

## Probiotics in fish nutrition: benefits and applicability

### Probioticele în nutriția peștilor: beneficii și aplicabilitate

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**Cuvinte cheie:** probiotice, nutriție, acvacultura, antibioretizenta, industria alimentara, imunomodularea.

#### Abstract

Probiotics play an essential role in fish nutrition, significantly contributing to their health and growth in aquaculture. By incorporating beneficial bacterial strains such as *Lactobacillus* and *Bacillus subtilis* into feed, the nutritional value of the feed is enhanced, enzymatic digestion is optimized, and pathogenic microorganisms are inhibited. Probiotics stimulate the immune response, increase intestinal microbial diversity, and have anti-mutagenic and anti-carcinogenic effects. Modern administration methods include bioencapsulation and the use of live foods, thus ensuring the probiotics' survival and effective colonization in the fish's digestive tract. Therefore, using probiotics in fish nutrition not only improves growth performance and health but also promotes sustainable and ecologically efficient aquaculture.

#### Rezumat

Probioticele joacă un rol esențial în nutriția peștilor, contribuind semnificativ la sănătatea și creșterea acestora în acvacultură. Prin includerea tulpinilor bacteriene benefice în furaje, cum ar fi *Lactobacillus* și *Bacillus subtilis*, se îmbunătățesc valorile nutritive ale furajelor, se optimizează digestia enzimatică și se inhibă microorganismele patogene. Probioticele stimulează răspunsul imunitar, cresc diversitatea microbiană intestinală și au efecte anti-mutagenice și anti-carcinogene. Metodele moderne de administrare includ bioîncapsularea și utilizarea alimentelor vii, asigurând astfel supraviețuirea și colonizarea eficientă a probioticelor în tractul digestiv al peștilor. Astfel, utilizarea probioticelor în alimentația peștilor nu doar îmbunătățește performanța de creștere și sănătatea acestora, ci și promovează o acvacultură sustenabilă și eficientă din punct de vedere ecologic.

### 1. Modern methods of administration of probiotics in fish feed

The concept behind the composition of probiotics in feed is to apply the beneficial bacterial strains in the feed using binding agents such as eggs and cod liver oil, to achieve beneficial microbial effects with more efficiency and a reduced environmental cost.

Most commercial preparations contain either *Lactobacillus* or *Saccharomyces cerevisiae*, nitrifying bacteria, *Streptococci*, *Roseobacter* and *Bacillus sp.* Beneficial effects of regular use of probiotics in fish feed in the UK and other European countries have been reported [3].



Fig.1. *Artemia shrimp* - Source: <https://tropical-fish-keeping.com/wp-content/uploads/2018/10/Brine-Shrimp-Artemia.jpg> [60]

In aquaculture, probiotics can also be encapsulated in feed or live foods such as rotifers and *Artemia* crustaceans [36].

Another effective application of probiotics for aquatic animals is through bioencapsulation or infusions in diets. Probiotic organisms used in food must be able to survive passage through the digestive tract, they must withstand gastric juices and exposure to bile. In addition, probiotics must be able to proliferate and colonize the digestive tract to be safe, effective, and to maintain their efficacy and potency throughout the shelf life of the product [5].



**Fig. 2. *Euchlanis dilatata* – Rotifer – Source:** <https://www.canadiannaturephotographer.com/rotifers.html> [61]

The benefits of including bacterial strains in feed ingredients include improved feed values, contribution to enzymatic digestion, inhibition of pathogenic microorganisms, anti-mutagenic and anti-carcinogenic activity, growth promoting factors and improved immune response.

Regarding the effects of *Bacillus subtilis* probiotics on intestinal microbial diversity and immunity of the *Epinephelus coioides* group of fish, it was shown that the innate cellular response and respiratory activity of the supplemented groups were significantly higher compared to the control group at 10 and 20 days after feeding and even more significant at 30 days [7].



**Fig. 3. Estuary cod - *Epinephelus coioides* – Source:** <https://indiabiodiversity.org/species/show/232208> [62].

The probiotic *B. Subtilis* increases intestinal microbial diversity by stimulating the bacterial populations of *Paenibacillus sp.*, *Lactobacillus oeni* strain 59b and *Methylococcus inferorum* strain V4, which are beneficial to *E. coioides*.

