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Review Article

A Brief Review on the Antioxidants and Antimicrobial Peptides Revealed in Mud Crabs from the Genus of *Scylla*

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Mud crab from the genus *Scylla* is also known as mangrove crab, which has been well-accepted as a good source of protein. Recently, the antioxidant properties present in mud crabs have been reported to have a part in the protection of cells against free radicals. Meanwhile, numerous antimicrobial peptides from mud crabs have managed to be characterized through the display of antimicrobial activities against Gram-positive and Gram-negative bacteria. Hence, this paper is an effort to collect recent literatures on antioxidant and antimicrobial properties in every part of mud crabs which include muscle tissue, hemolymph, and crab shell. Moreover, the effort to understand the biological properties of mud crabs is important to enhance its production in aquaculture industry. Therefore, this review hoped to attract the attention of natural product researchers to focus on the potential therapeutic applications of mud crabs.

1. Introduction

Mud crabs are also referred as mangrove crabs due to their wide distribution in mangrove areas. Mud crabs are consumed due to their high nutritional quality for marine lives as well as for human. Mud crabs from genus *Scylla* have been known to be commercially important worldwide, thus causing them to be cultured in many Asian countries such as Malaysia, Indonesia, Philippines, Taiwan, Sri Lanka, Vietnam, India, and China [1]. Mud crab that originates from genus of *Scylla* can be easily found in shallow water with the optimal salinity of 20 to 30 gL^{-1}, particularly in mangrove areas and estuaries [2]. The genetic data and morphological characters suggest that *Scylla* is made of four distinct species, namely, *Scylla paramamosain, Scylla serrata, Scylla olivacea*, and *Scylla tranquebarica*. The two morphological characters that are important in determining the species are frontal lobe spines and chelipeds [3]. Ikhwanuddin et al. [4] have studied the biological information as well as population features of mud crab in Malaysia at Sematan mangrove forest which is situated along coastal water. In the same study, two common mud crab species in the South China Sea managed to be found which are known as *S. tranquebarica* and *S. olivacea*. Mud crabs are commonly sold in many areas due to their delightful and good taste in soup making. Interestingly, mud crabs have been reported to exhibit the potential as an antioxidant and antimicrobial agents [5] despite their tasty meat and nutritional richness [6]. Elderly in Malaysia tend to consume mud crab soup as traditional remedy and folk medicine for the purpose of reducing the symptoms of dengue fever. Comprehensively, mud crabs are marine invertebrates that protect themselves against pathogen by solely relying on their innate immune system. Particularly, the defense system includes both humoral and cellular responses [7]. In addition, antimicrobial peptides present in the hemolymph of mud crab serve as humoral immunity, while antioxidants system benefits as the cellular response towards infectious diseases or pathogens [8]. The immune system of crustacean also plays a role when the organisms are exposed to abiotic stress or pollutions. Apart from that, it is reported that the immune system of mud crabs is also modulated based on the changes of environmental temperature and salinity [9].

On top of that, mud crabs have the benefits of biomarkers in the studies of environmental pollution to investigate the effect of pollutants in the environment [10]. Therefore, the objective of this review paper was to highlight the antioxidant and antimicrobial properties revealed in mud crabs from the genus of *Scylla* in order to discover its therapeutic applications and sustain the successive development of mud crabs in aquaculture industry.

