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MINI REVIEW

A review of lactic acid bacteria isolated from marine animals: their species, isolation site and applications

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Abstract

Marine animals are continuously exposed to a wide range of microorganisms present in their environment. Studies indicated that the microorganisms could be found in different parts of the animal's body. There are different types of lactic acid bacteria in various isolation sites and studies have disclosed the presence of *Lactobacillus*, *Lactococcus*, *Enterococcus*, *Streptococcus*, *Vagococcus*, *Pediococcus*, *Weissella*, *Leuconostoc*, and *Carnobacterium*. The lactic acid bacteria (LAB) of these animals have been the subject of various studies. They were studied for their inhibitory activity against pathogens, tested for their antibiotic resistance, and searched for the production of bacteriocin which some are eventually made into commercial products. This study reviewed isolated LAB from marine animals to discover the better potential of LAB that could be implemented in different industries such as food and beverages, pharmaceutical, aquaculture, nutraceutical, and medical. This review assembled the species of LAB that were isolated from different parts of the marine animals' bodies and their application.

1. Introduction

Lactic acid bacteria (LAB) are microorganisms known for their benefits to mankind. They are widely distributed in carbohydrate-rich environments and typically found in decayed plants and animal matter. LAB are described as a group of Gram-positive with the shape of rods or cocci, non-spore-forming, lack of catalase activity, anaerobic or facultative aerobic, non-motile and acid-tolerant microorganism (Florou-Paneri *et al*., 2013, Quinto *et al*., 2014, Gupta *et al*., 2018; Bintsis, 2018). LAB can be identified based on the morphology, their ability to ferment carbohydrates, carbon dioxide production, growth in different temperature and their ability to grow at high salt concentrations. Figure 1 shows the basic structure of a Lactic Acid Bacteria, *Lactobacillus*. LAB are classified into six main groups: *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Streptococcus*, *Enterococcus* and *Pediococcus* (Bennani *et al*., 2017). These types of bacteria are mostly present in the human body as normal flora to the alimentary tract. Their presence ensured control over less friendly bacteria as well as giving other benefits to the host (Gupta *et a*l., 2018). LAB have been regarded as safe food-grade microorganisms (Xu *et al*., 2016). They have been used as food preservatives and modifiers in flavours as well as the texture of food. LAB are also important in the fermentation of dairy products, meats, vegetables and

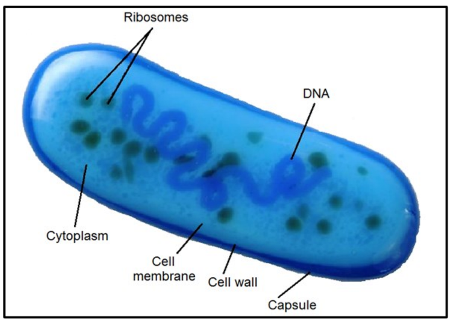

Figure 1. Structure of *Lactobacillus* (Anup, 2018)

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some traditional foods. They ferment carbohydrates and produce lactic acid as the main product of fermentation (Florou-Paneri *et al*., 2013).

Marine animals are adapted to live in saltwater. The animals are able to regulate salt intake, obtain oxygen and withstand the saltwater pressure (Kennedy, 2019). They live at all levels of the oceanic water column. The animals can be seen in the upper ocean, in deeper waters, and all over the ocean basins. The abundance of organisms decreases with depth (Cochran, 2014). LAB are generally considered as favourable bacteria to marine animals. They are known for their ability to act against bacterial pathogens (Merrifield *et al*., 2014). LAB are mostly isolated from the gastrointestinal tract (GIT) and muscle of marine animals. Variation of LAB suggests that real variation exists between marine animals' species and geographical location (Buntin *et al*., 2008).

2. Lactic acid bacteria

2.1 Characterisation of lactic acid bacteria

Lactate and acetate are the main products produced by LAB during carbohydrates fermentation. Previous studies proved that some LAB performed as an antagonist towards pathogenic and spoilage microorganisms (Moosavi-Nasab *et al*., 2014). There are two metabolic categories of LAB based on the sugar fermentation patterns: homofermentative, and heterofermentative. Figure 2 shows the metabolic pathway in LAB. Homofermentative LAB transforms almost all of the sugar into lactic acid. Meanwhile, the heterofermentative LAB does not produce lactic acid as the main product of fermentation. They may produce ethanol or acetate as the by-products (Ganzle, 2015). In general, the main products of LAB fermentation include alcohol, carbon dioxide and organic acid. They also produce aromatic molecules, vitamins, or bioactive peptides (O'Bryan *et al*., 2015).