The best dose of *B. subtilis* probiotic, based on growth performance, innate cellular responses and gut microbial profile of fish, is 0.1%, which showed equal efficacy to 1% diet.

Thus, the use of feed probiotics in aquaculture has opened up the possibility of sustainable commercial aquaculture [18].

## 2. Use of probiotics to increase feed efficiency in aquaculture

Certain probiotics and prebiotics can promote proper digestion, increase immune response, maintain water quality, and act as promoters of aquatic animal growth, survival, and health. In aquaculture, the intestines, gills, mucus on the skin of aquatic animals and their habitat, or even culture collections and commercial probiotic and prebiotic products can be Gram-positive and Gram-negative, as well as non-bacterial, such as bacteriophages, microalgae and yeast.

Finally, probiotic applications may include multiple strains or even a combination of prebiotics, symbiotics and live foams [47].

The use of probiotics can increase productivity in aquaculture, having beneficial ecological effects that can resist a wide range of pathogens and control infections.

Current research on probiotics for aquaculture, due to dietary supplementation with live microorganisms, shows improvements in intestinal digestibility and immune system in animals.

Probiotics can combat pathogenic bacteria such as *Lactobacillus sp.*, *Bifidobacterium*, *Lactococcus* and *Streptococcus sp.* [10].

Aquatic animal protein contributes 43% to the global supply of animal protein, and the importance of aquaculture in the evaluation and decisions related to fish, mollusk and crustacean production is well recognized.

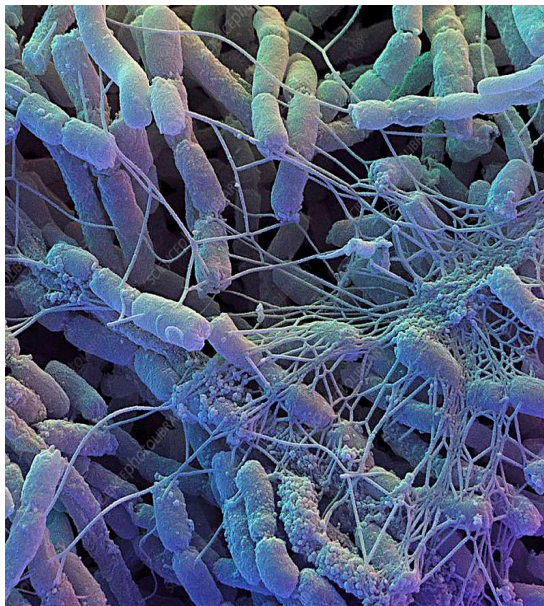


**Fig. 4. Catfish (*Silurus glanis*) – Source:** <https://naturescu.com/wp-content/uploads/2021/06/Tipuri-de-pestesomn> [63].

Probiotics, such as lactic acid bacteria and *Bacillus sp.*, are ecological supplements in animal feed, reducing pathogen levels without side effects and improving digestibility and growth of cultured organisms [11].

*Vibrio parahaemolyticus* affects the development of aquaculture, and food additives have shown that seafood is a source of probiotics that act against Gram-positive and Gram-negative bacteria.

Various microorganisms, such as *Streptomyces panacagri* and *Streptomyces flocculus*, improve digestibility and act as antagonistic probiotics against foodborne pathogens, providing an alternative to antibiotics [6].



**Fig. 5. *Streptomyces spp.* – Source:** David Scharf / Science photo library [64].

The intestine of healthy marine fish contains bacteria with antimicrobial effects and a broad spectrum of antimicrobial activity in strains of lactic acid bacteria, such as *Lactococcus lactis sp. lactis*, two *Enterococcus sp.*, *Lactobacillus plantarum* and *Leuconostoc mesenteroides sp. mesenteroides*, which are effective against aquaculture pathogens including *Vibrio harveyi*, *V. splendidus* and *Photobacterium damsela*.

*Actinomyces sp.* isolated from marine sediments has demonstrated probiotic-like properties in several *in vitro* tests [9].

Although probiotics also contain bacteriocin, a bioactive compound, it was collected from marine animals and contains antibiotic peptides that fight pathogens [23].

The marine environment provides a wide variety of *Streptomyces* that can be used as probiotics in aquaculture. The MSU3IR mechanism of *Lactococcus graviae* and *Lactobacillus sp.* increased bacteriocin levels, thereby inhibiting the pathogen *Listeria monocytogene* in shrimp.