2. Antioxidants Properties in Mud Crab

It is important to note that antioxidants are important in protecting cells. In relation to this, biological properties in aquatic resources from the ecosystem that are not yet exploited may offer many opportunities for the development of natural antioxidants in defense system. Surprisingly, a number of aquatic organisms are able to live in many contaminated areas due to the protective response to scavenge free radicals which is provided by the antioxidants defense system [11]. The mechanism of cellular defense system comprises of enzymatic and nonenzymatic antioxidants. Moreover, the inability of cells to be defended against reactive oxygen species (ROS) or reactive nitrogen species (RNS) is known as oxidative stress [12]. Particularly, oxidative stress tends to occur when the production of free radicals exceeds the removal capacity, thus resulting in excessive level of free radical intermediates [12]. In short, oxidative stress transpires when the imbalance between free radicals production and antioxidants defense exists. In this case, free radical is defined as a reactive molecule with unpaired electron in the outermost orbital which is capable of withstanding oxidation-reduction reactions. Specifically, it reacts with another molecule to produce a stable molecule or new free radical [13]. Meanwhile, the mechanism of cell injury is actively involved in the formation of free radicals which leads to structural alterations of protein, lipids, DNA, and RNA. It is important to understand that oxygen is the most abundant molecule in the cell which is very useful for biological life. However, excessive amount of oxygen may bring detrimental effects to the cells through the production of reactive oxygen species (ROS) such as oxide ($O_2^{\bullet}$), hydroperoxyl radical ($H_2O^{\bullet}$), hydrogen peroxide ($H_2O_2^{\bullet}$), and hydroxyl radical ($OH^{\bullet}$) [9]. In fact, ROS can damage cell via protein or DNA modification, membrane damage, protein tyrosine nitration, and RNA oxidation. Meanwhile, RNS is derived from nitrogen radical molecules such as peroxynitrite and nitric oxide which are very reactive and highly toxic to the cells that could negatively affect the biological system of cell. Several small antioxidant compounds such as reduced glutathione, ascorbic acid, uric acid, and carotenoids are the type of free radical scavengers that provide protection to the cells against oxidative stress [14]. A cascade of antioxidant enzymes, namely, superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR), and glutathione peroxidase (GPx), can further assist the cells to neutralize free radical damage [15]. On top of that, SOD acts as the first and important antioxidant enzyme to convert free radical superoxide ion (O_2^-) to oxygen (O_2) and further to hydrogen peroxide (H_2O_2) for the purpose of protecting the cells from injury induced by free radicals [15]. Furthermore, CAT efficiently converts H_2O_2 to water and molecular oxygen, in which it was found to be the key of antioxidant enzymes due to its capability to eliminate cytotoxic hydrogen peroxide and increase the survival of organisms. It is crucial to acknowledge that the role of GR is to catalyse the reduction of glutathione disulfide (GSSG) to sulfhydryl form glutathione (GSH) [16]. GPx is equally important because it possesses a biochemical function to reduce lipid hydroxides to their corresponding alcohols as well as to reduce free hydrogen peroxide to water molecules [17]. Recently, a study has been conducted to investigate the antioxidant properties in mud crab that are induced by lipopolysaccharides (LPS). Liu et al. [18] have reported the levels of CAT and SOD measured in hemocyte lysate in LPS challenged crab; *S. paramamosain* were increased. It is believed to be the response of antioxidant enzymes in balancing redox reactions and avoiding the damage of cells when a high production of ROS is detected after LPS induction is performed. In other crustacean, antioxidant status has also been investigated in the hemolymph of brachyuran crabs which is known as *Liagore rubromaculata* [19]. It was reported that the hemolymph of crabs *L. rubromaculata* had a maximum percentage scavenging activity of 2,2-diphenyl-1-picrylhydrazyl (DPPH), which was found to be 1.381% in male crab compared to 1.003% in female crab sample. This finding further suggests that a high scavenging activity illustrates the presence of natural antioxidants in the hemolymph of *L. rubromaculata*. Meanwhile, a study conducted by Duan et al. [20] found a significant increase of SOD activity in hepatopancreas of black tiger shrimp which is called *Penaeus monodon,* thus showing it could be induced in order to lower the concentration of ROS produced by desiccation stress. In regard to this, the determination of the total antioxidant status in the tissue of mud crab has been conducted by Sujeetha et al. [21] by performing two assays, free radical scavenging activity by DPPH and 2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid), (ABTS). The process required the samples to be taken from muscle tissue, hemolymph, and chitosan of *S. serrata* in order to be used for in vitro antioxidant assays. According to the results obtained, the muscle extract of mud crab of *S. serrata* had a maximum antioxidant activity with 49% inhibition in DPPH assay, including 69% inhibition in ABTS assay compared to