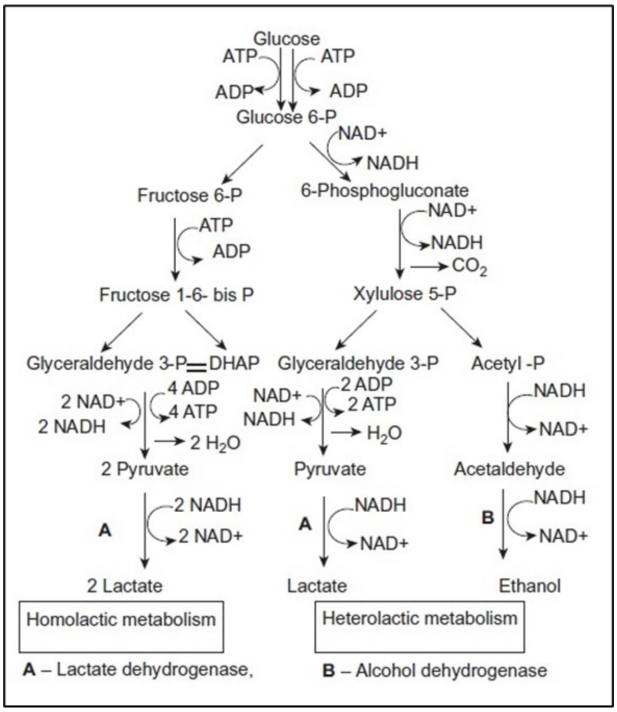

Figure 2. Metabolic pathway of Lactic Acid Bacteria (O'Bryan *et al.,* 2015)

Some LAB possesses a limited capacity to synthesize amino acids from inorganic nitrogen sources. They depend on the presence of amino acids available in the environment or medium of growth. Proteinase and peptidase can be found as extracellular or intracellular substances of the cell. A few LAB strains are able to metabolize lipids. The strains have either intracellular or extracellular lipases. Furthermore, they perform unique fatty acid transformation reactions including isomerization, saturation, hydration and dehydration. Their metabolic activities are also able to provide health benefits to the host. Lactobacilli are able to break down cholesterol into serum lipid and this had been proved by a few studies on mice, preclinical and clinical trials (Hayek *et al*., 2013). Some LAB can metabolize citrate. This metabolism requires citrate transportation, citrate conversion into oxaloacetate and pyruvate. Citrate metabolism by LAB leads to the production of 4-carbon compounds, i.e diacetyl, acetoin and 2,3-butanediol. These compounds possess aromatic properties and they give a certain odour to some fermented products (Cadwallader *et al*., 2009).

2.2 Application of lactic acid bacteria

Colonization of lactic acid bacteria is important to the development and physiology of the host. In the gut, they contribute to nutrient absorption, immune response, mucosal tolerance and epithelial development. A balanced population of intestinal bacteria is crucial in maintaining the health of the host (Rungrassamee *et al*., 2014, Russo *et al*., 2015). The intestinal tract is considered to be a valuable waste and a good source for LAB isolation (Moosavi-Nasab *et al*., 2014).

LAB have been applied as starter cultures in foods and beverages due to their ability to improve nutritional, organoleptic, technological and shelf-life characteristics. Lactic acid is the main product of fermentation, followed by acetic acid, while LAB can also produce ethanol, bacteriocin, aroma compounds, exopolysaccharides and some enzymes (Florou-Paneri *et al*., 2013, Mozzi, 2016). LAB is widely used as a source of probiotics because they play important roles in the host digestive tract, improving its immune status, modulating the bacterial community, and antagonizing opportunistic pathogens. They enhance the balance of the microbial community in the intestine, confer protection against potential pathogenic bacteria, and prevent and/or cure intestinal diseases (Azat *et al*., 2016). Probiotics have also been

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frequently administered in aquaculture because they give out several benefits including immunological, nutritional, and environmental benefits (Sha *et al*., 2016). LAB acts as the preservation to the food by producing metabolites such as lactic acid, fatty acid and bacteriocin by inhibiting the growth of spoilage pathogenic bacteria. The compounds produced by these LAB interact with the cell membranes of the harmful pathogens and inhibit the growth (Azat *et al*., 2016; Gupta *et al*., 2018). Intestinal LAB also can produce some vitamins that are needed by the body of the host (Florou-Paneri *et al*., 2013). *Lactobacillus* spp. (*L. lactis*, *L. plantarum*, *L. bulgaricus*), *Streptococcus* spp. and *Enterococcus* spp. are able to produce folate (Masuda *et al*., 2014). *Lactobacillus* spp. has the ability to produce vitamin B12. Strains of genera *Lactococcus*, *Lactobacillus*, *Enterococcus*, *Leuconostoc* and *Streptococcus* are able to produce vitamin K. LAB release a variety of enzymes into the gastrointestinal tract. Enzymes produced by the LAB during food fermentation are amylases and peptidases. Amylases are being used in sourdough technology and peptidases are used for cheese making. LAB are also important in winemaking. The bacteria grow in wine during malolactic fermentation, following alcoholic fermentation. These secondary modifications improve the taste and flavour of wine (Florou-Paneri *et al*., 2013).

