.aquaculture.2008.10.046>.
- [17] H. Liu, S. Wang, Y. Cai, X. Guo, Z. Cao, Y. Zhang, S. Liu, W. Yuan, W. Zhu, Y. Zheng, Z. Xie, W. Guo, Y. Zhou, Dietary administration of *Bacillus subtilis* HAINUP40 enhances growth, digestive enzyme activities, innate immune responses and disease resistance of tilapia, *Oreochromis niloticus*, *Fish Shellfish Immunol.* 60 (2017) 326–333 <https://doi.org/10.1016/j.fsi.2016.12.003>.
- [18] M. Venkateshwarlu, R.N.A. T, P. Kumara, Research article influence of probiotics on growth performance and digestive enzyme activity of common carp (*Cyprinus carpio*) *Ecology*, College of Fisheries, Mathsyangar, *Int. J. Curr. Res.* 5 (2013) 1696–1700.
- [19] H. Sankar, B. Philip, R. Philip, I.S.B. Singh, Effect of probiotics on digestive enzyme activities and growth of cichlids, *Etropilus suratensis* (Pearl spot) and *Oreochromis mossambicus* (Tilapia), *Aquacult. Nutr.* 23 (2017) 852–864, <https://doi.org/10.1111/anu.12452>.
- [20] T.J. Adorian, H. Jamali, H.G. Farsani, P. Darvishi, S. Hasanpour, T. Bagheri, R. Roozbehfar, Effects of probiotic bacteria *Bacillus* on growth performance, digestive enzyme activity, and hematological parameters of Asian sea bass, *Lates calcarifer* (Bloch), probiotics antimicrob, *Proteins* (2018), <https://doi.org/10.1007/s12602-018-9393-z>.
- [21] M.S. Sumon, F. Ahmmed, S.S. Khushi, M.K. Ahmmed, M.A. Rouf, M.A.H. Chisty, M.G. Sarower, Growth performance, digestive enzyme activity and immune response of *Macrobrachium rosenbergii* fed with probiotic *Clostridium butyricum* incorporated diets, *J. King Saud Univ. Sci.* 30 (2018) 21–28 <https://doi.org/10.1016/j.jksus.2016.11.003>.
- [22] W. Afrilasari, Widanarni, A. Meryandini, Effect of probiotic *Bacillus megaterium* PTB 1.4 on the population of intestinal microflora, digestive enzyme activity and the growth of catfish (*Clarias* sp.), *Hayati J. Biosci.* 23 (2016) 168–172, <https://doi.org/10.1016/j.hjb.2016.12.005>.
- [23] M. Amin, Z. Rakhisi, A.Z. Ahmady, Isolation and identification of *Bacillus* species from soil and evaluation of their antibacterial properties, *Avicenna J Clin Microb Infec* (2015) 10–13, <https://doi.org/10.17795/ajcimi-23233>.
- [24] M.M. Al-Ajlani, S. Hasnain, Bacteria exhibiting antimicrobial activities; screening for antibiotics and the associated genetic studies, *Open Conf. Proc. J.* 1 (2010) 230–238, <https://doi.org/10.2174/2210289201001010230>.
- [25] C.D. McKeen, C.C. Reilly, P.L. Pusey, Production and partial characterization of antifungal substances antagonistic to *Monilinia fructicola* from *Bacillus subtilis*, *Phytopathology* 76 (1985) 136–139, <https://doi.org/10.1016/j.soilbio.2014.03.012>.
- [26] L.A. Silo-Suh, B.J. Lethbridge, S.J. Raffel, H. He, J. Clardy, J. Handelsman, Biological activities of two fungistatic antibiotics produced by *Bacillus cereus* UW85, *Appl. Environ. Microbiol.* 60 (1994) 2023–2030, <https://doi.org/10.1093/ecam/nej025>.
- [27] O. Violeta, S. Oana, C. Matilda, C.D. Maria, V. Catalina, C. Gheorghe, C.C. Petruta, Production of biosurfactants and antifungal compounds by new strains of *Bacillus* Spp. isolated from different sources, *Rom. Biotechnol. Lett.* 16 (2011) 84–91.
- [28] A. Mathur, A. Rawat, G. Bhatt, S. Baweja, F. Ahmad, A. Grover, K. Madhav, D. Mathur, S.K. Verma, S.K. Singh, V.K. Dua, Isolation of *Bacillus* producing chitinase from Soil: production and purification of chito-oligosaccharides from chitin extracted from fresh water Crustaceans and antimicrobial activity of chitinase, *Recent Res. Sci. Technol.* 3 (2011) 1–6.
- [29] E.D. Abarike, J. Cai, Y. Lu, H. Yu, L. Chen, J. Jian, J. Tang, L. Jun, F.K.A. Kuebutornye, Effects of a commercial probiotic BS containing *Bacillus subtilis* and *Bacillus licheniformis* on growth, immune response and disease resistance in Nile tilapia, *Oreochromis niloticus*, *Fish Shellfish Immunol.* 82 (2018) 229–238 <https://doi.org/10.1016/j.fsi.2018.08.037>.
- [30] J. Béahdy, Recent developments of antibiotic research and classification of antibiotics according to chemical structure, *Adv. Appl. Microbiol.* Elsevier, 1974, pp. 309–406.
- [31] I. V. Pinchuk, P. Bressollier, B. Verneuil, B. Fenet, I.B. Sorokulova, F. Mégraud, M.C. Urdaci, *In vitro* anti-Helicobacter pylori Activity of the probiotic strain *Bacillus subtilis* 3 is due to secretion of antibiotics, *Antimicrob. Agents Chemother.* 45 (2001) 3156–3161.
- [32] M. Urdaci, I. Pinchuk, Antimicrobial Activity of *Bacillus* Probiotics-Bacterial Spore Formers: Probiotics and Emerging Applications, (2004), pp. 171–182.
- [33] T. Stein, *Bacillus subtilis* antibiotics: structures, syntheses and specific functions, *Mol. Microbiol.* 56 (2005) 845–857, <https://doi.org/10.1111/j.1365-2958.2005.04587.x>.
- [34] K.S. Musthafa, V. Saroja, S.K. Pandian, A.V. Ravi, Antipathogenic potential of marine *Bacillus* sp. SS4 on N-acyl-homoserine- lactone-mediated virulence factors production in *Pseudomonas aeruginosa* (PAO1), *J. Biosci.* 36 (2011) 55–67, <https://doi.org/10.1007/s12038-011-9011-7>.