chitosan and hemolymph. It was further revealed that the muscle extract of mud crab has the ability to exhibit a potent ability to scavenge the free radicals due to the content of antioxidants. It is crucial to acknowledge that the former assay was conducted based on the ability of antioxidants to donate its electron to neutralize DPPH radicals, while the latter assay is performed for the purpose of determining the antioxidant capacity based on the ability of antioxidants to scavenge ABTS radicals [22]. Moreover, several studies have managed to determine the activities of antioxidant enzyme, catalase, and the nonenzyme glutathione have in the crude tissue extract of *S. serrata* during its molting cycle [23]. Hence, the finding suggests that tissues of mud crab contain antioxidant reactions which are vital in molting considering the increase in metabolism activity and oxygen uptake. In regard to this, the molecular transcriptions of antioxidant enzymes were also performed to investigate the genes response towards oxidative stress. According to Fu et al. [24], the antioxidant enzymes system was completely developed by the green mud crab, *S. paramamosain,* when the expression levels of enzyme, namely, GPx, SOD, and CAT, are upregulated after LPS induction. In the same study, it was revealed that GPx is expressed in selected tissues and the level of expression tends to fluctuate during gonad development of *S. paramamosain*. In addition, the expression of GPx which is performed using real time polymerase chain reaction (PCR) was found to be higher in the testis and ovaries. Hence, this suggests that GPx plays an important role in protecting the reproductive tissues from oxidative stress resulted by the overproduction of radical oxygen species, ROS during oogenesis, and spermatogenesis. Apart from that, antioxidant enzymes are also crucial in crustaceans' immune response during environmental stress such as seasonal changes, pollutants, and salinity changes [20, 25]. Boudjema et al. [26] discovered that the activity of antioxidant enzyme, CAT, is elevated in brown mussels that are exposed to heavy metals pollutant, thus indicating the role of the enzyme as a potential biomarker of pollution. Furthermore, environmental salt stress seems to produce hypoxic condition that may lead to high production of hydrogen peroxide which could result in oxidative stress [9]. On top of that, several isoenzymes of SOD have been found in abdominal muscle, hepatopancreas, and gills of *S. serrata* which are subjected to various salinities and seasons [9]. The localisation pattern of SOD isoenzymes in the study was discovered to be different in all tissues, thus proposing that SOD isoenzymes possess different role against abiotic factors such as salinity and temperature change. In relation to this, the levels of CAT and SOD were observed to be significantly higher in ovary and testis of experimental crabs, *S. olivacea*. It happens particularly when they are exposed to cadmium nanoparticle compared to controls, which demonstrates that the two enzymes are actively involved in eliminating free radicals and maintaining the reproductive organs [11]. However, another study found that antioxidants in *S. serrata* that are exposed to polyaromatic hydrocarbons tend to be ineffective in protecting the cells against lipid peroxidation when the level of antioxidants activity decreases [27]. In addition, chitosan and its derivatives have been widely studied in marine life compared to hemolymph and muscle tissues, which reported the presence of antioxidant properties. According to the study conducted by Limam et al. [28], chitin and chitosan from shrimp, *Parapenaeus longirostris* managed to present the highest value of inhibition for peroxide in linoleic acid peroxidation, hence, suggesting the presence of antioxidant properties. The similar study expresses that chitosan from *Squilla mantis* by-products showed effective inhibition to lipid peroxidation. Moreover, antioxidant activities are reported to be involved with chitosan and its derivatives, particularly in the exoskeleton and carapace of mud crab shell [29, 30]. Hence, it is important to note that crab shell is made of polysaccharide which is chemically similar to plants cellulose. Meanwhile, Yen et al. [29] explained in their study that chitosan from crab shell is a good scavenger on hydroxyl radicals and has the ability to act as a chelating agent. In this case, scavenging activity of chitosan is ascribed based on the presence of free amino group that reacts with free radicals in order to form a stable macromolecular radical [31]. In a study performed by Sarbon et al. [30], the process involved the extraction of chitosan from the mud crab shell of *S. olivacea*, followed by the characterization based on colour, moisture, ash, and degree of deacetylation, and then its comparison with commercial chitosan that is purchased from the Sigma Aldrich Company. Interestingly, the antioxidant properties of chitosan of the mud crab, *S. olivacea,* tend to appear when the extracted chitosan displays a reducing power activity in comparison to commercial chitosan. Additionally, chitosan and chitin of the *S. tranquebarica* were also extracted, analysed, and compared with the commercial standard [32]. Therefore, the study on chitosan and its derivatives has been gaining positive momentum considering that these compounds seem to have wide potential applications.