3. Lactic acid bacteria isolated from marine animals

3.1 Shellfish

LAB isolated from the gastrointestinal tract of wild shrimp was revealed to have high prevalence and diversity. The LAB isolated from the wild shrimp also possesses inhibitory properties towards *Vibrio harveyi*. Coccoid LAB is the most prevalent LAB in the gastrointestinal tract of aquatic animals (Kongnum *et al*., 2012). Table 1 shows the LAB isolated from various species of shellfish. *Streptococcus phocae* isolated from Indian white shrimp by Kanmani and colleagues (2010) has the ability to restrain mortality and improve the survival rate of the shrimp. *Lactococcus lactis* isolated from kuruma shrimp (*Marsupenaeus japonicus*) was claimed to have the potential in controlling and preventing *Vibrio penaeicida* infection (Maeda *et al*., 2014). Samples taken from muscle and intestine of shrimp collected from Tunisia showed the presence of *Lb. paracasei* (Boulares *et al*., 2011). Microbiota that inhabits the intestine of wild-caught and domesticated giant tiger prawn (*Penaeus monodon*) were compared by Rungrassamee and team (2014). The study showed the presence of *Lactobacillus* sp., *Lactococcus* sp. and *Pediococcus* sp. in wild-caught giant tiger prawns. Out of the 24 isolates from the GIT of black tiger shrimp (*Penaeus monodon*) and ornate spiny lobster (*Panulirus ornatus*), 8.3% was detected as *Enterococcus faecalis*. This strain showed strong antimicrobial activity against *Proteus* sp., *Proteus mirabilis* and *E. coli*. However, the antimicrobial activity of its bacteriocins lost completely after incubation at 60^{o}C for 30 mins (Nguyen *et al*., 2014). Azahar *et al* (2018) had isolated 14 probiotic strains from GIT of prawn (*Macrobrachium rosenbergii*). Molecular identification using 16s rRNA genes sequences identified them as *E. faecalis*, *Lc. lactis* and *Lc. garvieae*. Three of the 14 strains showed antimicrobial activities towards *V. parahaemolyticus*, *V. alginolyticus* and *Aeromonas hydrophila*. However, the authors did not mention the specific strains which possess growth inhibition towards the pathogens.

Lactobacillus spp. were isolated from the oyster (*Crassostrea gigas*) by Lee and colleagues (2010) and was expected to be more adaptable to marine aquaculture conditions compared to freshwater animals. Kang *et al*. (2016) claimed that *Lb. rhamnosus* MH22 exhibited relatively high antagonism to the two strains of *Vibrio* spp. *Lb. plantarum* isolated from the muscle of shellfish; oyster (*Crassostrea gigas*) and shortnek clam (*Tapes philippinarum*) showed inhibitory activity against pathogens including *E. coli*, *Edwardsiella tarda*, *Staphylococcus aureus*, *Salmonella enterica* serovar Enteriditis, *Streptococcus inae*, *S. enterica* serovar Typhimurium, *V. ichthyoenteri* and *V. parahaemolyticus* (Kang *et al*., 2016). Meanwhile, *Lactobacillus paracasei* ssp. *paracasei* was successfully isolated from the gastrointestinal tract of abalone (*Holiotis asinina*). This species was discovered to be able to inhibit the growth of enteropathogenic bacteria (*E. coli*, *Bacillus cereus* and *S. aureus*) and able to grow in acidic conditions and tolerant of bile during 24 hrs incubation (Sarkono *et al*., 2010).

Furthermore, the intestinal content of clam (*Meretrix lamarckii*) may harbour different *Lc. lactis* subsp. *lactis* and *Lc. lactis* subsp. *cremoris* strains as reported by Itoi *et al*. (2013). The clam inhabits the intertidal zone with the changes of osmotic pressure, dissolved oxygen and temperature. The changes would also force the LAB to adapt to the condition. *Leuconostoc pentosus* and *E. faecium* was isolated from the whole body without a shell of oyster (*Crassostrea gigas*). *Enterococcus faecium* was found to be resistant to 10 types of antibiotics. Probiotic strains with antibiotic resistance would be captivating if the probiotic is administered during antibiotic treatment (Kang *et al*., 2017).

Kim and colleagues (2017) studied the influence of season and changes in water temperature on the microbiota of swimming crab (*Portunus trituberculatus*).