- [35] C. Reimann, N. Ginet, L. Michel, C. Keel, P. Michaux, V. Krishnapillai, M. Zala, K. Heurlier, K. Triandafyllu, H. Harms, G. Défago, D. Hass, Genetically programmed autoinducer destruction reduces virulence gene expression and swarming motility in *Pseudomonas aeruginosa* PAO1, *Microbiology* 148 (2002) 923–932, <https://doi.org/10.1099/0021287-148-4-923>.
- [36] G.A. Bizilevičius, V. Ąukaitė, Comparative antimicrobial activity of lysostatin and its acid-resistant derivative, Ferosorb, *Int. J. Antimicrob. Agents.* 20 (2002) 65–68 [https://doi.org/10.1016/S0924-8579\(02\)00117-6](https://doi.org/10.1016/S0924-8579(02)00117-6).
- [37] M. Suva, V. Sureja, D. Khani, Novel insight on probiotic *Bacillus subtilis*: mechanism of action and clinical applications, *J. Curr. Res. Sci. Med.* 2 (2017) 65–72.
- [38] Y. Yi, Z. Zhang, F. Zhao, H. Liu, L. Yu, J. Zha, G. Wang, Probiotic potential of *Bacillus velezensis* JW: antimicrobial activity against fish pathogenic bacteria and immune enhancement effects on *Carassius auratus*, *Fish Shellfish Immunol.* 78 (2018) 322–330 <https://doi.org/10.1016/j.fsi.2018.04.055>.
- [39] R.M. Reda, M.A. El-Hady, K.M. Selim, H.M. El-Sayed, Comparative study of three predominant gut *Bacillus* strains and a commercial *B. amyloliquefaciens* as probiotics on the performance of *Clarias gariepinus*, *Fish Shellfish Immunol.* 80 (2018) 416–425 <https://doi.org/10.1016/j.fsi.2018.06.031>.
- [40] N. Gobi, B. Vaseeharan, J.C. Chen, R. Rekha, S. Vijayakumar, M. Anjugam, A. Iswarya, Dietary supplementation of probiotic *Bacillus licheniformis* Dab1 improves growth performance, mucus and serum immune parameters, antioxidant enzyme activity as well as resistance against *Aeromonas hydrophila* in tilapia *Oreochromis mossambicus*, *Fish Shellfish Immunol.* 74 (2018) 501–508, <https://doi.org/10.1016/j.fsi.2017.12.066>.
- [41] P.-A. Mouthuy, S.J.B. Snelling, S.G. Dakin, L. Milković, A.Č. Gašparović, A.J. Carr, N. Žarković, Biocompatibility of implantable materials: an oxidative stress viewpoint, *Biomaterials* 109 (2016) 55–68 <https://doi.org/10.1016/j.biomaterials.2016.09.010>.
- [42] A. Bermejo-Nogales, M. Fernández, M.L. Fernández-Cruz, J.M. Navas, Effects of a silver nanomaterial on cellular organelles and time course of oxidative stress in a fish cell line (PLHC-1), *Comp. Biochem. Physiol. C Toxicol. Pharmacol.* 190 (2016) 54–65 <https://doi.org/10.1016/j.cbpc.2016.08.004>.
- [43] I. Messaoudi, S. Barhoumi, K. Said, A. Kerken, Study on the sensitivity to cadmium of marine fish *Salarias basilisca* (Pisces: Blenniidae), *J. Environ. Sci.* 21 (2009) 1620–1624, [https://doi.org/10.1016/S1001-0742\(08\)62464-X](https://doi.org/10.1016/S1001-0742(08)62464-X).
- [44] S.V. Hindu, S. Thanigaivel, S. Vijayakumar, N. Chandrasekaran, A. Mukherjee, J. Thomas, Effect of microencapsulated probiotic *Bacillus vireti* 01-polysaccharide extract of *Gracilaria folifera* with alginate-chitosan on immunity, antioxidant activity and disease resistance of *Macrobrachium rosenbergii* against *Aeromonas hydrophila* infection, *Fish Shellfish Immunol.* 73 (2018) 112–120 <https://doi.org/10.1016/j.fsi.2017.12.007>.
- [45] R.T. Di Giulio, C. Habig, E.P. Gallagher, Effects of Black Rock Harbor sediments on indices of biotransformation, oxidative stress, and DNA integrity in channel catfish, *Aquat. Toxicol.* 26 (1993) 1–22 [https://doi.org/10.1016/0166-445X\(93\)90002-1](https://doi.org/10.1016/0166-445X(93)90002-1).
- [46] M. Castex, P. Lemaire, N. Wabete, L. Chim, Effect of probiotic *Pediococcus acidilactici* on antioxidant defences and oxidative stress of *Litopenaeus stylirostris* under *Vibrio nigripulchritudo* challenge, *Fish Shellfish Immunol.* 28 (2010) 622–631 <https://doi.org/10.1016/j.fsi.2009.12.024>.
- [47] J. Li, Y. Xu, L. Jin, X. Li, Effects of a probiotic mixture (*Bacillus subtilis* YB-1 and *Bacillus cereus* YB-2) on disease resistance and non-specific immunity of sea cucumber, *Apostichopus japonicus* (Selenska), *Aquacult. Res.* 46 (2015) 3008–3019, <https://doi.org/10.1111/are.12453>.
- [48] L. Wang, C. Ge, J. Wang, J. Dai, P. Zhang, Y. Li, Effects of different combinations of *Bacillus* on immunity and antioxidant activities in common carp, *Aquacult. Int.* 25 (2017) 2091–2099, <https://doi.org/10.1007/s10499-017-0175-5>.
- [49] W.F. Li, B. Deng, Z.W. Cui, L.Q. Fu, N.N. Chen, X.X. Zhou, W.Y. Shen, D.Y. Yu, Several indicators of immunity and antioxidant activities improved in grass carp given a diet containing bacillus additive, *J. Anim. Vet. Adv.* 11 (2012) 2392–2397, <https://doi.org/10.3923/javaa.2012.2392.2397>.