3. Antimicrobial Peptides in Mud Crabs

Antimicrobial peptides (AMPs) are described as a group of molecules of the host immune response that are vital in exhibiting antimicrobial activity against the invasion of intruding microorganisms. In particular, AMPs in marine organisms have been drawing excellent attention from the scientists since 1988 due to their roles and properties in developing promising antibacterial agents. The earliest AMP that was characterized in crab by Nakamura et al. [46] includes tachyplesin, which is a peptide derived from a combination of 18 amino acids that was isolated from the hemocytes of the Japanese horseshoe crab, *Tachypleus tridentatus*. The AMPs are relatively small (mostly less than 10 kDA) which are comprised of different structure, length, and sequence. Another crucial point to take note is that fish and marine invertebrates in aquatic system are largely exposed to various bacterial strains [47]. Hence, AMPs play their role in host innate immunity as a response to combat infections and diseases while living in that particular type of habitat. Other than that, it is expressed that AMPs have the ability to exhibit wide activities against bacteria, fungi, protozoa, yeasts, and viruses [48]. Over the past several years, numerous counts of antimicrobial peptides have been found and reported in crabs. In the same token, Schnapp et al. [49] have purified another AMP from the hemocytes of the shore crab *Carcinus maenas* which was known as a proline peptide of 6.5 kDa. In 2014, a research performed by Priya et al. [19] managed to find the hemolymph of female crabs *Liagore rubromaculata* which possibly contain the antibiotic potential against *Proteus vulgaris* and *Enterobacter faecalis*, provided that a maximum zone of inhibition is achieved. Moreover, Sivaperumal et al. [50] have found another peptide from crab haemolymph of *Ocypode macrocera* that displayed double properties, antimicrobial activity, and antioxidant activity. The purification and characterization of the new AMPs in marine organisms are important in order to find new solution to the existence of bacterial resistances towards conventional antibiotics [51]. Recently, the antibacterial activities of mud crab from the genus *Scylla* have been intensively studied and reported in many researches [42, 47, 51–53]. Furthermore,

Table 1: The antibacterial peptides that have been identified from mud crab of the genus *Scylla*.

S. number	Antibacterial peptides	Species	Reference
1	Scygonadin (an anionic AMP)	*S. serrata*	Wang et al., 2006, [33]
2	ALF (ALF*Sp1*)	*S. paramamosain*	Imjongjirak et al., 2007, [34]
3	Crustin (Crus*Sp*)	*S. paramamosain*	Imjongjirak et al., 2009, [35]
4	SSAP (*Scylla serrata* antimicrobial protein)	*S. serrata*	Yedery and Reddy, 2009, [36]
5	ALF isoform (Sc-ALF) & crustin (Sc-crustin)	*S. serrata*	Afsal et al., 2011, [37]
6	ALF (ALF*Sp2*)	*S. paramamosain*	Imjongjirak et al., 2011, [38]
7	ALF (SpALF3)	*S. paramamosain*	Liu et al., 2012, [39]
8	ALF (SpALF4)	*S. paramamosain*	Zhu et al., 2014, [40]
9	ALF (SpALF5)	*S. paramamosain*	Sun et al., 2015, [41]
10	Ab-Hcy (antibacterial hemocyanin)	*S. serrata*	Velayutham and Munusamy, 2016, [42]
11	Sphistin (histone derived peptide)	*S. paramamosain*	Chen et al., 2015, [43]
12	SCY2 (Scygonadin-2)	*S. paramamosain*	Qiao et al., 2016, [44]
13	SpHyastatin (a cationic AMP)	*S. paramamosain*	Shan et al., 2016, [45]