Table 1. Lactic acid bacteria isolated from shellfish

Marine organism	Location	Lactic Acid Bacteria	Part of isolation	References
Indian white shrimp (*Penaeus indicus*)	ni*	*Streptococcus phocae*	GIT	Kanmani *et al*. (2010)
Kuruma shrimp (*Marsupenaeus japonicus*)	Kanmon Strait, Fukuoka and Tachibana Bay, Nagasai, Japan	*Enterococcus faecalis, E. faecium, E. pseudovium, E. raffinosus, Lactobacillus* sp., *Lb. plantarum, Lb. nagelii, Lactococcus garvieae, L. lactis, Pediococcus pentosaceus, Vagococcus campiphilus, Vc. Fluvialis, E. pallens, Lb. amylophilus*	GIT	Maeda *et al*. (2014)
Giant tiger prawn (*Penaeus monodon*)	Andaman Sea, Thailand	*Lactobacillus* sp., *Lactococcus* sp., *Pediococcus* sp.	GIT	Rungrassamee *et al*. (2014)
Banana shrimp (*Fenneropenaeus merguiensis*)	Songkhla province, Thailand	LAB	GIT	Kongnum *et al*. (2012)
Swimming crab (*Callinectes* sp.)	Lagos, Nigeria	*Streptococcus agalactie*	GIT	Uaboi-Egbenni *et al*. (2010)
Blue swimming crab (*Portunus pelagicus*)	Strait of Tebrau, Johor, Malaysia	*Lactobacillus plantarum*, *Lb. salivarius, Lb. rhamnosus, Weissella confusa* and *W. cibaria*	GIT	Talpur *et al*. (2012)
Swimming crab (*Portunus trituberculatus*)	Yellow Sea, Korea	*Carnobacterium, Lactococcus, Streptococcus* and *Vagococcus*	Whole body	Kim *et al*. (2017)
Oyster (*Crassostrea gigas*)	Taean coast, South Korea	*Lactobacillus pentosus, Enterococcus faecium*	Whole body without shell	Kang *et al*. (2017)
Corb shell (*Cyclina sinensis*)	West Sea, Korea	*Lactobacillus* sp.	Muscle	Kang *et al*. (2016)
Mussel (*Mytilus edulis*)	West Sea, Korea	*Lactobacillus* sp.	Muscle	Kang *et al*. (2016)
Surf clam (*Mactra veneriformis* Reeve)	West Sea, Korea	*Lactobacillus* sp.	Muscle	Kang *et al*. (2016)
Oyster (*Crassostrea gigas*)	West Sea, Korea	*Lactobacillus* sp. and *Lb. plantarum*	Muscle	Kang *et al*. (2016)
Shortnek clam (*Tapes philippinarum*)	West Sea, Korea	*Lactobacillus plantarum*	Muscle	Kang *et al*. (2016)
Spiny top shell (*Batillus cornutus*)	West Sea, Korea	*Lactobacillus* sp.	Muscle	Kang *et al*. (2016)
Mud crab (*Scylla paramamosain*)	Southern Chinese coasts, China	*Lactobacillus, Lactococcus*	GIT	Wei *et al*. (2019)
Mud crab (*Scylla paramamosain*)	Shantou, China	*Enterococcus faecalis, Pediococcus pentosaceus*	GIT	Yang *et al*. (2019)
Clam (*Meretrix lamarckii*)	Ibaraki, Japan	*Lb. curvatus, Lb. plantarum, Lc. lactis ssp cremoris, Pediococcus pentosaceus, Lc. lactis* ssp. *lactis*	GIT	Itoi *et al*. (2013)
Prawn (*Macrobrachium rosenbergii*)	Kuala Terengganu, Terengganu, Malaysia	*Enterococcus faecalis, Lc. lactis* and *Lc. garvieae*	GIT	Azahar *et al*. (2018)
Shrimp	Tunisia	*Lb. paracasei*	Muscle and intestine	Boulares *et al*. (2011)
Abalone (*Holiotis asinina*)	Lombok, Indonesia	*Lb. paracasei* ssp. *paracasei*	GIT	Sarkono *et al*. (2010)
Oyster (*Crassostrea gigas*)	Geunso bay of Taean, South Korea	*Lb. paracasei*, *Lb. plantarum, Lb. johnsonii, Lb. rhamnosus, Lb. parabuchneri, Lb. pentosus, Lb. paraplantarum*	Whole body without shell	Lee *et al*. (2010)
Black tiger shrimp (*Penaeus monodon*)	Khanh Hoa province, Vietnam	*Enterococcus faecalis*	GIT	Nguyen *et al*. (2014)
Ornate spiny lobster (*Panulirus ornatus*)	Khanh Hoa province, Vietnam	*Enterococcus faecalis*	GIT	Nguyen *et al*. (2014)

* ni - no further information, GIT – gastrointestinal tract, E. – *Enterococcus*, Lb. – *Lactobacillus*, Lc. – *Lactococcus*, Vc. – *Vagococcus*, W. – *Weissella*

They isolated *Streptococcus*, *Lactococcus*, *Carnobacterium* and *Vagococcus* from the whole body of the swimming crab and the isolated LAB were the dominant genera in spring crab. Yang *et al*. (2019) isolated *E. faecalis* and *P. pentosaceus* from GIT of mud crab (*Scylla paramamosain*). They found *E. faecalis* and *P. pentosaceus* exhibited a strong growth inhibition to *A. hydrophila*, Beta *Streptococcus*, *S. aureus* and *V. alginolyticus*. A study conducted by Talpur and colleagues (2012) indicated that *Lb. plantarum*, *Lb. salivarius* and *Lb. rhamnosus* isolated from the gastrointestinal tract of blue swimming crab (*Portunus pelagicus*)improved the survival of *P. pelagicus* larvae. GIT of female mud crab (*Scylla paramamosain*) assembled 0.37% abundance *Lactobacillus* genus. Genus of *Lactococcus* and *Lactobacillus* were found in GIT of male samples with a relative abundance of 0.7% and 1.10% respectively (Wei *et al*., 2019). *S. agalactiae* was isolated from GIT of swimming crab (*Callinectes* sp.). The swimming crab was collected from the open lagoon at 28^{o}C and from the market samples at 0^{o}C. The study showed the least hemolytic values compared to other isolated bacteria. This strain was previously belonging to pyrogenic mastitis in cows (Uaboi-Egbenni *et al*., 2010).

