**Bacillus subtilis** A Potential Probiotic Bacterium to Formulate Functional Feeds for Aquaculture

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**Abstract**

In shrimp/fish aquaculture, feed represents the most expensive production cost. The quantity and quality of diets are primary factors influencing shrimp/fish growth, health status, disease prevention, pound contamination and expenses. Utilization of probiotic bacteria has emerged as a solution with enormous applications in the aquaculture feeding industry. *Bacillus* species principally *B. subtilis* are one of the most investigated bacteria for animal probiotic development due to: a) versatility of growth nutrients utilization, b) high level of enzymes production, c) secretion of antimicrobial compounds, d) spore producers, e) develops in aerobic and anaerobic conditions, and f) *B. subtilis* is Generally Recognized As Safe (GRAS) by the Food and Drug Administration (FDA). Functional feeds with alternative-economic nutrient vegetable sources of proteins, carbohydrates, lipids and *Bacillus subtilis* probiotic strains, must be considered in shrimp/fish aquaculture production systems; as an option to eliminate animal feed ingredients, improves digestion-assimilation, reduce water pollution and diseases, and to increase yields and profits.

**Keywords:** Bacillus subtilis; Probiotics; Functional Feed; Vegetable ingredients

**Bacillus subtilis** Properties

Bacteria of the *Bacillus* genus are among the most widespread microorganisms in nature, they can be found in soil, water and air. *Bacillus* constitutes a diverse group of rod-shaped, Gram-positive bacteria, characterized by their ability to produce a robust spore [1-5]. The *Bacillus subtilis* genome is totally sequenced, leading to generation of a great amount of basic knowledge in this bacterium [6]. Additionally, developments of molecular and genetic methodologies are well established in *B. subtilis* [7-9]. *B. subtilis* is not harmful to mammals, including humans, and is commercially important as a producer of a high and diverse amount of secondary metabolites like antibiotics, fine chemicals and enzymes, as well as heterologous proteins, antigens and vaccines [1,10-15]. *B. subtilis* grow efficiently with low-cost carbon and nitrogen sources, because its enzymes are very efficient breaking down a great variety of proteins, carbohydrates and lipids from animal and vegetable origin, into their constituent units [1,16-18]. The enzymes also degrade organic accumulated debris from shrimp/fish cultures inducing ponds bioremediation and consequently the prevention of viral and bacterial diseases [19-22]. On the other hand, the antimicrobial activity of *Bacillus* is greatly determined by their ability to produce antibiotics, principally from peptide origin [23]. There were identified 795 antibiotics from *Bacillus* species [11]. *B. subtilis* is the genus most productive species devoting 4-5% of its genome to their synthesis, producing 66 antibiotics [11]. Furthermore, *Bacillus subtilis* is Generally Recognized as Safe (GRAS) by the FDA, meaning this bacterium is not harmful to animals or humans (Figure 1). Taking into account beneficial properties of *B. subtilis*, this bacterium is a potential probiotic candidate to be considered in “Functional Feeds” of crustaceans and fishes [16-19,24].

**Bacillus subtilis** Probiotic Capacities

*B. subtilis* is between the oldies species on earth, reason why animals and humans since the beginning of their existence have been in contact with this bacterium [25,26]. In this sense, recognition of *B. subtilis* for animal and human immune system is well established and a symbiotic relationship had been developed for a long period of time [27]. On the other hand, million years of evolution has created an amazing quorum sensing communication-recognition mechanism between beneficial and pathogenic bacteria [1,28,29]. However, animals and humans only sense pathogens when the disease had been developed, due equilibrium between beneficial and pathogenic bacteria had been broken because; environmental, nutritional and/or metabolic changes has occurred favoring pathogens proliferation. Synthetic antibiotics was the first option to control pathogens overgrowth in humans and animals, however the unregulated use of these compounds induced a multi-resistant mechanisms preferentially developed by the pathogenic bacteria [30]. Today, antibiotics utilization is well regulated in humans and also in animals including aquaculture. In this sense, the utilization of beneficial bacteria (probiotics) has emerge as an alternative due good results are been obtained in both; animals and humans [27].