in supporting the antimicrobial activity in mud crab from earlier studies, Hoq et al. [52] have partially purified the antimicrobial protein from the induced hemolymph of *S. serrata*. In this case, hemolymph refers to a fluid that circulates in the interior parts of crabs [53], with copper containing hemocyanins as the major protein component of hemolymph in crustaceans. In a more recent study, the humoral immune function of hemocyanins that has been isolated from the serum of mud crab, *S. serrata* was characterized by Velayutham and Munusamy [42]. It has been reported that hemocyanin possesses the immune function for the purpose of preventing possible disease in aquaculture industry. Meanwhile, hemolymph tends to show significant effects on the antibacterial activity against different strains of marine or nonmarine Gram-positive and Gram-negative bacteria. In the study by Hoq et al. [52], hemolymph of *S. serrata* was induced by the injection of *Escherichia coli* in order to investigate the presence of inducible and constitutive antibacterial proteins. The findings show that the induced hemolymph of mud crab determined by disk diffusion technique has been found to possess a significant antibacterial activity when tested against *Bacillus subtilis, Bacillus cereus, Bacillus megaterium, Staphylococcus aureus*, and *Streptococcus pyogenes*. Contrastingly, the noninduced hemolymph was discovered to have no antimicrobial activity when tested against microorganisms, which possibly indicates that the antibacterial activity is only active to other bacteria that are not tested in the study. In another study, the seminal plasma obtained from the mid vas deferens of male mud crabs, *S. serrata,* has been tested for antibacterial activity towards a number of commonly occurred bacteria such as *Cytophaga* sp., *Vibrio furnissii, Alteromonas* sp., *Flexibacter* sp., and *Pseudomonas* sp. [54]. Following it, a series of dilution was conducted in the research for the purpose of testing it on the growth of the five strains of bacteria. All concentration of seminal plasma was discovered to possess an inhibition action on the growth of three strains of bacteria which include *Cytophaga* sp., *Vibrio furnissii,* and *Alteromonas* sp. In regard to this, *Cytophaga* sp. was found to be the most sensitive strain to the seminal plasma because the inhibition zone was presented in every series of dilution. However, it was also discovered that the seminal plasma of mud crab does not possess inhibition action for the growth of *Flexibacter* sp. and *Pseudomonas* sp. In spite of that, approximately 20 kDa of protein in the seminal plasma of *S. serrata* that is exhibited for the antibacterial activity was partially purified by gel permeation chromatography on a Sephadex G-200 column [54]. To date, published literature on the antimicrobial activities of the two mud crab species known as *S. olivacea* and *S. tranquebarica* is scanty with no clarification of antimicrobial peptides. However, Ramalingam et al. [55] have studied the serum effectiveness of *S. tranquebarica* towards bacteria of *Pseudomonas aeruginosa* particularly in two forms, namely, live form and heat killed form. In the study, antibacterial assay was performed by disc diffusion with the result showing that the antibacterial activity towards *P. aeruginosa* was only discernible after 48 hours in heat killed group, while no antibacterial activity was present in live group which suggests that the bacterial population can possibly inhibit the synthesis of antibacterial peptides in the serum. Therefore, more studies are needed to further investigate the antimicrobial peptides in *S. olivacea* and *S. tranquebarica*. In addition, antilipopolysaccharide factor, ALF, is another small group of AMPs with a broad antimicrobial activity towards bacteria, fungi, and parasites which has the ability to bind and neutralize the lipopolysaccharides (LPS) [34, 40]. Collective information on antibacterial peptides from mud crab, genus *Scylla,* has been identified based on the recent published literature presented in Table 1. In 2006, the anionic AMP known as scygonadin with the isoelectric pH, pI, of 6.09 and 11 kDa was extracted from seminal plasma of the gonads of *S. serrata* [33]. The protein was purified via ion-exchange chromatography and reverse phase chromatography, while the molecular weight of the protein was determined through Tricine SDS-PAGE analysis. The antimicrobial activity of scygonadin was performed against *Aeromonas hydrophila* and *Micrococcus luteus* whereby it was discovered to exhibit antibacterial activity against the Gram-positive bacterium, *Micrococcus luteus*. Later, the scygonadin was cloned from the gonads of *S. serrata* through the methods of degenerated reverse transcriptase polymerase chain reaction, RT-PCR, as well as rapid amplification of cDNA ends (RACE) for peptide sequencing and genomic analysis [56]. Imjongjirak et al. [34] successfully cloned and characterized *S. paramamosain*, a full length cDNAs encoding for the small proteins of ALF, ALF*Sp1* which consists of 24 amino acid residues with molecular weight of 11.18 kDa. The ALF*Sp1* protein concentration in the range of 0.1 to 50 μM has shown the ability to inhibit the growth of Gram-positive and Gram-negative bacteria when tested using minimal inhibition