3.2 Finfish

LAB has gained attention with respect to its beneficial effects on fish health. LAB play important role in the fish GIT. The LAB is able to stimulate the fish GI development, digestive function, mucosal tolerance, stimulate immune response and improve disease resistance (Ringo *et al*., 2018). Wild fish could be a substantial source of LAB that could be suitable for use as probiotics in feed for fish (Kim *et al*., 2013). Table 2 shows the LAB isolated from finfish. A study conducted by Salas-Leiva and colleagues (2017) reported that they had isolated *Carnobacterium*, *C. divergen*, *Lactobacillus*, *Streptococcus*, *Vagococcus*, and *Weissella* from the intestine of fine flounder (*Paralichthys adspersus*). Boulares and team (2011) had isolated LAB from muscle and intestine of eight types of marine fish. *Lactobacillus* was mostly found genus in fish followed by *Lactococcus*. The team also isolated *Lb. paracasei* from red mullet, *Lb. brevaris* from whiting and *Leu. citream* from pageot. The most dominant phylum isolated from Atlantic salmon (*Salmo salar*) was Firmicutes. *Carnobacterium*, *C. divergen*, *Lactobacillus*, *Lactococcus*, *Streptococcus* were found in the gastrointestinal tract of the fish (Dehler *et al*., 2017). A study conducted by Svanevik and Lunestad (2011) was to examine the microorganisms obtained from the gill, skin and GIT of Atlantic mackerel (*Scomber scombrus*). As the result, they found two species of LAB which were *Vagococcus* sp. (isolated from GIT) and *V. carniphilus* (isolated from gill, skin and GIT).

Lactobacillus. buchneri, *Lc. lactis*, *Lb. acidophilus, Lb. fermentum*, and *S. salivarius* isolated from the intestine of Narrow-barred Spanish mackerel (*Scomberomorus commerson*) showed different degrees of inhibitory activity. It was probably due to the synergistic effect of both bacteria and antimicrobial substances, hence enhancing their antimicrobial effect against *Listeria innocua* (Moosavi-Nasab et al., 2014). *S. parauberis* strain *maris rubric* was identified from broomtail wrasse (*Cheilinus lunulatus*). It is known for causing bovine mastitis and this type of LAB was tested to be resistant to oxytetracycline, baytril (enofloxacin) and doxycycline. *Streptococcus iniae* was isolated from the goatfish (*Parupeneus* sp.), grouper (*Epinephelus fasciatus*), and rabbitfish (*Siganus rivulatus*). This strain was tested to be sensitive to oxytetracycline, chloramphenicol, florfenicol, baytril (enrofloxacin), doxycycline, sulphamethoxazole/trimethoprim and clindamycin (Ucko *et al*., 2013). The LAB isolated from the gut of Indian mackerel (*Rastrelliger kanagurta*) were identified as *Lb. plantarum*, *Lb. viridiscens*, *Lb. bulgaricus*, and *Lb. brevis*. From the isolated LAB, *Lb. plantarum* was found to possess good antibacterial activity (Ghosh *et al*., 2014). *Enterococcus durans* was isolated from the viscera of five species of fish from the Mediterranean coast, Tunisia. *E. faecium* was the only LAB found from red mullet (*Mullus surmutelus*) and *Lc. lactis* from picarel (Spicara smaris). *Lc. lactis* from picarels showed a broader inhibitory spectrum and displayed important inhibitory activity against *Saccharomyces cerevisiae* and *Candida pseudotropicalis*. A bacteriocin was purified from *E. durans* (isolated from Pandora). The molecular mass of the purified peptide was 6316.89±0.64 Da (Migaw *et al*., 2013).

Belfiore and colleagues (2010) also isolated four species of *Leuconostoc* from anchovy (*Engraulis anchoita*). They suggested that the generated amino acid from fish would be transformed into aroma compounds by *Lc. mesenteroides* subsp. *dextranicum*, *Lc. carnosum* and *Lc. mesenteroides* subsp. *mesenteroides*. An anti-Listeria compound was also detected for *Leuc. mesenteroides*. Two species of LAB; *Lb. casei* and *Lb. plantarum* were selected from 84 isolated lactobacilli from the intestine of Persian sturgeon (*Acipenser persicus*) and Beluga (*Huso huso*). From the study, both species were able to produce antibacterial substances. They have a high inhibitory potential against *Listeria monocytogenes* (Ghanbari *et al*., 2013). A total of 13 marine fishes obtained from Cantabrian Sea Coast, Gijou, Spain indicated that the main LAB was *Lc. lactis* subsp. *lactis*. The entire five isolated LAB displayed a