*Bacillus subtilis* strain MMA7, isolated from the marine sponge *Haliclona simulans*, exhibits broad-spectrum antimicrobial activity against both Gram-positive and Gram-negative pathogens, as well as various pathogenic *Candida* species.

This antimicrobial effect is partly attributed to a newly discovered lantibiotic, which has been named subtilomycin. [19].



**Fig. 6. *Haliclona simulans* – Source:** [https://inpn.mnhn.fr/espece/cd\\_nom/71649?lg=en](https://inpn.mnhn.fr/espece/cd_nom/71649?lg=en) [65].

## 2.1. The most widely used probiotics in feed

Probiotic microorganisms have beneficial effects on the gastrointestinal tract of aquatic animals, aiding in the digestion of dietary nutrients and energy production. The most common probiotic preparations used for this purpose are lactic acid bacteria [22].

The improvement in nutrient digestibility is due to the increased level of digestive enzymes (protease, amylase, cellulase, phytase, etc.) produced by the probiotic-modified intestinal microbial community in the host.

For example, some bacteria (*Rhodobacter sphaeroides* and *Bacillus sp.*) contribute effectively to digestion processes by significantly activating protease, lipase, amylase and cellulase enzymes in white shrimp (*Litopenaeus vannamei*) and bivalves [8].



**Fig. 7. *Litopenaeus vannamei* – Source:** [https://euimg.eworldtrade.com/uploads/user\\_products/4/8/product-680338-g-0-t-1561046610-o.jpg](https://euimg.eworldtrade.com/uploads/user_products/4/8/product-680338-g-0-t-1561046610-o.jpg) [66]

In addition, recent studies have shown that probiotics can stimulate nutrient absorption by increasing the surface area of the host's gastrointestinal tract, based on quantitative changes in histological measurements of the area of intestinal folds, enterochromaffin cells, and microvilli [59].

To date, several bacteria (*Pseudomonas sp.*, *Brevibacterium sp.*, *Microbacterium sp.*, *Agrobacterium sp.* and *Staphylococcus sp.*) have been reported to aid nutritional and metabolic physiology in Arctic trout (*Salvelinus alpinus*) [44].

Different bacterial strains in the form of probiotics also contribute significantly by modulating the intestinal microbial population of host organisms, especially by synthesizing essential fatty acids, minerals, vitamins and amino acids [37].



**Fig. 8. Arctic trout (*Salvelinus alpinus*)**  
Source: <https://www.flickr.com/photos/72616463@N00/3798548888/> [67]

## 2.2. Bioencapsulation of probiotics in feed

Bioencapsulation involves encasing tissues or biologically active substances in a semipermeable membrane to protect enclosed biological structures from potentially hazardous processes in the immediate environment.

The field of application of bioencapsulation is wide. Bioencapsulation or bioenrichment is a process that can improve the nutritional status of living food organisms, either by feeding them or by incorporating them with various types of nutrients [35].

Probiotic encapsulation technology has the potential to protect microorganisms and deliver them to the gut. However, the inoculation of probiotics by bioencapsulation in live food such as microalgae, rotifers and *Artemia* is an interesting approach, although the administration process through enriched live food does not appear to be economically viable and is difficult to achieve in large-scale aquaculture practices. It is feasible to use microalgae cultures as vectors for the introduction of bacterial antagonists to combat bacterial pathogens in aquaculture [55].

However, the influence of the bacteria brought by the live food organisms was particularly dramatic during the first feeding. Following a study, the effects of different concentrations of probiotic *Bacillus spp.* at different intervals of bioencapsulation on the growth performance and survival rate of Persian sturgeon larvae were evaluated (*Acipenser persicus*).



**Fig. 9.** Persian sturgeon (*Acipenser persicus*)  
Source: <https://animalesenpeligrodeextincion.eu/wp-content/uploads/Acipenser-persicus1.jpg> [68]

This study demonstrated significant conversion efficiency ratio, specific growth rate, feed conversion ratio, condition factor and daily growth coefficient ( $p < 0.05$ ). However, the survival of all groups was not significantly different after 28 days [46].

An alternative would be the technique of controlled transfer of immunostimulants by incorporating *Artemia* and rotifers into live food.