- [50] N. Gobi, B. Malaikozhundan, V. Sekar, S. Shanthi, B. Vaseeharan, R. Jayakumar, A.K. Nazar, GFP tagged *Vibrio parahaemolyticus* Dabv2 infection and the protective effects of the probiotic *Bacillus licheniformis* Dab1 on the growth, immune and antioxidant responses in *Pangasius hypophthalmus*, *Fish Shellfish Immunol.* 52 (2016) 230–238 <https://doi.org/10.1016/j.fsi.2016.03.006>.
- [51] M.A. Esteban, H. Cordero, M. Martínez-Tomé, A.M. Jiménez-Monreal, A. Bakhrouf, A. Mahdhi, Effect of dietary supplementation of probiotics and palm fruits extracts on the antioxidant enzyme gene expression in the mucosae of gilt-head seabream (*Sparus aurata* L.), *Fish Shellfish Immunol.* 39 (2014) 532–540 <https://doi.org/10.1016/j.fsi.2014.06.012>.
- [52] Y. Yu, C. Wang, A. Wang, W. Yang, F. Lv, F. Liu, B. Liu, C. Sun, Effects of various

- feeding patterns of *Bacillus coagulans* on growth performance, antioxidant response and Nrf2-Keap1 signaling pathway in juvenile gibel carp (*Carassius auratus gibelio*), *Fish Shellfish Immunol.* 73 (2018) 75–83 <https://doi.org/10.1016/j.fsi.2017.11.050>.
- [53] N. Eissa, H.P. Wang, H. Yao, E. Abou-ElGheit, Mixed *Bacillus* species enhance the innate immune response and stress tolerance in yellow perch subjected to hypoxia and air-exposure stress, *Sci. Rep.* 8 (2018), <https://doi.org/10.1038/s41598-018-25269-z>.
- [54] N. Eissa, H.P. Wang, Transcriptional stress responses to environmental and husbandry stressors in aquaculture species, *Rev. Aquacult.* 8 (2016) 61–88, <https://doi.org/10.1111/raq.12081>.
- [55] M. Yamashita, T. Yabu, N. Ojima, Stress protein HSP70 in fish, *Aqua-BioScience Monogr.* 3 (2010) 111–141, <https://doi.org/10.5047/absm.2010.00304.0111>.
- [56] D. Abdollahi-Arpanahi, E. Soltani, H. Jafaryan, M. Soltani, M. Naderi-Samani, A.I. Campa-Córdova, Efficacy of two commercial and indigenous probiotics, *Bacillus subtilis* and *Bacillus licheniformis* on growth performance, immunophysiology and resistance response of juvenile white shrimp (*Litopenaeus vannamei*), *Aquaculture* 496 (2018) 43–49 <https://doi.org/10.1016/j.aquaculture.2018.06.082>.
- [57] V.I. Fuchs, J. Schmidt, M.J. Slater, B.H. Buck, D. Steinhagen, Influence of immunostimulant polysaccharides, nucleic acids, and *Bacillus* strains on the innate immune and acute stress response in turbot (*Scophthalmus maximus*) fed soy bean- and wheat-based diets, *Fish Physiol. Biochem.* 43 (2017) 1501–1515, <https://doi.org/10.1007/s10695-017-0388-6>.
- [58] S.H. Hoseinifard, Z. Roosta, A. Hajimoradloo, F. Vakili, The effects of *Lactobacillus acidophilus* as feed supplement on skin mucosal immune parameters, intestinal microbiota, stress resistance and growth performance of black swordtail (*Xiphophorus helleri*), *Fish Shellfish Immunol.* 42 (2015) 533–538 <https://doi.org/10.1016/j.fsi.2014.12.003>.
- [59] H. Segner, H. Sundh, K. Buchmann, J. Douxfils, K.S. Sundell, C. Mathieu, N. Ruane, F. Jutfelt, H. Toften, L. Vaughan, Health of farmed fish: its relation to fish welfare and its utility as welfare indicator, *Fish Physiol. Biochem.* 38 (2012) 85–105, <https://doi.org/10.1007/s10695-011-9517-9>.
- [60] H.T.T. Thy, N.N. Tri, O.M. Quy, R. Fotedar, K. Kannika, S. Unajak, N. Areechon, Effects of the dietary supplementation of mixed probiotic spores of *Bacillus amyloliquefaciens* 54A, and *Bacillus pumilus* 47B on growth, innate immunity and stress responses of striped catfish (*Pangasianodon hypophthalmus*), *Fish Shellfish Immunol.* 60 (1) (2017) 391–399 <https://doi.org/10.1016/j.fsi.2016.11.016>.
- [61] K.-F. Liu, C.-H. Chiu, Y.-L. Shiu, W. Cheng, C.-H. Liu, Effects of the probiotic, *Bacillus subtilis* E20, on the survival, development, stress tolerance, and immune status of white shrimp, *Litopenaeus vannamei* larvae, *Fish Shellfish Immunol.* 28 (2010) 837–844 <https://doi.org/10.1016/j.fsi.2010.01.012>.
- [62] M.N. Forsatkar, M.A. Nematollahi, G. Rafiee, H. Farahmand, C. Lawrence, Effects of the probiotic mannan-oligosaccharide on the stress response of feed deprived zebrafish (*Danio rerio*), *Physiol. Behav.* 180 (2017) 70–77 <https://doi.org/10.1016/j.physbeh.2017.08.010>.
- [63] A.A. Shaheen, N. Eissa, E.N. Abou-El-Gheit, H. Yao, H.P. Wang, Probiotic effect on molecular antioxidant profiles in yellow perch, *Perca flavescens*, *Glob. J. Fish. Aquac. Res.* 1 (2014) 16–29.
- [64] G.S. Telli, M.J.T. Ranzani-Paiva, D.D.C. Dias, F.R. Sussel, C.M. Ishikawa, L. Tachibana, Dietary administration of *Bacillus subtilis* on hematology and non-specific immunity of Nile tilapia *Oreochromis niloticus* raised at different stocking densities, *Fish Shellfish Immunol.* 39 (2014) 305–311, <https://doi.org/10.1016/j.fsi.2014.05.025>.
- [65] S. Kunjappan, C. Bhattacharjee, R. Chowdhury, In vitro antioxidant and hepatoprotective potential of *Azolla microphylla* phytochemically synthesized gold nanoparticles on acetaminophen – induced hepatocyte damage in *Cyprinus carpio* L. *In Vitro Cell. Dev. Biol. Anim.* 51 (2015) 630–643, <https://doi.org/10.1007/s11626-014-9841-3>.