The term “probiotics” was derived from the Greek word, meaning “for life” [31]. According to the currently adopted definition by FAO/WHO, probiotics are: “Live microorganisms which when administered in adequate amounts confer a health benefit on the host [32]. Since 50 year ago exists a scientific and commercial interest in the use of beneficial bacteria for the prevention and treatment of diseases [27,33]. *Lactobacillus* and *Bifidobacterium* genera has been used almost exclusively for the competitive exclusion of pathogenic bacteria from the...
B. subtilis periods of storage without refrigeration [1]. In summary, in this sense, and most importantly, to take advantage of them [17-19,24,35-37].

and metabolic changing conditions where probiotic will be involve bacterium” it is recommended, to support environmental, nutritional spore producing multifunctional probiotic products and (d) support extreme changing environmental and quality of environmental parameters by the bioremediation of waste degradation-assimilation enhancing its nutritional values; (c) improves its immune system; (b) secrete a variety of enzymes to increases feed status by modifying the host-associated microbial community and (a) positively affects host health sense, and based in our own experiences, we redefined probiotics as several areas like; immune system stimulation, vaccine production, bioremediation and functional feed development [15-19,24,35]. In this sense, and in our own experiences, we redefined probiotics as a living microbial supplement that: (a) positively affects host health status by modifying the host-associated microbial community and its immune system; (b) secrete a variety of enzymes to increases feed degradation-assimilation enhancing its nutritional values; (c) improves quality of environmental parameters by the bioremediation of waste products and (d) support extreme changing environmental and physical parameters (Figure 2).

However, to accomplish all these objectives the utilization of “Bacillus subtilis spore producing multifunctional probiotic bacterium” it is recommended, to support environmental, nutritional and metabolic changing conditions where probiotic will be involve and most importantly, to take advantage of them [17-19,24,35-37]. In this sense, B. subtilis spores have the capacity to resist extreme pH conditions, UV irradiation, high temperatures, solvents and long time periods of storage without refrigeration [1] In summary, B. subtilis has a) versatility of growth nutrients utilization, b) high level of enzymes production, c) secretion of antimicrobial compounds, d) spore producer, e) develops in aerobic and anaerobic conditions, and f) B. subtilis is Generally Recognized As Safe (GRAS) by the Food and Drug Administration (FDA) (Figure 1). In this sense, B. subtilis in “theory” could be considered as a perfect multifunctional probiotic bacterium for humans and animals [1,16-19,23,24,27,33,38,39].

**Bacillus subtilis Recombinant Probiotic Development**

The global sales of probiotic supplements were predicted to rise 48% from $2.7bn in 2011 to $4bn in 2016. In US, per capita spending on probiotic supplements is expected to nearly double by 2016 and overtakes Japan [34]. In this sense, the utilization of non-recombinant probiotic strains in humans, farmed animals and aquaculture systems is well established, principally for the competitive exclusion of pathogenic bacteria (Table 1) [27,33,40-42].

On the other hand, utilization of recombinant probiotic strains in humans and animals it is not accepted due Genetically Modified Organism (GMO) regulations [27,43]. B. subtilis strains with overproduction of antimicrobial peptides or enzymes already exist scientifically and commercially, but only their products are being sold not the strains [12,23,44,45]. Overproduction of antimicrobial peptides and/or enzymes by recombinant probiotic strains could induce health problems in animals and consequently in the consumers, as the unregulated utilization of synthetic antibiotics did. Human and animal market “supposedly” consumes non recombinant Bacillus probiotic strains, due health FDA regulation and restrictions that must be solved, before acceptance of GMO products commercialization.

However, diseases like the one induced by White Spot Syndrome Virus (WSSV) in shrimps, cannot be controlled at the moment by any non-recombinant bacterial probiotic strain. In this sense, production of vaccines using B. subtilis probiotic recombinant strains, are starting to be developed to prevent disease impacts on animals and humans [15,46-48]. Environmental contamination and utilization of strong stressful agents are inducing development of new bacterial and virus diseases. In this sense, recombinant probiotic utilization could be the only effective way to fight versus pathogen agent’s proliferation. However, even when promising results have been obtained inducing immunization with recombinant B. subtilis probiotic strains, several FDA tests must be carried out in animal models before a massive food/feed inclusion and commercialization of recombinant probiotics can be done.