After 12-24 hours of enrichment of newly hatched *A. franciscana* with a lipid source, a significant increase in the content of unsaturated fatty acids (HUFA) is detected. Thus, it was reported that *Bacillus subtilis* and *Lactobacillus plantarum* bioencapsulated in *Artemia* achieved good results against vibriosis [33].

*Lactobacillus rhamnosus* GG of human origin was used on tilapia (*Oreochromis niloticus*) to study growth performance, intestinal mucosal immunity, and humoral and cellular immune response, and a feeding experiment was performed by directly incorporating the bacteria into dry commercial pellets, having favorable results on their development and reproduction [12].



**Fig. 10.** Tilapia (*Oreochromis niloticus*).  
Source: [https://fish-commercial-names.ec.europa.eu/fish-names/species/oreochromis-niloticus\\_ro](https://fish-commercial-names.ec.europa.eu/fish-names/species/oreochromis-niloticus_ro) [69]

### 3. Improving growth performance and health of fish by administration of probiotics

The intestinal environment provides a favorable habitat for indigenous microorganisms, providing them with space, attachment sites, and nutrition. Balanced microbial communities are very important for maintaining gut health.

During disease, the natural microbial communities in the gut are disrupted, leading to various health problems.

Fish live in an environment surrounded by a vast population of pathogenic bacteria, fungi and deadly viruses. Restoring gut microbial communities by supplementing the diet with probiotics is an effective method to improve fish health [43].

However, the selection of probiotics varies significantly from one fish species to another to maintain the correct ratio of good to bad bacteria in the intestinal mucosa.

To date, several bacterial candidates have been tested for probiotic potential; however, several candidates from the genera *Bacillus*, *Micrococcus*, *Enterococcus*, *Phaeobacter*, *Shewanella*, lactic bacteria, and *Pseudomonas* have gained popularity in manipulating gut flora in fish.

In one study, the beneficial effects of three probiotics (*Shewanella sp.* AFG21, *Bacillus sp.* AHG22 and *Alcaligenes sp.* AFG22) were reported in *Tor tambroides*, which are able to alter the microbial composition in favor of beneficial bacterial populations [27].



**Fig. 11.** A species of carp (*Tor tambroides*).  
Source: <https://laukkanca.blogspot.com/2012/12/red-mahseer-tor-tambroides.html> [70]

Several articles have reported that probiotics have positive effects on growth performance. For example, an indigenous LAB strain probiotic was mixed into the feed, while another indigenous *Bacillus* strain was added to the growth system, and both probiotics were combined for testing in tilapia culture.

This approach resulted in higher final fish weight, higher absolute growth rate and higher specific growth rate than in the control group. In addition, potential probiotics have been reported to produce high efficiency in low-protein diets, which may reduce production costs [15].

Moreover, different probiotic properties (high adherence and low adherence) showed different effects on feed conversion ratio and weight gain of hybrid tilapia. Adverse effects of probiotics include reports of reduced growth in the fry stage of tilapia. In other studies, it was reported that supplementation of feed for pangasius fish (*Pangasianodon hypophthalmus*) with *S. cerevisiae* probiotic in freeze-dried microencapsulated form had major favorable effects on feed conversion ratio and growth performance was significantly improved [2].



**Fig. 12.** Pangasius (*Pangasianodon hypophthalmus*).  
Source: <https://www.fishhobbyist.net/2022/01/getting-to-know-pangasianodon.html> [71]

The probiotic *Acinetobacter* KU011TH, used as a feed additive, produced improvements in growth performance and better survival rate in bighead catfish (*Clarias macrocephalus*) [14].

A previous study reported that the probiotic-supplemented diet in rainbow trout was highly effective in increasing the population of the beneficial bacteria *Bacillus subtilis* [25].



**Fig. 13.** Rainbow trout (*Oncorhynchus mykiss*).  
Source: <http://underwater-fish.blogspot.com/2011/11/rainbow-trout-oncorhynchus-mykiss.html> [72]

It was also reported that colonization of *B. subtilis* on the intestinal epithelial surface conferred protection (increased immunity, reduced oxidative stress, increased serum lysozyme concentration and enhanced phagocytic activity of specialized cells) against pathogenic strains of *Aeromonas sp* [42].