- [66] D. Babazadeh, T. Vahdatpour, H. Nikpiran, M.A. Jafargholipour, S. Vahdatpour, Effects of probiotic, prebiotic and synbiotic intake on blood enzymes and performance of Japanese quails (*Coturnix Japonica*), *Indian J. Anim. Sci.* 81 (2011) 106–110.
- [67] B. Allah Abdulraheem, Aspartate transaminase (AST) activity in selected tissues & organs of *Clarias gariepinus* exposed to different levels of paraquat, *J. Environ. Anal. Toxicol.* 04 (2014) 3–4, <https://doi.org/10.4172/2161-0525.1000214>.
- [68] N. Sutthi, W. Thaimuangphol, M. Rodmongkoldee, W. Leelapatra, P. Panase, Growth performances, survival rate, and biochemical parameters of Nile tilapia (*Oreochromis niloticus*) reared in water treated with probiotic, *Comp. Clin. Pathol.* 27 (2018) 597–603, <https://doi.org/10.1007/s00580-017-2633-x>.
- [69] M.S. Hassaan, M.A. Soltan, S. Jarmolowicz, H.S. Abdo, Combined effects of dietary malic acid and *Bacillus subtilis* on growth, gut microbiota and blood parameters of Nile tilapia (*Oreochromis niloticus*), *Aquacult. Nutr.* 24 (2018) 83–93, <https://doi.org/10.1111/anu.12536>.
- [70] A. Nandi, G. Banerjee, S.K. Dan, K. Ghosh, A.K. Ray, Evaluation of *in vivo* probiotic efficiency of *Bacillus amyloliquefaciens* in *Labeo rohita* challenged by pathogenic strain of *Aeromonas hydrophila* MTCC 1739, probiotics antimicrob, *Proteins* 10 (2018) 391–398, <https://doi.org/10.1007/s12602-017-9310-x>.
- [71] R. Meidong, K. Khotchanalekha, S. Doolgindachaporn, T. Nagasawa, M. Nakao, K. Sakai, S. Tongpim, Evaluation of probiotic *Bacillus aerius* B81e isolated from healthy hybrid catfish on growth, disease resistance and innate immunity of Plango *Pangasius bocourti*, *Fish Shellfish Immunol.* 73 (2018) 1–10 <https://doi.org/10.1016/j.fsi.2017.11.032>.
- [72] W. Bei, L. Yishan, W. Zaohe, Immune response in Tilapia, *Oreochromis niloticus*, induced by the surface immunogenic protein (sip) of *Streptococcus agalactiae* Guangdong provincial key laboratory of pathogenic biology key laboratory of control for diseases of aquatic economic animal, *Isr. J. Aquacult. Bamidgeh* 65 (2015) 10 <http://hdl.handle.net/10524/49174>.
- [73] M.K.P. Iwashita, I.B. Nakandakare, J.S. Terhune, T. Wood, M.J.T. Ranzani-Paiva, Dietary supplementation with *Bacillus subtilis*, *Saccharomyces cerevisiae* and *Aspergillus oryzae* enhance immunity and disease resistance against *Aeromonas hydrophila* and *Streptococcus iniae* infection in juvenile tilapia *Oreochromis niloticus*, *Fish Shellfish Immunol.* 43 (2015) 60–66, <https://doi.org/10.1016/j.fsi.2014.12.008>.
- [74] R. Cerezuela, F.A. Guardiola, J. Meseguer, M.Á. Esteban, Increases in immune parameters by inulin and *Bacillus subtilis* dietary administration to gilthead seabream (*Sparus aurata* L.) did not correlate with disease resistance to *Photobacterium damsela*, *Fish Shellfish Immunol.* 32 (2012) 1032–1040 <https://doi.org/10.1016/j.fsi.2012.02.025>.
- [75] D. Ramesh, S. Souissi, Effects of potential probiotic *Bacillus subtilis* KADR1 and its subcellular components on immune responses and disease resistance in *Labeo rohita*, *Aquacult. Res.* 49 (2018) 367–377, <https://doi.org/10.1111/are.13467>.
- [76] S.S. Giri, S.S. Sen, V. Sukumaran, Effects of dietary supplementation of potential probiotic *Pseudomonas aeruginosa* VSG-2 on the innate immunity and disease resistance of tropical freshwater fish, *Labeo rohita*, *Fish Shellfish Immunol.* 32 (2012) 1135–1140 <https://doi.org/10.1016/j.fsi.2012.03.019>.
- [77] A. Das, K. Nakhro, S. Chowdhury, D. Kamilya, Effects of potential probiotic *Bacillus amyloliquefaciens* FPTB16 on systemic and cutaneous mucosal immune responses and disease resistance of catla (*Catla catla*), *Fish Shellfish Immunol.* 35 (2013) 1547–1553 <https://doi.org/10.1016/j.fsi.2013.08.022>.
- [78] A. Newaj-Fyzul, A.H. Al-Harbi, B. Austin, Review: developments in the use of probiotics for disease control in aquaculture, *Aquaculture* 431 (2014) 1–11 <https://doi.org/10.1016/j.aquaculture.2013.08.026>.
- [79] P. Martínez Cruz, A.L. Ibáñez, O.A. Monroy Hermsillo, H.C. Ramírez Saad, Use of probiotics in aquaculture, *ISRN Microbiol* (2012) 1–13, <https://doi.org/10.5402/2012/916845> 2012.
- [80] S. Mohapatra, T. Chakraborty, A.K. Prusty, P. Das, K. Paniprasad, K.N. Mohanta, Use of different microbial probiotics in the diet of rohu, *Labeo rohita* fingerlings: effects on growth, nutrient digestibility and retention, digestive enzyme activities and intestinal microflora, *Aquacult. Nutr.* 18 (2012) 1–11, <https://doi.org/10.1111/j.1365-2095.2011.00866.x>.
- [81] A. Newaj-Fyzul, A.A. Adesiyun, A. Mutani, A. Ramsuhag, J. Brunt, B. Austin, *Bacillus subtilis* AB1 controls *Aeromonas* infection in rainbow trout (*Oncorhynchus mykiss*, Walbaum), *J. Appl. Microbiol.* 103 (2007) 1699–1706, <https://doi.org/10.1111/j.1365-2672.2007.03402.x>.