concentration, MIC, and bactericidal assay in the study. The results of RT-PCR obtained from the same study also demonstrated that the ALF*Sp1* transcript was highly expressed in hemocytes, intestines, and muscles of *S. paramamosain* but failed to be detected in eyestalk. In relation to this, second isoform of ALF known as ALF*Sp2*, from *S. paramamosain,* was described and characterized by Imjongjirak and his colleagues in 2011 [38]. ALF*Sp2* has a fair distinction from ALF*Sp1* based on amino acid sequence which is highly expressed in hemocytes, gill, and intestine. Hence, this suggests that ALF protein in crabs was expressed in various tissues, thus contributing to the defense of crab against bacterial infection when exposed to bacteria in the environment and systemic infection [38]. Furthermore, a protein of 11 kDa weight known as SSAP (*Scylla serrata* antimicrobial protein) was found by Yedery and Reddy [36]. In this case, the SSAP protein was expressed in hemocytes, gills, and reproductive tract of male and female mud crabs. The characteristics give the idea that SSAP could be the other variant of scygonadin, the former AMP found in *S. serrata* due to the fact that these two proteins are 94% similar in sequence homology. However, these two proteins have slightly different mass and pI with SSAP having the mass of 11435 Da and pI of 5.77. The purified SSAP displayed higher antimicrobial activity against Gram-negative bacteria which include *E. coli* and *P. aeruginosa* compared to Gram-positive bacteria when tested via two-layer radial diffusion method. Another finding that managed to be achieved about the antimicrobial peptide of mud crab involves the identification and characterization of crustin, Crus*Sp,* from the hemocyte of mud crab, *S. paramamosain,* which is accomplished through an expressed sequence tag (EST) and rapid amplification cDNA end (RACE) approaches [35]. The recombinant Crus*Sp* was produced to assess its antimicrobial activities against Gram-negative bacteria, with the indication that Crus*Sp* may be involved in the innate immunity of *S. paramamosain*. Interestingly, Afsal et al. [37] successfully identified a new isoform of ALF, Sc-ALF, and first crustin, Sc-crustin, from the haemocyte of the *S. serrata*. On top of that, the nucleotides sequence of Sc-ALF was found to be 100% similar to ALF in S. *paramamosain*, which is almost similar to several AMP from other decapods crustaceans when tested with BLAST analysis. The mature peptide of Sc-ALF has a molecular weight of 11.17 kDa and its pI was estimated to be 9.95. Meanwhile, Sc-crustin was composed of 433 base pairs in length and 144 amino acid residues with an estimated molecular weight of 10.24 kDa and pI of 8.76. In relation to this, another AMP known as SpALF3 was identified by Liu's group which further demonstrated that both SpALF1 (former name was ALF*Sp1*) and SpALF3 tend to exhibit strong antibacterial activity [39]. Moreover, a new ALF which was known as SpALF4 with low isoelectric point (pI) for the LPS binding domain managed to be identified [40]. Specifically, SpALF4 was identified and extracted from the mud crab, *S. paramamosain*. The new ALF was different from the former ALFs due to its low pI for mature peptide which was 6.93, which demonstrated antibacterial and antifungal activities. Sun et al. [41] have isolated SpALF5 from the hemocytes of *S. paramamosain* and the protein encoded for 125 amino acids. Apart from that, antibacterial activity of histones from hemolymph of mud crab *S. paramamosain* has been discovered by Chen et al. [43]. In this case, the histone derived peptide was designed as sphistin in order to function as AMP molecules when the antimicrobial activity is exerted against aquatic pathogens such as *Aeromonas hydrophila, Pseudomonas fluorescens*, and *Pseudomonas stutzeri*. AMP also plays a role in reproductive immune function of mud crabs as described by Qiao et al. [44], whereby a new AMP known as SCY2 was found which is dominantly expressed in the ejaculatory duct of male crabs. Amino acid sequences of SCY2 were 65.08% similar to the previous scygonadin found in seminal plasma of *S. serrata*. In a more recent finding achieved by Shan et al. [45], the new cationic AMP, SpHyastatin, in the hemocytes of mud crab, *S. paramamosain,* managed to be discovered. Interestingly, the recombinant product of SpHyastatin tends to exert different mechanisms to kill different bacteria such as *Staphylococcus aureus, Aeromonas hydrophila*, and *Pseudomonas fluorescens*.

4. Conclusion

Mud crabs have been discovered to possess various antioxidant and antimicrobial properties which allow them to protect themselves from oxidative stress or aquatic pathogens in their habitat. Moreover, knowledge on the endogenous antioxidant and antimicrobial properties in mud crabs is important for therapeutic benefits in biomedical area and aquaculture field. Future research on the potential applications of antimicrobial peptides such as anticancer, anti-inflammatory, or antiviral agent should be conducted. This includes possible applications of some AMPs to be applied in pharmaceutical, cosmetics, and other industries.

Conflicts of Interest

The authors have declared that there are no conflicts of interest regarding the publication of this article.

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