In the same direction, a study performed on four species of fish (*Poecilia sphenops*, *Xiphophorus maculatus*, *Poecilia reticulata* and *Xiphophorus helleri*) fed a diet containing *B. subtilis* reported an increase in the population of *B. subtilis* on the surface of the intestinal mucosa [38].

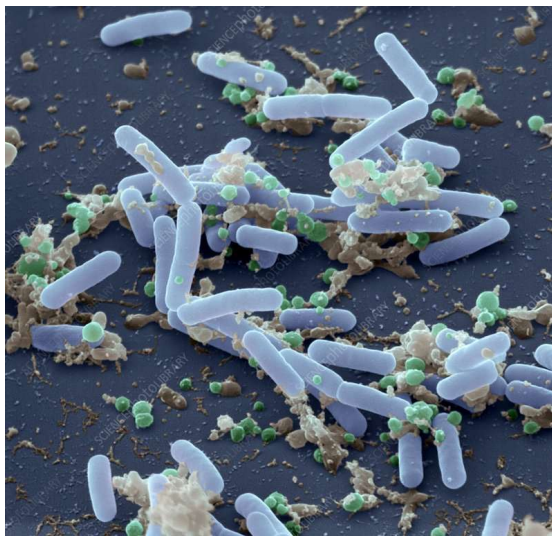


**Fig. 14.** Molly fish (*Poecilia sphenops*).  
Source: <https://aquaria.pro/product/poecilia-sphenops>. [73]

Recently, the effects of two probiotic strains *Bacillus subtilis* and *Rhodococcus sp.* were evaluated on the intestinal microbiota of the species *Oreochromis niloticus*. The results of the study indicated a significant change in the intestinal microbial community (increase in the percentage of *Proteobacteria* and *Bacteroidetes*) in fish fed probiotics compared to those in the control group. The study also

reported that bacteria belonging to the *Proteobacteria* family are important members as they are involved in the mineralization of organic compounds and nutrient recycling in fish [19].

The ability of two probiotics to restore gut microbiota was also tested in antibiotic-treated black molly fish (*Poecilia sphenops*). The results of the study indicated that both probiotic candidates (*Phaeobacter inhibens* S4Sm and *Bacillus pumilus* RI06-95Sm) were able to restore the microbial community to normal [14].



**Fig. 15.** *Bacillus pumilus* RI06-95Sm

Source: <https://www.sciencephoto.com/media/12402/view> [74]

Among the many probiotic strains, lactobacilli groups as probiotics in aquaculture have been extensively studied. It is well established that lactobacilli have a high colonization capacity and thus maintain for a longer period on the intestinal epithelial surface, conferring greater beneficial effects on the host and the intestinal microbiota [48]. Research in germ-free fish models has indicated that probiotics together with environmental factors have a large impact on the modulation of gut microbiota in terms of antibody production, stress release and resistant colonization.

The ability of probiotics to manipulate the gut microbiota depends on several external/environmental (water quality, temperature and pH) and internal (fish age, probiotic binding strength, duration of probiotic-

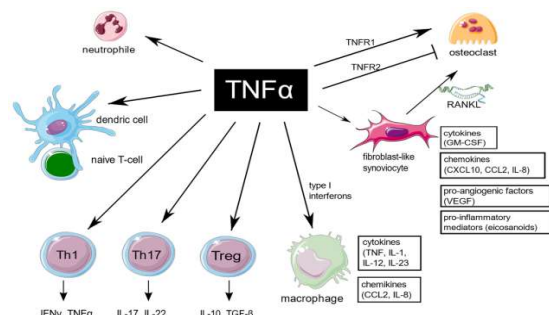
supplemented diet, administration system, etc.) factors. Changing any of these factors can affect the effectiveness of probiotics [13].

### 3.1. The role of probiotics in improving the immunity of aquaculture fish

Probiotics play a beneficial role as immunostimulators, helping to protect aquaculture species by reducing the impact of disease and preventing the entry of pathogens [20].

Thus, their use as immunostimulants is a very practical approach to improve success in aquaculture. Many authors have confirmed the use of probiotics to increase immune response, disease resistance and reduce malformations in carp species [17].

Their possible mechanism of action includes cellular and humoral immune responses, and the expression of IL-1b, TNF $\alpha$  and lysozyme-C increases when fish are fed a diet enriched with *Aeromonas veronii*, *Vibrio lentus* and *Flavobacterium sasangense* [30].