- [82] S.M. Aly, Y. Abdel-Galil Ahmed, A. Abdel-Aziz Ghareeb, M.F. Mohamed, Studies on *Bacillus subtilis* and *Lactobacillus acidophilus*, as potential probiotics, on the immune response and resistance of Tilapia nilotica (*Oreochromis niloticus*) to challenge infections, *Fish Shellfish Immunol.* 25 (2008) 128–136, <https://doi.org/10.1016/j.fsi.2008.03.013>.
- [83] D.-Y. Tseng, P.-L. Ho, S.-Y. Huang, S.-C. Cheng, Y.-L. Shiu, C.-S. Chiu, C.-H. Liu, Enhancement of immunity and disease resistance in the white shrimp, *Litopenaeus vannamei*, by the probiotic, *Bacillus subtilis* E20, *Fish Shellfish Immunol.* 26 (2009) 339–344 <https://doi.org/10.1016/j.fsi.2008.12.003>.
- [84] J. Dalsgaard, I. Lund, R. Thorarinsdottir, A. Drengstig, K. Arvonen, P.B. Pedersen, Farming different species in RAS in Nordic countries: current status and future perspectives, *Aquacult. Eng.* 53 (2013) 2–13 <https://doi.org/10.1016/j.aquaeng.2012.11.008>.
- [85] R.M. Reda, K.M. Selim, Evaluation of *Bacillus amyloliquefaciens* on the growth performance, intestinal morphology, hematology and body composition of Nile tilapia, *Oreochromis niloticus*, *Aquacult. Int.* 23 (2015) 203–217, <https://doi.org/10.1007/s10499-014-9809-z>.
- [86] D.L. Merrifield, A. Dimitroglou, A. Foey, S.J. Davies, R.T.M. Baker, J. Børgwald, M. Castex, E. Ringø, The current status and future focus of probiotic and prebiotic applications for salmonids, *Aquaculture* 302 (2010) 1–18 <https://doi.org/10.1016/j.aquaculture.2010.02.007>.
- [87] J.P. Apún-Molina, A. Santamaría-Miranda, A. Luna-González, S.F. Martínez-Díaz, M. Rojas-Contreras, Effect of potential probiotic bacteria on growth and survival of tilapia *Oreochromis niloticus* L., cultured in the laboratory under high density and suboptimum temperature, *Aquacult. Res.* 40 (2009) 887–894, <https://doi.org/10.1111/j.1365-2109.2009.02172.x>.
- [88] A. Irianto, B. Austin, Use of probiotics to control furunculosis in rainbow trout, *Oncorhynchus mykiss* (Walbaum), *J. Fish. Dis.* 25 (2002) 333–342, <https://doi.org/10.1046/j.1365-2761.2002.00375.x>.
- [89] M.S. Hassaan, M.A. Soltan, Evaluation of essential oil of fennel and garlic separately or combined with *Bacillus licheniformis* on the growth, feeding behaviour, hemato-biochemical indices of *Oreochromis niloticus* (L.) fry, *J. Aquacult. Res. Dev.* 07 (2016) 4–11, <https://doi.org/10.4172/2155-9546.1000422>.
- [90] V.I. Fuchs, J. Schmidt, M.J. Slater, J. Zentek, B.H. Buck, D. Steinhagen, The effect of supplementation with polysaccharides, nucleotides, acidifiers and *Bacillus* strains in fish meal and soy bean based diets on growth performance in juvenile turbot (*Scophthalmus maximus*), *Aquaculture* 437 (2015) 243–251 <https://doi.org/10.1016/j.aquaculture.2014.12.007>.
- [91] M. Gullian, F. Thompson, J. Rodriguez, Selection of probiotic bacteria and study of their immunostimulatory effect in *Penaes vannamei*, *Aquaculture* 233 (2004) 1–14 <https://doi.org/10.1016/j.aquaculture.2003.09.013>.
- [92] S.M. Aly, M.F. Mohamed, G. John, Effect of probiotics on the survival, growth and challenge infection in Tilapia nilotica (*Oreochromis niloticus*), *Aquacult. Res.* 39 (2008) 647–656, <https://doi.org/10.1111/j.1365-2109.2008.01932.x>.
- [93] X. Zhou, Z. Tian, Y. Wang, W. Li, Effect of treatment with probiotics as water additives on tilapia (*Oreochromis niloticus*) growth performance and immune response, *Fish Physiol. Biochem.* 36 (2010) 501–509, <https://doi.org/10.1007/>

- s10695-009-9320-z.
- [94] M. ElSabbagh, R. Mohamed, E.M. Moustafa, A. Hamza, F. Farrag, O. Decamp, M.A.O. Dawood, M. Eltholth, Assessing the impact of *Bacillus* strains mixture probiotic on water quality, growth performance, blood profile and intestinal morphology of Nile tilapia, *Oreochromis niloticus*, Aquac. Nutr. (2018) 1–10, <https://doi.org/10.1111/anu.12797>.
- [95] N. Sadat Hoseini Madani, T.J. Adorian, H. Ghafari Farsani, S.H. Hoseinifar, The effects of dietary probiotic Bacilli (*Bacillus subtilis* and *Bacillus licheniformis*) on growth performance, feed efficiency, body composition and immune parameters of whiteleg shrimp (*Litopenaeus vannamei*) postlarvae, Aquacult. Res. 49 (2018) 1926–1933, <https://doi.org/10.1111/are.13648>.
- [96] H. Fei, G. Lin, C. Zheng, M. Huang, S.-C. Qian, Z. Wu, C. Sun, Z. Shi, J. Li, B. Han, Effects of *Bacillus amyloliquefaciens* and *Yarrowia lipolytica* lipase 2 on immunology and growth performance of Hybrid sturgeon, Fish Shellfish Immunol. 82 (2018) 250–257 <https://doi.org/10.1016/j.fsi.2018.08.031>.
- [97] M.T. Hasan, W.J. Jang, H. Kim, B.-J. Lee, K.W. Kim, S.W. Hur, S.G. Lim, S.C. Bai, L.-S. Kong, Synergistic effects of dietary *Bacillus* sp. SJ-10 plus  $\beta$ -glucosaminoglycans as a synbiotic on growth performance, innate immunity and streptococcal resistance in olive flounder (*Paralichthys olivaceus*), Fish Shellfish Immunol. 82 (2018) 544–553 <https://doi.org/10.1016/j.fsi.2018.09.002>.