Table 2. Lactic acid bacteria isolated from finfish

Marine Organism	Location	Lactic Acid Bacteria	Part of Isolation	References
Persian sturgeon (*Acipenser persicus*), Beluga (*Huso huso*)	Caspian Sea, Iran	*Lactobacillus casei, Lb. plantarum*	Intestine	Ghanbari *et al.* (2013)
Sardine (*Sardina pilchardus*)	ni*	*Lactobacillus homohiochii, Lb. farciminis*	Viscera	Poffo *et al.* (2011)
Leatherjacket (*Oligoplites saliens*)	ni*	*Lb. intestinalis*	Viscera	Poffo *et al.*
Sardine	Tunisia	*Lc. lactis, Carnobacterium divergens, Carnobacterium*	Muscle and intestine	Boulares *et al.* (2011)
Whiting	Tunisia	*Lb. brevis*	Muscle and intestine	Boulares *et al.*
Sole	Tunisia	*Leuconostoc mesenteroides, Lb. brevis*	Muscle and intestine	Boulares *et al.* (2011)
Red mullet	Tunisia	*Lb. paracasei*	Muscle and intestine	Boulares *et al.*
Mullet	Tunisia	*Lc. lactis, Leuconostoc mesenteroides, Lb. plantarum, Lb.*	Muscle and intestine	Boulares *et al.* (2011)
Sea bream	Tunisia	*Lc. lactis, Leu. Mesenteroides, Lb. plantarum, Lb. paracasei, Lb. brevis, Carnobacterium piscicola, Lb. delbruekeii*	Muscle and intestine	Boulares *et al.* (2011)
Atlantic salmon (*Salmo salar*)	West coast of Scotland	*Carnobacterium, C. divergen, Lactobacillus, Lactococcus, Streptococcus*	GIT	Dehler *et al.* (2017)
Fine flounder (*Paralichthys adspersus*)	Region of Coquimbo, Chile	*Carnobacterium, C. divergen, Lactobacillus, Streptococcus, Vagococcus, Weissella*	Intestine	Salas-Leiva *et al.* (2017)
Broomtail wrasse (*Cheilinus lunulatus*)	Eilat, Israel	*Streptococcus parauberis* strain *marin rubri*	Spleen, kidney, blood	Ucko *et al.* (2014)
Goatfish (*Parupeneus* sp.)	Eilat, Israel	*Streptococcus iniae*	Spleen, kidney, blood	Ucko *et al.* (2014)
Grouper (*Epinephelus fasciatus*)	Eilat, Israel	*Streptococcus iniae*	Spleen, kidney, blood	Ucko *et al.* (2014)
Rabbitfish (*Siganus rivulatus*)	Eilat, Israel	*Streptococcus iniae*	Spleen, kidney, blood	Ucko *et al.* (2014)
Indian mackerel (*Rastrelliger kanagurta*)	Ernakulan, Kerala, India	*Lb. plantarum, Lb. viridiscens, Lb. bulgaricus, Lb. brevis*	GIT	Ghosh *et al.* (2014)
Olive flounder (*Paralichthyls olivaceus*)	Wando, South Korea	*Streptococcus salivarius, Lactococcus lactis, Lc. chungangensis, Enterococcus durans, Leuconostoc lactis, Weissella cibaria, W. thailandensis, Lb. brevis, Lb. crustorum, Lb. sakei, Pediococcus pentosaceus, Lb. oligofermentans*	Mucus of hindgut	Kim *et al.* (2013)
Anchovy (*Engraulis anchoita*)	Mar del Plata, Argentina	*Leuconostoc mesenteroides* ssp. *mesenteroide*, *Leu. mesenteroides* ssp. *dextranicum, Leu. mesenteroides* ssp. *cremoris*, *Leu. mesenteroides* ssp. *carnosum*	GIT	Belfiore *et al.* (2010)

* ni - no further information, Lb. – *Lactobacillus*, Lc. – *Lactococcus*, Leu. – *Leuconostoc*, C. – *Carnobacterium*, W. – *Weissella*, S. – *Streptococcus*, E. – *Enterococcus*, GIT – gastrointestinal tract

Table 2 (Cont.). Lactic acid bacteria isolated from finfish

Marine Organism	Location	Lactic Acid Bacteria	Part of Isolation	References
White trevally (*Pseducaranx dentex*)	Moreton Bay, Sunshine Coast and Gold Coast, Queensland, Australia	*Streptococcus uberis, S. equinus, S. constellatus, Enterococcus faecium, E. avium, Vagococcus fluvialis*	Muscle, gill, gut	Al Bulushi *et al*. (2010)
Silver seabream (*Pagrus auratus*)	Moreton Bay, Sunshine Coast and Gold Coast, Queensland, Australia	*S. uberis, S. equinus, S. salivarius, S. constellatus, E. faecium, Aerococcus* spp.	Muscle, gill, gut	Al Bulushi *et al*. (2010)
Flathead grey mullet (*Mugil cephalus*)	Moreton Bay, Sunshine Coast and Gold Coast, Queensland, Australia	*S. uberis, S. equinus, s. salivarius, S. constellatus, E. faecium, E. avium*, *Aerococcus* spp., *Carnobacterium* spp.	Muscle, gill, gut	Al Bulushi *et al*. (2010)
Narrow-barred Spanish mackerel (*Scomberomorus commerson*)	Persian Gulf	*Lb. buchneri, Lc. lactis, Lb. acidophilus, Lb. fermentum, Streptococcus salivarius*	Intestine	Moosavi-Nasab *et al*. (2014)
Caspian sea golden grey mullet (*Liza aurata*)	Caspian Sea, Northern Iran	LAB	Muscle	Bahmani *et al*. (2013)
Atlantic mackerel (*Scomber scombrus*)	Norwegian Sea	*Vagococcus* sp. and *Vagococcus carniphilus*	Gill, skin and gut	Svanevik and Lunestad (2011)
Sea bass	Tunisia	*Lc. lactis, Leu. mesenteroides, Lb. plantarum, Lb. paracasei, Lb. brevis, Lb. acidophilus*	Muscle and intestine	Boulares *et al*. (2011)
Pageot	Tunisia	*Lb. acidophilus*	Muscle and intestine	Boulares *et al*. (2011)
Picarel (*Spicara smaris*)	Mediterranean coast, Tunisia	*Lc. lactis*	Viscera	Migaw *et al*.
Red mullet (*Mullus surmutelus*)	Mediterranean coast, Tunisia	*Enterococcus faecium*	Viscera	Migaw *et al*.
Horse mackerel (*Trachurus trachurus*)	Mediterranean coast, Tunisia	*Enterococcus durans*	Viscera	Migaw *et al*. (2013)
Bogue (*Boops boops*)	Mediterranean coast, Tunisia	*Enterococcus durans*	Viscera	Migaw *et al*. (2013)
Stripped mullet (*Mugil cephalus*)	Mediterranean coast, Tunisia	*Enterococcus durans*	Viscera	Migaw *et al*. (2013)
Pandora (*Pagellus erythrinus*)	Mediterranean coast, Tunisia	*Enterococcus durans*	Viscera	Migaw *et al*. (2013)
Atlantic mackerel (*Scomber scombrus*)	Mediterranean coast, Tunisia	*Enterococcus durans*	Viscera	Migaw *et al*. (2013)
Ballan wrasse (*Labrus bergyta*), White seabream (*Diplodus sargus sargus*), Peter's fish (*Zeus faber*), European conger (*Conger conger*), Red scorpionfish (*Scorpeana scrofa*), Gray mullet (*Mugil cephalus*), Zebra sea bream (*Diplodus cervinus cervinus*), Dreamfish (*Sarpa salpa*), Small-spotted catshark (*Scyliorhinus canicula*), Triggerfish (*Balistes capriscus*) Cuckoo wrasse (*Labrus mixtus*)	Cantabrian Sea Coast, Gijon, Spain	*Lactobacillus plantarum, Leuconostoc mesenteroides, Enterococcus faecalis, E. gallinarum, Lactococcus lactis* ssp. *lactis*	GIT	Alonso *et al*. (2018)