**Aquaculture Development Restrictions**

The United Nations Food and Agriculture Organization (FAO) define aquaculture as the farming of aquatic organisms including mollusks, crustaceans, fish and plants. Marine capture fisheries and aquaculture, supplied the world with about 154 million tons of marine products in 2011 [49]. However, global population demanding for marine food products is increasing around the world, but fisheries capture production has leveled off, due principal fishing areas have reached their maximum potential and some have started to go down [24,49,50]. In this sense, aquaculture the multibillion dollar fastest growing industry of the world food economy, is increasing by more than 10% per year and currently accounts for more than 50% of all shrimp/fish consumed [49]. For this reason, prices of fishmeal and oil utilized precisely to produce aquaculture feeds have increased considerably last years, making the industry unprofitable in many countries [24,50]. Worry about negative impacts of fishmeal and oil overproduction in ecology of global fisheries and environmental alterations have arisen [51,52]. Aquaculture represents the greatest potential to meet demands for aquatic food products; however, instead of helping to ease the crisis
in wild fisheries, unsustainable aquaculture development may aggravate the problems and create new ones, damaging our important and already-stressed coastal areas [53]. In order to solve these aquaculture restrictions, the development of Functional Feeds using alternative-economical vegetable protein, carbohydrates, lipids and “Bacillus subtilis” spore producing multifunctional probiotic bacterium” are recommended, to increase aquaculture profitability and environmental and ecological sustainability [16-19,24].

**Importance of Functional Feed Development in Aquaculture**

The rapid development of aquaculture from last years has increased feed ingredients demand and its prices, for this reason feeding represents 40-60% of the total production costs in shrimp/fish farming. In this sense, aquaculture industry development has become a great challenge for future generations; not only for feeding expenses but also from availability of fishmeal and oil ingredients. Reduced inclusion of fishmeal and oil in formulations is a tendency for almost a decade. It is estimated that these ingredients will be minimal or null in diets by the year 2020 [50]. Consequently, alternative feed formulation ingredients development is urgent and they must meet the animal nutritional requirements, be less expensive and sustainable with the environment [17,18,35,51,54-57]. Partial or complete fishmeal and oil substitution by alternative-economic vegetable protein, carbohydrates and lipids has been the goal for the field for more than 10 years, without satisfactory results due toxic effects and anti-nutritional nature of some vegetable molecules [58-63]. However, feeds evolution with inclusion of vegetable ingredients inducing; growth, health, environmental and economic benefits beyond traditional feeds, is a great opportunity to assure the future of a profitable and sustainable aquaculture [16-19,24]. Nevertheless, proteases, carbohydrases and lipases limited expression in wild fisheries, unsustainable aquaculture development may aggravate the problems and create new ones, damaging our important and already-stressed coastal areas [53].

**BACILLUS PROBIOTIC FOR HUMAN USE**

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<thead>
<tr>
<th>Product</th>
<th>Manufacturer</th>
<th>Comments</th>
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<tr>
<td>Bio-Kult®</td>
<td>Probiotics International Ltd (Protexin), UK. <a href="http://www.bio-kult.com">http://www.bio-kult.com</a></td>
<td>B. subtilis is one component of 14 strains carried in this probiotic supplement (minimum 2x10^9 CFU/capsule).</td>
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<tr>
<td>Biobaby®</td>
<td>Ildong Pharmaceutical Ho Chi Minh, Vietnam <a href="http://www.thuocbo.com.vn/Danhi-muc-thuoc-bo-men-vi-sinh/biobaby.html">http://www.thuocbo.com.vn/Danhi-muc-thuoc-bo-men-vi-sinh/biobaby.html</a></td>
<td>Granules for solution with B. subtilis 3 mg/g (3x10^8 CFU/g), in combination with Lactobacillus sporogenes and Clostridium butyricum (1x10^8 CFU/g).</td>
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**BACILLUS PROBIOTIC FOR AQUACULTURE**