- [98] S. Lee, K. Katya, A. Hamidoghli, J. Hong, D.-J. Kim, S.C. Bai, Synergistic effects of dietary supplementation of *Bacillus subtilis* WB60 and mannanoligosaccharide (MOS) on growth performance, immunity and disease resistance in Japanese eel, *Anguilla japonica*, Fish Shellfish Immunol. 83 (2018) 283–291 <https://doi.org/10.1016/j.fsi.2018.09.031>.
- [99] D. De, R. Ananda Raja, T.K. Ghoshal, S. Mukherjee, K.K. Vijayan, Evaluation of growth, feed utilization efficiency and immune parameters in tiger shrimp (*Penaeus monodon*) fed diets supplemented with or diet fermented with gut bacterium *Bacillus* sp. DDKRCL1. isolated from gut of Asian seabass (*Lates calcarifer*), Aquacult. Res. 49 (2018) 2147–2155, <https://doi.org/10.1111/are.13669>.
- [100] A.M. Goda, E.A. Omar, T.M. Srour, A.M. Kotiet, E. El-Haroun, S.J. Davies, Effect of diets supplemented with feed additives on growth, feed utilization, survival, body composition and intestinal bacterial load of early weaning European seabass, *Dicentrarchus labrax* post-larvae, Aquacult. Int. 26 (2018) 169–183, <https://doi.org/10.1007/s10499-017-0200-8>.
- [101] C. Suzer, D. Çoban, H.O. Kamaci, Ş. Saka, K. Firat, Ö. Otcuoglu, H. Küçüksarı, *Lactobacillus* spp. bacteria as probiotics in gilthead sea bream (*Sparus aurata*, L.) larvae: effects on growth performance and digestive enzyme activities, Aquaculture 280 (2008) 140–145 <https://doi.org/10.1016/j.aquaculture.2008.04.020>.
- [102] M.M. Solovyev, E.N. Kashinskaya, G.I. Izvekova, E. Gisbert, V.V. Glupov, Feeding habits and ontogenic changes in digestive enzyme patterns in five freshwater teleosts, J. Fish. Biol. 85 (2014) 1395–1412, <https://doi.org/10.1111/jfb.12489>.
- [103] C.H. Liu, C.S. Chiu, P.L. Ho, S.W. Wang, Improvement in the growth performance of white shrimp, *Litopenaeus vannamei*, by a protease-producing probiotic, *Bacillus subtilis* E20, from natto, J. Appl. Microbiol. 107 (2009) 1031–1041, <https://doi.org/10.1111/j.1365-2672.2009.04284.x>.
- [104] B. Han, W. Long, J. He, Y. Liu, Y. Si, L. Tian, Effects of dietary *Bacillus licheniformis* on growth performance, immunological parameters, intestinal morphology and resistance of juvenile Nile tilapia (*Oreochromis niloticus*) to challenge infections, Fish Shellfish Immunol. 46 (2015) 225–231 <https://doi.org/10.1016/j.fsi.2015.06.018>.
- [105] Y. Fan, L. Liu, L. Zhao, X. Wang, D. Wang, C. Huang, J. Zhang, C. Ji, Q. Ma, Influence of *Bacillus subtilis* ANSB060 on growth, digestive enzyme and aflatoxin residue in Yellow River carp fed diets contaminated with aflatoxin B1, Food Chem. Toxicol. 113 (2018) 108–114 <https://doi.org/10.1016/j.fct.2018.01.033>.
- [106] M.A.O. Dawood, S. Koshio, M. Ishikawa, M. El-Sabbagh, M.A. Esteban, A.I. Zaineldin, Probiotics as an environment-friendly approach to enhance red sea bream, *Pagrus major* growth, immune response and oxidative status, Fish Shellfish Immunol. 57 (2016) 170–178 <https://doi.org/10.1016/j.fsi.2016.08.038>.
- [107] Z.X. Wu, X. Feng, L.L. Xie, X.Y. Peng, J. Yuan, X.X. Chen, Effect of probiotic *Bacillus subtilis* Ch9 for grass carp, *Ctenopharyngodon idella* (Valenciennes, 1844), on growth performance, digestive enzyme activities and intestinal microflora, J. Appl. Ichthyol. 28 (2012) 721–727, <https://doi.org/10.1111/j.1439-0426.2012.01968.x>.
- [108] A. Gupta, G. Verma, P. Gupta, Growth performance, feed utilization, digestive enzyme activity, innate immunity and protection against *Vibrio harveyi* of freshwater prawn, *Macrobrachium rosenbergii* fed diets supplemented with *Bacillus coagulans*, Aquacult. Int. 24 (2016) 1379–1392, <https://doi.org/10.1007/s10499-016-9996-x>.
- [109] M.R. Hauville, J.L. Zambonino-Infante, J. Gordon Bell, H. Migaud, K.L. Main, Effects of a mix of *Bacillus* sp. as a potential probiotic for Florida pompano, common snook and red drum larvae performances and digestive enzyme activities, Aquacult. Nutr. 22 (2016) 51–60, <https://doi.org/10.1111/anu.12226>.
- [110] A. Hamza, K. Fdhila, D. Zouiten, A.S. Masmoudi, *Virgibacillus proomii* and *Bacillus mojavensis* as probiotics in sea bass (*Dicentrarchus labrax*) larvae: effects on growth performance and digestive enzyme activities, Fish Physiol. Biochem. 42 (2016) 495–507, <https://doi.org/10.1007/s10695-015-0154-6>.
- [111] H. Zokaeifar, J.L. Balcázar, C.R. Saad, M.S. Kamarudin, K. Sijam, A. Arshad, N. Nejat, Effects of *Bacillus subtilis* on the growth performance, digestive enzymes, immune gene expression and disease resistance of white shrimp, *Litopenaeus vannamei*, Fish Shellfish Immunol. 33 (2012) 683–690, <https://doi.org/10.1016/j.fsi.2012.05.027>.
- [112] Y.-Z. Sun, H.-L. Yang, K.-P. Huang, J.-D. Ye, C.-X. Zhang, Application of autochthonous *Bacillus* bioencapsulated in copepod to grouper *Epinephelus coioides* larvae, Aquaculture (2013) 392–395 44–50 <https://doi.org/10.1016/j.aquaculture.2013.01.037>.
