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A REVIEW ON QUORUM SENSING INHIBITORS

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ABSTRACT: Antibiotic is the powerful invention of science to damage bacterial infections. But nowadays, the use of careless increasing doses of this antibiotic has led to increasing the resistant power of enemy bacteria. Bacteria are caused by many infectious diseases by proliferation within quorum sensing (QS) mediated biofilms. Quorum sensing can develop microbial pathogenic traits, including biofilm formation. Try to smash biofilms have led the identification of bioactive molecules evolved by prokaryotes and eukaryotes. The activity of these bioactive molecules is done by quenching the QS systems. For this reason, we need to inhibit quorum sensing, which may be done by various types of inhibitors called quorum sensing inhibitors (QSI). Synthetic and natural QSIs plays a vital role to inhibit QS. In this review, some examples of QS inhibitors like synthetic and natural based QS inhibitors are highlighted. This review is also focused on the inhibition of QS mechanisms and the application of QSI in various fields.

INTRODUCTION: Antibiotics which discovered at the beginning of the twentieth century gave release for all human beings from various live threatening diseases [1]. But after the 20th century, excessive use of antibiotics causes several problems like emergences of multiple drug-resistant bacterial strains [2]. About 16 million people died because of this infectious diseases [3, 4]. It is useful to mention that at least 65% of all these infectious diseases are linked to bacterial communities, which grow an enormous number by forming biofilms [5]. It is seen that bacteria having special structure have high resistant power to antibiotics than planktonic counterparts [6, 7].

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In biofilms, quorum sensing control bacterial behavior and express intensive genes in a cell-dependent manner [8, 9, 10, 11]. If some efforts are applied to disrupt the biofilms, then it is easy to identify the molecules produced by eukaryotes and prokaryotes with ability to quench the QS system, known as quorum quenching (QQ) [3, 4, 12-21]. It can be noted that some synthetic compounds have very much effective power to regulate QS [22-27].

Quorum Sensing (QS): Bacteria behave as social organisms that interact with each other and their surroundings, *i.e.* they can coordinate gene expression with their population density. This process is termed quorum sensing (QS) [28]. It is known as a cell density-dependent process (cell to cell communication) by which cells measure the population density and trigger proper responses [29]. Hastings *et al.*, in 1977, reported the first QS phenomenon in the marine bacterium *Vibrio fischeri* [30]. Auto-inducers as specific signaling molecules play a vital role in QS and have three

different classes based on their specific structures and functions. The main QS signal molecules are acyl-homoserine lactones, AIPs (auto-inducing peptides) [31]. Gram-negative bacteria use AHLs as signaling molecules, and gram-positive bacteria produce AIPs as auto-inducers [32]. Compounds with inhibiting power have been applied to preserve food, preventing biofilm growth and used for bacterial infections treatment. But when the growth of bacteria is blocked, they are in the high pressure to develop resistance. So we require to identify a suitable drug target [33]. QS enables bacteria to make collective decisions for a specific set of genes. Acyl homoserine lactones (AHLs) are the most signal molecules in gram-negative bacteria, synthesized by the LuxI homolog proteins [34].

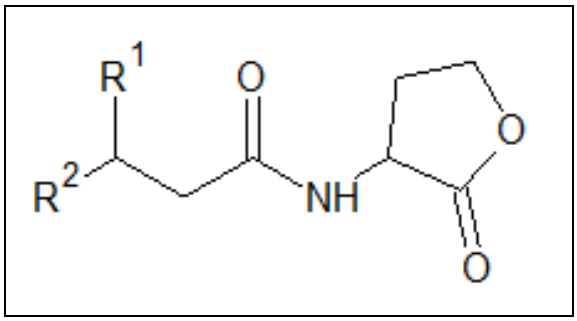

FIG. 1: BASIC STRUCTURE OF THE AHL SIGNAL MOLECULE WHERE R^1 = H, OH, OR O AND R^2 = C1–C18 [28]

Hypothetically AHL analogous may act as competitive inhibitors, and various QSIs were designed based upon this. In different species, the AHLs structures vary, but they have the main features of a lactonized homoserine ring and a hydrocarbon through amide bond [35].