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<th>Brand</th>
<th>Animal</th>
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<th>Comments</th>
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<tr>
<td>Naturalle Bacillus subtilis</td>
<td>Shrimp, fish</td>
<td>Wuhan Nature’s Favour Bioengineering Co., Ltd., Wuhan City, China <a href="http://www.wuhannature.com">http://www.wuhannature.com</a></td>
<td>Bacillus subtilis (2x10^10 CFU/g).</td>
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<tr>
<td>Fubon Bacillus subtilis</td>
<td>Shrimp, fish</td>
<td>Angel Yeast Co., Ltd. Hubei, China <a href="http://www.angelyeast.com">http://www.angelyeast.com</a></td>
<td>Bacillus subtilis (≥ 2 billion CFU/g).</td>
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**BACILLUS PROBIOTIC FOR VETERINARY USE**

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<tr>
<th>Brand</th>
<th>Animal</th>
<th>Manufacturer</th>
<th>Comments</th>
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<tr>
<td>BioGrow®</td>
<td>Poultry, calves and</td>
<td>Provita Eurotech Ltd., Omagh, Northern Ireland, UK <a href="http://www.provita.co.uk">http://www.provita.co.uk</a></td>
<td>Listed as containing spores of B. licheniformis (1.6x10^9 CFU/g) and B. subtilis (1.6x10^8 CFU/g).</td>
</tr>
<tr>
<td>BioPlus® 2B</td>
<td>Pigs, turkeys for fattening</td>
<td>Christian Hansen Hoechsholm, Denmark <a href="http://www.chr-hansen.com">http://www.chr-hansen.com</a></td>
<td>Mixture (1/1) of B. licheniformis (DSM 5749) and B. subtilis (DSM 5750) at 1x10^8 CFU/g of each bacterium, EU approved</td>
</tr>
<tr>
<td>Proflora</td>
<td>Poultry</td>
<td>Zoetis, New Jersey, USA <a href="http://www.zoetisus.com">http://www.zoetisus.com</a></td>
<td>Proflora is a unique combination product with a Live DFM B. subtilis strain QST 713 plus Beta Mos®, a yeast-extract prebiotic.</td>
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Table 1: Bacillus subtilis commercial products from humans and animals.

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**Figure 3: Functional Feed particle formulated with soybean meal, complex carbohydrates, vegetable oil and Bacillus subtilis multifunctional probiotic strain [20].**

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formulations [58-63]. Thus, the utilization of specifically selected “Bacillus subtilis spore producing multifunctional probiotic bacterium” has emerged as a solution with huge applications in the aquaculture feeding industry (Figures 1 and 2). In this sense, excellent results have been obtained in Litopenaeus vannamei, Oreochromis niloticus and Atractoscion nobilis; increasing digestion-assimilation of vegetable ingredients, improving Food Conversion Ratio (FCR) and inducing optimal growth on cultivated animals, when a B. subtilis probiotic strain have been added to feeds. Additionally, inhibition of pathogens proliferation and increased health status of animals was also improved. Finally, bioremediation of pond contaminated water was also achieved efficiently by B. subtilis probiotic bacteria used [16-19,24]. These results open great opportunities to new Functional Feeds production for shrimp and fish aquaculture (Figure 3).

Complex carbohydrates degradation, proteses inhibitors inactivation and lipids assimilation, were not a problem to animals when “Bacillus subtilis spore producing multifunctional probiotic bacterium” was added to vegetable based-feed formulations [16-19,24].

Conclusion

The world market for probiotics supplements has been growing for the last 50 years; today most dairy human products contain probiotic bacteria. Lactobacillus and Bifidobacterium are the most used genera the last 50 years; today most dairy human products contain probiotic strains have been added to feeds. Additionally, inhibition of pathogens proliferation and increased health status of animals was also improved. Finally, bioremediation of pond contaminated water was also achieved efficiently by B. subtilis probiotic bacteria used [16-19,24]. These results open great opportunities to new Functional Feeds production for shrimp and fish aquaculture (Figure 3).

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References


60. Daranee S, Davis DA (2011) Pond production of Pacific white shrimp (Litopenaeus vannamei) fed high levels of soybean meal in various combinations. Aquaculture 319: 141-149.