* ni - no further information, Lb. – *Lactobacillus*, Lc. – *Lactococcus*, Leu. – *Leuconostoc*, C. – *Carnobacterium*, W. – *Weissella*, S. – *Streptococcus*, E. – *Enterococcus*, GIT – gastrointestinal tract

broad-spectrum antibacterial activity against *V. harveyi*, *V. splendidus*, and *Photobacterium damselae* (Alonso *et al*., 2018).

Al Bulushi *et al*. (2010) conducted a study by storing the white trevally (*Pseducaranx dentex*), silver seabream (*Pagrus auratus*) and flathead grey mullet (*Mugil cephalus*) at 25°C for 15 hours. They mentioned that the highest frequency of LAB was found in the gills of the fish and the lowest in the gut. From that, the frequencies of *S. uberis* and *E. faecium* were found the most at 15 hours of storage. Bahmani *et al*. (2014) studied the effect of delayed icing on the quality of mullet. They investigated the total viable count of LAB and Enterobacteriaceae. From their study, the growth rate of the total viable count population of bacteria decreased at the end of storage. They suggested that the bacteria might be inhibited or killed with the more production of natural preservatives by LAB such as short-chain fatty acid and bacteriocins. This condition may help in maintaining an appropriate pH and protect against pathological changes in fish during storage. Nine LAB were isolated from sardine (*Sardina pilchardus*) and leatherjacket (*Oligoplites saliens*). *Lb. homohiochii* and *Lb. farciminis* were detected from viscera of sardine and *Lb. intestinalis* was obtained from viscera of leatherjacket. Further study showed that *Lb. homohiochii* grew optimally at 40°C, meanwhile *Lb. intestinalis* grew optimally at 30°C (Poffo *et al*., 2011).

3.3 Invertebrate marine organism

Table 3 shows LAB isolated from invertebrate marine organisms. A study conducted by Iehata *et al*. (2013) discovered that there were different bacterial communities and bacterial nutritional enzyme activity between both female and male Chilean octopus (*Octopus mimus* Gould). They suggested the possibility of different feeding habits and the formation of the bacterial community could reflect the environment of the host digestive tract. From this study, *Lc. garvieae* was found in both male and female octopuses. Eventually, *Lc. garvieae* and *Lc. formosensis* isolated from red octopus (*Octopus maya*) were detected as histamine producing strains. They represented 6% of the total isolates (Gullian *et al*., 2018). *E. faecium*, *E. hirae*, *E. faecalis* and *E. gallinarum* were isolated from faeces of black sea urchin (*Arbacia lixula*), sea urchin (*Paracentrotus lividus*), purple sea urchin (*Sphaerechinus granularis*), and sea cucumber (*Holothuria mammata* and *Holothuria sanctori*). The investigation showed that *E. faecium* was obtained as the predominant enterococcal species in the faecal samples. The enterococci showed high resistance to ampicillin, tetracycline and ciprofloxacin (Marinho *et al*., 2013).

A study conducted by Boulares and colleagues (2011) showed that *Lb. brevis* and *Leu. mesenteroides* was found in cuttlefish. *Lc. lactis*, *P. pentosaceus*, *Lb. curvatus*, *Leu. mesenteroides*, *Lb. paracasei*, and *Lb. brevis* were found in the muscle and intestine of octopus. The composition of bacterial communities in the gut