**Fig. 16.** TNF $\alpha$  (tumor necrosis factor) is a pleiotropic cytokine, which is involved in the function of various cells

Source: <https://encyclopedia.pub/entry/20537> [75]

An experimental report claimed that probiotics, supplemented at 10 CFU/g diet for 2 weeks, act as immunomodulators by binding MAMPs (microorganism-associated molecular patterns) to pathogen pattern recognition receptors (PRRs) on immunogenic cells such as dendritic cells and macrophages, triggering an intracellular signaling cascade that leads to the release of specific cytokines and interleukins by activated T cells to exert antiviral, pro- or anti-inflammatory effects.

Unfortunately, the specific role of probiotic supplementation on the expression of immunological parameters is not yet fully understood. [21].

### 3.2. Antiviral properties on aquaculture fish

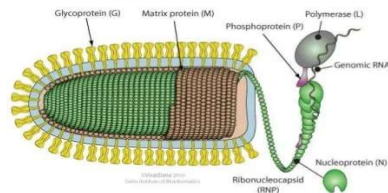
Although data indicate that virus inactivation can occur by means of extracts from various probiotic bacterial strains in aquaculture, the exact mechanism by which they exert their action is not known. It is well established that probiotics such as *Pseudomonas sp.* and *Vibrios sp.* are highly effective against infectious hematopoietic necrosis virus (IHNV) [31].

#### Aetiological agent

##### Agent strains

The fish rhabdovirus, IHNV, has a bullet-shaped virion containing

- ❖ a non-segmented,
- ❖ negative-sense,
- ❖ single-stranded RNA genome



**Fig. 17.** Infectious hematopoietic necrosis virus  
Source: <https://www.slideshare.net/slideshow/infectious-hematopoietic-necrosis-virus/69788210> [76]

Moreover, *Paralichthys olivaceus* fed on food supplemented with Sporolac (*Lactobacillus sp.*) develops resistance against lymphocystic disease virus (LCDV). Similar experiments also demonstrated the increased power of resistance to viruses in grouper fish fed with the probiotic strain *Bacillus subtilis* E20 [22].



**Fig. 18.** A species of halibut (*Paralichthys olivaceus*)  
Source: [http://www.fishbiosystem.ru/PLEURONECTIFORMES/Paralichthyidae/Paralichthys\\_olivaceus2.html](http://www.fishbiosystem.ru/PLEURONECTIFORMES/Paralichthyidae/Paralichthys_olivaceus2.html) [77]

## 4. Probiotics and gut microbial diversity in fish

The main function of the gastrointestinal (GI) tract consists in the processes of digestion and absorption of nutrients present in the intestinal lumen. In addition to these nutrients from food, exogenous microorganisms such as bacteria, fungi, parasites and viruses can also enter the intestine.

The abundance of innate immune cells and adaptive immune cells that coexist with the trillions of beneficial commensal microorganisms in the gastrointestinal tract dictates the need for an effective barrier.

This barrier has the role of regulating host-microbiome interactions and maintaining tissue homeostasis.

### 4.1. Intestinal flora stimulant

Several researchers have reported that probiotics significantly stimulate gut microbiota to produce more metabolites, including short-chain volatile fatty acids, which play a vital role in maintaining gut health in fish.

Research has also shown that gut microbiota modulation by probiotics is not limited by fish age and maturity, as probiotics confer beneficial effects on all age groups, from larvae to adults [40].

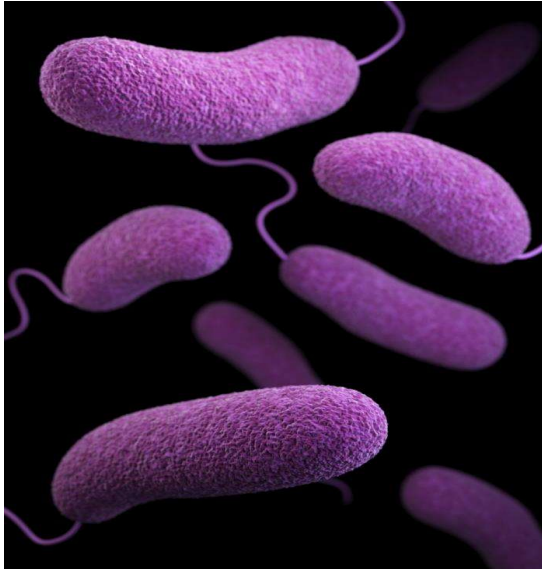
## 5. Efficacy of probiotic strains in combating pathogens in aquaculture