- [113] C.-N. Zhang, X.-F. Li, W.-N. Xu, D.-D. Zhang, K.-L. Lu, L.-N. Wang, H.-Y. Tian, W.-B. Liu, Combined effects of dietary fructooligosaccharide and *Bacillus licheniformis* on growth performance, body composition, intestinal enzymes activities and gut histology of triangular bream (*Megalobrama terminalis*), Aquacult. Nutr. 21 (2015) 755–766, <https://doi.org/10.1111/anu.12200>.
- [114] L. Verschuere, G. Rombaut, P. Sorgeloos, W. Verstraete, Probiotic bacteria as biological control agents in aquaculture, Microbiol. Mol. Biol. Rev. 64 (2000) 655–671, <https://doi.org/10.1128/MMBR.64.4.655-671.2000.Updated>.
- [115] C.P. Alexander, C.J.W. Kirubakaran, R.D. Michael, Water soluble fraction of *Tinospora cordifolia* leaves enhanced the non-specific immune mechanisms and disease resistance in *Oreochromis mossambicus*, Fish Shellfish Immunol. 29 (2010) 765–772, <https://doi.org/10.1016/j.fsi.2010.07.003>.
- [116] P.R. Rauta, B. Nayak, S. Das, Immune system and immune responses in fish and their role in comparative immunity study: a model for higher organisms, Immunol. Lett. 148 (2012) 23–33, <https://doi.org/10.1016/j.imlet.2012.08.003>.
- [117] T.N. McNeilly, S.W. Naylor, A. Mahajan, M.C. Mitchell, S. McAteer, D. Deane, D.G.E. Smith, J.C. Low, D.L. Gally, J.F. Huntley, Escherichia coli O157:H7 colonization in cattle following systemic and mucosal immunization with purified H7 flagellin, Infect. Immun. 76 (2008) 2594–2602, <https://doi.org/10.1128/IAI.01452-07>.
- [118] A.K. Nigam, U. Kumari, S. Mittal, A.K. Mittal, Comparative analysis of innate immune parameters of the skin mucous secretions from certain freshwater teleosts, inhabiting different ecological niches, Fish Physiol. Biochem. 38 (2012) 1245–1256, <https://doi.org/10.1007/s10695-012-9613-5>.
- [119] T.S. Jung, C.S. del Castillo, P.K. Javaregowda, R.S. Dalvi, S.W. Nho, S. Bin Park, H. Bin Jang, I.S. Cha, H.W. Sung, J. ichi Hikima, T. Aoki, Seasonal variation and comparative analysis of non-specific humoral immune substances in the skin mucus of olive flounder (*Paralichthys olivaceus*), Dev. Comp. Immunol. 38 (2012) 295–301, <https://doi.org/10.1016/j.dci.2012.06.005>.
- [120] N. Sheikhzadeh, A. Karimi Pashaki, K. Noufouzi, M. Heidarieh, H. Tayefi-Nasrabadi, Effects of dietary Ergosan on cutaneous mucosal immune response in rainbow trout (*Oncorhynchus mykiss*), Fish Shellfish Immunol. 32 (2012) 407–410, <https://doi.org/10.1016/j.fsi.2011.11.028>.
- [121] L.H.H. Hernandez, T.C. Barrera, J.C. Mejia, G.C. Mejia, M. Del Carmen, M. Dosta, R. de Lara Andrade, J.A.M. Sotres, Effects of the commercial probiotic *Lactobacillus casei* on the growth, protein content of skin mucus and stress resistance of juveniles of the Porthole livebearer *Poeciliopsis gracilis* (Poeciliidae), Aquacult. Nutr. 16 (2010) 407–411, <https://doi.org/10.1111/j.1365-2095.2009.00679.x>.
- [122] T. Sangma, D. Kamilya, Dietary *Bacillus subtilis* FPTB13 and chitin, single or combined, modulate systemic and cutaneous mucosal immunity and resistance of catla, *Catla catla* (Hamilton) against edwardsiellosis, Comp. Immunol. Microbiol. Infect. Dis. 43 (2015) 8–15, <https://doi.org/10.1016/j.cimid.2015.09.003>.
- [123] V. Rajanbabu, J.Y. Chen, Antiviral function of tilapia hepcidin 1-5 and its modulation of immune-related gene expressions against infectious pancreatic necrosis virus (IPNV) in Chinook salmon embryo (CHSE)-214 cells, Fish Shellfish Immunol. 30 (2011) 39–44, <https://doi.org/10.1016/j.fsi.2010.09.005>.
- [124] K.C. Peng, S.H. Lee, A.L. Hour, C.Y. Pan, L.H. Lee, J.Y. Chen, Five different piscidins from Nile Tilapia, *Oreochromis niloticus*: analysis of their expressions and biological functions, PLoS One 7 (2012), <https://doi.org/10.1371/journal.pone.0050263>.
- [125] R. Cerezuela, J. Meseguer, M.Á. Esteban, Effects of dietary inulin, *Bacillus subtilis* and microalga on intestinal gene expression in gilthead seabream (*Sparus aurata* L.), Fish Shellfish Immunol. 34 (2013) 843–848 <https://doi.org/10.1016/j.fsi.2012.12.026>.
- [126] M.A. Avella, G. Gioacchini, O. Decamp, P. Makridis, C. Bracciatelli, O. Carnevali, Application of multi-species of *Bacillus* in sea bream larviculture, Aquaculture 305 (2010) 12–19 <https://doi.org/10.1016/j.aquaculture.2010.03.029>.
- [127] J. Wang, H.-L. Yang, H.-Q. Xia, J.-d. Ye, K.-L. Lu, X. Hu, Y. Feng, L. Ruan, Y.-Z. Sun, Supplementation of heat-inactivated *Bacillus clausii* DE5 in diets for grouper, *Epinephelus coioides*, improves feed utilization, intestinal and systemic immune responses and not growth performance, Aquacult. Nutr. 24 (2018) 821–831, <https://doi.org/10.1111/anu.12611>.
- [128] O.A. Galagarza, S.A. Smith, D.J. Drahos, J.D. Eifert, R.C. Williams, D.D. Kuhn, Modulation of innate immunity in Nile tilapia (*Oreochromis niloticus*) by dietary supplementation of *Bacillus subtilis* endospores, Fish Shellfish Immunol. 83 (2018) 171–179 <https://doi.org/10.1016/j.fsi.2018.08.062>.