Table 3. Lactic acid bacteria isolated from invertebrate marine organism

Marine Organism	Location	Lactic Acid Bacteria	Part of Isolation	References
Sea cucumber (*Apostichopus*	Weihai, Shandong Province, China	*Carnobacterium, Lactococcus, Lactobacillus, Streptococcus*	GIT	Wang *et al*. (2018)
Black sea urchin (*Arbacia lixula*), Sea urchin (*Paracentrotus lividus*), Purple sea urchin (*Sphaerechinus granularis*), Sea cucumber (*Holothurai mammata* and	São Miguel, São Jorge and Flores, Portugal	*Enterococcus faecium, E. hirae, E. faecalis and E. gallinarum*	Feces	Marinho *et al*. (2013)
Chilean octopus (*Octopus mimus* Gould)	Antofagasta, Chile	*Lactococcus garvieae*	Crop and Intestine	Iehata *et al*. (2013)
Red octopus (*Octopus maya*)	State of Yucatan, Mexico	*Lactococcus garvieae and Lc. formosensis*	Crop	Gullian *et al*. (2018)
Octopus	Tunisia	*Lc. lactis, Pediococcus pentosaceus, Lb. curvatus, Leuconostoc mesenteroides, Lb. paracasei, Lb. brevis*	Muscle and intestine	Boulares *et al*. (2011)
Cuttlefish	Tunisia	*Leu. mesenteroides, Lb. brevis*	Muscle and intestine	Boulares *et al*. (2011)

* E – *Enterococcus*, Lc. – *Lactococcus*, Lb. – *Lactobacillus*, Leu. – *Leuconostoc*, GIT – gastrointestinal tract

content of sea cucumber *A. japonicus* and ambient sediments of two different habitats*, Z. marina* seagrass bed and rocky intertidal habitat was compared using Illumina Miseq high-throughput sequencing. It showed that *Carnobacterium*, *Lactococcus*, *Lactobacillus*, and *Streptococcus* were relatively more abundant from seagrass bed habitat samples. This suggested that the seagrass bed ecosystem could represent a better source of candidate probiotics which beneficial for the survival of *A. japonicus* (Wang *et al*., 2018).

3.4 Marine mammal

Table 4 shows LAB isolated from marine mammals. Firmicutes phylum was composed as the highest in the dugong's faecal content. The bacterial flora in the same group including manatee and dugong may be varied according to several factors such as species, age, habitat, eating habits, digestive tract and tract position. It was unclear whether the seasonal variation can be related to the variation of chemical composition and digestion potential, or changes of the physiological or digestion metabolism of the dugong that related to the ageing of the animal (Tsukinowa *et al*., 2008). *Lactobacillus salivarius* isolated from the gastric fluid of bottlenose dolphin (*Tursiops truncatus*) revealed the potential to suppress the proliferation of enteric pathogen and stimulate tumour necrosis factor production in mammalian myeloid cells. Novel *Lactobacillus* spp. was isolated and related to *Leuconostoc ceti* (Diaz *et al*., 2013).

Two unidentified cocci were also isolated from the dead seal and porpoise. Comparative 16S rRNA gene sequencing was performed to determine the phylogenetic affinities of the two unknown cocci. Both isolates were 100% identical to each other and from the phylogenetic and phenotypic distinctiveness of the unknown bacterium, it was proposed as *Vagococcus fessus* (Hoyles *et al*., 2000).

3.5 Marine reptile

Sample from faeces and cloaca were collected from hospitalized sea turtles and the intestine samples were taken from the dead sea turtles. LAB was obtained from the faeces, cloaca and intestine of sea turtles (*Caretta caretta*). Sample from faeces and cloaca were collected from hospitalized sea turtles and the intestine samples were taken from the dead sea turtles. The location of the sample taken was in Tuscany and Liguria, Italy. From taxonomic composition, it showed that 66% of Firmicutes dominated the faeces sample and 87% from the intestine samples. *Vagococcus* with 42.3% was the most presented bacteria in the intestine (Abdelrhman *et al*., 2016). To the best of our knowledge, there were very limited studies conducted on marine reptiles.

4. Conclusion

Lactic acid bacteria have been isolated from marine animals from various sites of the animal's part in different parts of the geographical area. Various species were isolated from marine animals with the most dominant genus from Lactobacillus. The bacteria inhabit mostly the GIT of the animals. LAB protect the host by producing bacteriocin to control the growth of pathogens. The resistance of LAB towards antibiotics could be useful in playing a role as a probiotic in the medical industry. LAB isolated from the marine environment has the benefits of resilience to temperature and salty environment compared to other LAB strains. However, to the best of our knowledge, there is a lack of study in the discovery of the potential of LAB from marine animals to industries. More studies should be conducted to get the potential LAB to be manipulated into commercial products.

Conflict of interest

The authors declare no conflict of interest.

Table 4. Lactic acid bacteria isolated from marine mammal

Marine Organism	Location	Lactic Acid Bacteria	Part of Isolation	References
Dugong (*Dugong dugong*)	Toba, Japan	*Lc. lactis* ssp. *lactis*	Feces	Tsukinowa *et al*. (2008)
Bottlenose dolphin (*Tursiops truncatus*)	San Diego Bay, California	*Lb. salivarius,*	Oral and rectal swabs, milk, and gastric fluid	Diaz *et al*. (2013)
Seal	ni*	*Vagococcus fessus* sp.	Liver and kidney	Hoyles *et al*.
Porpoise	ni*	*Vagococcus fessus* sp.	Peritoneum, spleen, kidney, liver, lung, brain, placenta and small intestine.	Hoyles *et al*. (2000)

* ni – no further information, Lb. – *Lactobacillus*, Lc. – *Lactococcus*

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