### 5.1. Gram-positive bacteria

#### 5.1.1. *Lactobacillus*

In an experiment, the diet of Indian white shrimp (*Penaeus indicus*) was supplemented with a single dose ( $5 \times 10^6$  CFU g<sup>-1</sup>) of various probiotics, including *Lb. acidophilus*, *S. cremoris*, *Lb. bulgaricus* 56, or *L. bulgaricus* 57, for 4 weeks.

At the end of the feeding period, the shrimp were experimentally exposed to *Vibrio alginolyticus* infection.



**Fig. 19.** *Vibrio alginolyticus*

Source: <https://kswfoodmicro.com/category/vibrio-albensis/> [78]

The results showed significantly higher resistance (56–72%) compared to the control group (20%). Also, supplementing the diet with  $10^{10}$  CFU  $\text{kg}^{-1}$  of *Lb. plantarum* increased proPO and PE gene expression, improved PO and SOD activities, as well as resistance against *V. alginolyticus* in white shrimp [1]. In addition, a *Lactobacillus* sp. has been reported to improve survival (72%) and performance of the pearl mussel, *P. mazatlanica* [50].



**Fig. 20.** Mazatlan pearl oyster (*Pinctada Mazatlanica*)

Source: <https://www.pearl-guide.com/threads/a-review-the-history-of-pearls-in-the-gulf-of-california-mexico-part-3.453033/> [79]



**Fig. 21.** Tiger prawns (*Penaeus monodon*)

Source: [https://animaldiversity.org/accounts/Penaeus\\_monodon/](https://animaldiversity.org/accounts/Penaeus_monodon/) [80].

Feeding *E. faecium* MC13 and *Lactococcus garvieae* B49 protected post-larval shrimp, *P. monodon*, against *V. harveyi* and *V. parahaemolyticus* challenges.

Similarly, feeding blue shrimp (*Litopenaeus stylirostris*) with the probiotic *P. acidilactici* increased protection against *V. nigripulchritudo* SFn1; mortality in the probiotic and control groups was 25% and 41.7%, respectively [29].



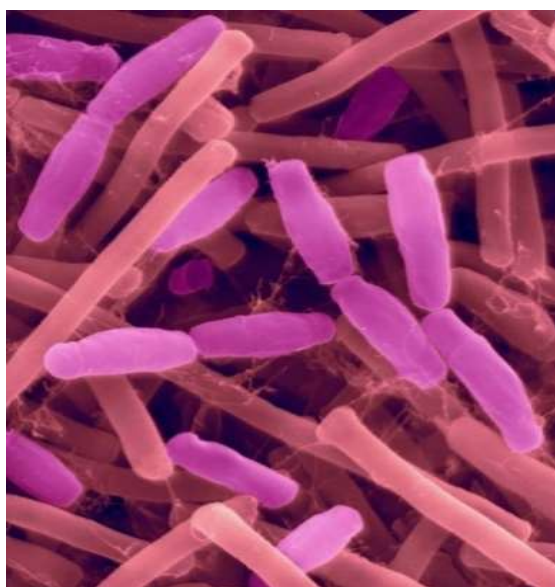
**Fig. 22.** Blue shrimp (*Litopenaeus stylirostris*)

Source: <https://theoceaninsider.com/seafood-guide/blue-shrimp-everything-you-need-to-know-about-genus-neocaridina/> [81]

### 5.1.2. *Bacillus*

To study the protective effects of *Bacillus subtilis* BT23, black tiger shrimp were treated with  $10^6$ - $10^8$  CFU ml<sup>-1</sup> probiotic for 6 days and then challenged with *V. harveyi* infection. The results showed a significantly lower mortality in the treated groups [41].

One study attempted the combined administration of two probiotic strains (*B. subtilis* L10 and G1) to juvenile white shrimp, which were fed two levels of  $10^5$  and  $10^8$  CFU g<sup>-1</sup> of selected probiotics for 8 weeks.