- [129] M.U.D. Hura, T. Zafar, K. Borana, J.R. Prasad, J. Iqbal, Effect of commercial probiotic *Bacillus megaterium* on water quality in composite culture of major carps, Int. J. Curr. Agric. Sci. 8 (2018) 268–273.
- [130] H. Zokaeifar, N. Babaei, C.R. Saad, M.S. Kamarudin, K. Sijam, J.L. Balcázar, Administration of *Bacillus subtilis* strains in the rearing water enhances the water quality, growth performance, immune response, and resistance against *Vibrio harveyi* infection in juvenile white shrimp, *Litopenaeus vannamei*, Fish Shellfish Immunol. 36 (2014) 68–74 <https://doi.org/10.1016/j.fsi.2013.10.007>.
- [131] M. NavinChandran, P. Iyapparaj, S. Moovendhan, R. Ramasubburayan, S. Prakash, G. Immanuel, A. Palavesam, Influence of probiotic bacterium *Bacillus cereus* isolated from the gut of wild shrimp *Penaeus monodon* in turn as a potent growth promoter and immune enhancer in *P. monodon*, Fish Shellfish Immunol. 36 (2014) 38–45 <https://doi.org/10.1016/j.fsi.2013.10.004>.
- [132] S. Nimrat, S. Saksawat, T. Boonthai, V. Vuthiphanchai, Potential *Bacillus* probiotics enhance bacterial numbers, water quality and growth during early development of white shrimp (*Litopenaeus vannamei*), Vet. Microbiol. 159 (2012) 443–450 <https://doi.org/10.1016/j.vetmic.2012.04.029>.
- [133] J. Ochoa-Solano, J. Olmos-Soto, The functional property of *Bacillus* for shrimp feeds, Food Microbiol. 23 (2006) 519–525, <https://doi.org/10.1016/j.fm.2005.10>.

- 004.
- [134] D. Xu, Y. Wang, L. Sun, H. Liu, J. Li, Inhibitory activity of a novel antibacterial peptide AMPNT-6 from *Bacillus subtilis* against *Vibrio parahaemolyticus* in shrimp, *Food Control* 30 (2013) 58–61 <https://doi.org/10.1016/j.foodcont.2012.07.025>.
- [135] A. Eissa, M. Zaki, A. Baiomy, *Flavobacterium columnare/Myxobolus tilapiae* concurrent infection in the earthen pond reared Nile Tilapia (*Oreochromis niloticus*) during the early summer, *Interdiscipl. Bio Cent.* 2 (2010) 1–10 <https://doi.org/10.4051/Early>.
- [136] T.N. Tuan, P.M. Duc, K. Hatai, Overview of the use of probiotics in aquaculture, *Int. J. Res. Fish. Aquac.* 3 (2013) 89–97 doi:ISSN 2277-7729.
- [137] I.C. Zink, D.D. Benetti, P.A. Douillet, D. Margulies, V.P. Scholey, Improvement of water chemistry with *Bacillus* probiotics inclusion during simulated transport of Yellowfin Tuna Yolk sac larvae, *N. Am. J. Aquacult.* 73 (2011) 42–48, <https://doi.org/10.1080/15222055.2011.544622>.
- [138] K.M. Mujeeb Rahiman, Y. Jesmi, A.P. Thomas, A.A. Mohamed Hatha, Probiotic effect of *Bacillus* NL110 and *Vibrio* NE17 on the survival, growth performance and immune response of *Macrobrachium rosenbergii* (de Man), *Aquacult. Res.* 41 (2010) 120–134, <https://doi.org/10.1111/j.1365-2109.2009.02473.x>.
- [139] Z.-F. Song, J. An, G.-H. Fu, X.-L. Yang, Isolation and characterization of an aerobic denitrifying *Bacillus* sp. YX-6 from shrimp culture ponds, *Aquaculture* 319 (2011) 188–193 <https://doi.org/10.1016/j.aquaculture.2011.06.018>.
- [140] R. Lakshmanan, P. Soundarapandian, Effect of commercial probiotics on large scale culture of black tiger shrimp *Penaeus monodon* (Fabricius), *Res. J. Microbiol.* 3 (2008) 198–203, <https://doi.org/10.3923/jm.2008.198.203>.
- [141] S. Nimrat, T. Boonthai, V. Vuthiphandchai, Effects of probiotic forms, compositions of and mode of probiotic administration on rearing of Pacific white shrimp (*Litopenaeus vannamei*) larvae and postlarvae, *Anim. Feed Sci. Technol.* 169 (2011) 244–258 <https://doi.org/10.1016/j.anifeedsci.2011.07.003>.
- [142] Y.-B. Wang, Z.-R. Xu, M.-S. Xia, The effectiveness of commercial probiotics in northern white shrimp *Penaeus vannamei* ponds, *Fish. Sci.* 71 (2005) 1036–1041, <https://doi.org/10.1111/j.1444-2906.2005.01061.x>.
- [143] F. Xie, T. Zhu, F. Zhang, K. Zhou, Y. Zhao, Z. Li, Using *Bacillus amyloliquefaciens* for remediation of aquaculture water, *SpringerPlus* 2 (2013) 119, <https://doi.org/10.1186/2193-1801-2-119>.
- [144] J.A. Camargo, Á. Alonso, Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment, *Environ. Int.* 32 (2006) 831–849 <https://doi.org/10.1016/j.envint.2006.05.002>.
- [145] I.E. Luis-Villaseñor, M.E. Macías-Rodríguez, B. Gómez-Gil, F. Ascencio-Valle, Á.I. Campa-Córdova, Beneficial effects of four *Bacillus* strains on the larval cultivation of *Litopenaeus vannamei*, *Aquaculture* 321 (2011) 136–144 <https://doi.org/10.1016/j.aquaculture.2011.08.036>.
- [146] P. Tattiyapong, W. Dachavichitlead, W. Surachetpong, Experimental infection of Tilapia lake virus (TiLV) in Nile tilapia (*Oreochromis niloticus*) and red tilapia (*Oreochromis spp.*), *Vet. Microbiol.* 207 (2017) 170–177, <https://doi.org/10.1016/j.vetmic.2017.06.014>.
- [147] S. Senapin, K.U. Shyam, W. Meemetta, T. Rattanarajpong, H.T. Dong, Inapparent infection cases of tilapia lake virus (TiLV) in farmed tilapia, *Aquaculture* 487 (2018) 51–55, <https://doi.org/10.1016/j.aquaculture.2018.01.007>.