**Fig. 23.** *Bacillus subtilis* BT23

Source: Dennis Kunkel Microscopy/science Photo Library [82]

At the end of the feeding period, increased growth performance, digestive enzyme activity, up-regulated immunity-related genes, as well as resistance against *V. harveyi* were observed [53].

## 5.2. Gram-negative bacteria

### 5.2.1. *Vibrio*

In vitro research demonstrated inhibition of the growth of shrimp pathogens by the probiotic *V. gazogenes* NCIMB 2250.

Feeding white shrimp a diet supplemented with *V. gazogenes* NCIMB 2250 improved

performance and health status, as well as reduced the number of *Vibrio sp.* in the intestinal microbiota.

Also, *Vibrio* NE17 isolated from egg samples improved the performance and immune parameters of the freshwater shrimp, *Macrobrachium rosenbergii* [58].

Furthermore, in marine gastropod mollusks, the combined administration of three probiotics (*Vibrio sp.* C21-UMA, *Agarivorans albus* F1-UMA and *Vibrio sp.* F15-UMA) using the macroalga *M. integrifolia* as a vector significantly increased survival over a period of 210 days [51].



**Fig. 24.** *Macrobrachium integrifolia* algae

Source: <https://www.inaturalist.org/taxa/528651-Macrobrachium-integrifolia> [83].

### 5.2.2. *Streptomyces*

The use of marine *Streptomyces* strains (CLS-28, CLS-39) in *Artemia* culture significantly increased the resistance of *Artemia* adults against *V. harveyi* and *V. proteolyticus* species, and adding 1% *Streptomyces* to the diet of black tiger shrimp postlarvae for 15 days, resulted in improved resistance against *V. harveyi* and growth performance in probiotic-fed shrimp [52].

## 6. Probiotics as a strategy for sustainable aquaculture

The future growth of the aquaculture industry will face many challenges, including biological challenges and legislative pressures, and sustainability will be supported by the use of natural feed additives, ensuring long-term profitability.

In this context, algae culture is above all a production method that contributes to potential solutions and to the sustainability of aquaculture, having a beneficial role for a healthy ecosystem.

There are ways to improve aquaculture practices by reducing the risk of fish loss, shortening periods of accelerated growth, setting fish size targets, facilitating access to urban markets and promoting low-cost investments.

Asia Pacific is expected to hold the largest share of the global market, with countries such as China occupying a leading position.

In India and Japan, production of animal feed additives has seen steady growth. Integrated multitrophic aquaculture also presents ecological and socioeconomic advantages, recycling the co-production of different fish species for increased nutritional impact and economic value [16].

In 2020, the global pandemic caused by the coronavirus has spread worldwide, and most countries have imposed quarantines and social distancing as the new norms.

Malaysia has implemented a Recovery Control Ordinance for the seafood sector, an important source of protein, supported by the aquaculture sector involving small and large scale fisheries [24].

One study evaluated the cost-effectiveness of fish production by supplementing the diet with certain additives such as probiotics (bactocell), antibiotics (oxytetracycline) and vitamins (C and E); also, the addition of common culture fry in certain proportions was analyzed in terms of cost-effectiveness, with results showing higher fish growth and lower price compared to the use of Nile tilapia fish, common in Egypt [35].

Public policy decisions to restrict and eliminate the economic impacts of aquaculture

farm management, together with the use of natural feed additives, have contributed to good cost-effectiveness and control of farm pollution.



**Fig. 25.** Commercial probiotics Bactocell  
Source: <https://khasmart.pk/product/bactocell-sachets/> [84]

## 7. Conclusions

Current research is focused on optimizing the use of probiotics in the aquaculture industry, given the growing demand for these products.

The promising future application involves the identification and selection of the most suitable probiotic strains for the aquaculture system in order to improve its quality and functionality.

The research also aims to understand the effects and mechanisms of action of probiotics on reproductive performance and development in the industrial hatchery environment.

Although probiotic bacteria bring multiple benefits to the host, there are limitations because certain antimicrobial compounds produced by them are not specific for certain species of pathogenic bacteria.

Thus, strain improvement is necessary to enhance the effectiveness of probiotics. Modern molecular biology techniques, such as

recombinant technology, can be applied to genetically modify probiotic strains, but are limited for probiotic candidates used in aquaculture.

Future investigations are needed to address these issues and develop more effective probiotics for the aquaculture industry.

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