Synergism between QSIs and Antibiotics: There are a large number of bacteria that develop multiple drug resistance to antibiotics. The effect is best observed in the biofilms than the free-living counterparts [36]. It has been suggested that disrupt biofilms make the bacteria efficient even in low concentration of antibiotics [37]. The synergism between QSI and antibiotics is observed in *Staphylococcus* pathogenesis in which RNAIII-inhibiting peptide improve the clinically used antibiotics [38, 39, 40, 41, 42]. Ampicillin and baicalein antibiotics showed this synergism against *P. aeruginosa* [43]. Some QSI likes furanone C30, penicillic acid, and patulin increase the susceptibility of *P. aeruginosa* to tobramycin [4, 5, 44, 46]. Tobramycin (antibiotic) with baicalin hydrate (QSI) reduces the microbial population load in lungs [47].

Examples of QS Inhibitors:

Synthetic QSIs: AHL scaffold is developed by three procedures: substitution and alternative introduction in the acyl side chain to maintain the lactone ring, substitutive and alternative introduction in the lactone ring to leave the acyl side chain unchanged and finally extensive modifications of both acyl side chain and lactone ring [28].

Persson *et al.*, created analogs able to block expression in both LuxR- and LasR-controlled QS reporters when he introduces sulfur in the acyl side chain instead of C-3 atom. Another QSI compounds are found in 3-oxo-C6 HSL/LuxR-controlled system by substitute the aryl group at the end of the side chain at least. The antagonistic effect is lost when the size of the substituent is increased beyond that of a phenyl group. Aryl compounds interact with aromatic amino acid residues in LuxR protein to prevent normal activation, if the difference in size of the aryl substituents and the cyclic alkyls is low [48]. Aryl AHLs become very effective as QSI when a sulphonyl group replaces the C-1 carbonyl group of the side chain [49]. AHL analogs interact with the receptor proteins, because of extra moieties on the C-3 ring atom. But they function as agonists [50].

Natural QSIs: Plants and fungi are natural sources from which QSI compounds isolate. As QS bacteria have co-existed with both fungi and plants for many years, it may be expected that some of them produce compounds of QSI to reduce colonize of pathogenic capability, compete and transited bacteria [28]. There are a large number of organisms, which coexist in natural ecosystems. Bacteria can be communicated to co-operate among them and compete with others [51].

Prokaryotic QSI: Table 1 shows various organisms that produce QQ enzymes: (i) Actinobacteria- *Streptomyces* and *Rhodococcus*, (ii) Firmicutes- *Bacillus*, *Arthrobacter*, and *Oceanobacillus* (iii) Bacteroidetes -*Tenacibaculum*, (iv) Cyanobacteria - *Anabaena*, (v) Proteobacteria - *Comomonas, Halomonas, P. aeruginosa, Ralstonia Acinetobacter, Variovorax paradaoxus, A.*

tumefaciens, *Alteromonas*, *Klebsiella pneumonia*, *Hyphomonas* and *Stappia* [16, 52-57]. Enzymes of four types decompose QS signals- AHL-lactonases, decarboxylases hydrolyze Lactone ring. But the acyl side chain is cleaved by AHL-acylase and deaminase. AHL- acylase present in *P. aeruginosa* (PAO1), *Ralstonia sp.* (XJ12B) **Table 1** share identity around 39% at the level of amino acid [52, 58, 59]. Produce from *Streptomyces sp.*, AHL-acylase degradation occurs at acyl chain having more than containing six carbon atoms. That is why it is specific [60]. *B. subtilis*, *B. cereus*, *B. thuringiens* is known as *Bacillus spp.* [54, 61, 62, 63, 64] produce AHL-lactones are sharing of 90% identity at their level of peptide [52] **Table 2**. AHL- lactones from *A. tumefaciens* share about 30-50% identity of their amino acid [52].

TABLE1: BACTERIAL ENZYMES AS QUORUM SENSING INHIBITORS [74]

Source of quorum sensing inhibitor	Enzyme	The degraded quorum-sensing signal	Reference
Acinetobacter sp. strain C1010	Lactonase	AHLs	65
Agrobacterium tumefaciens	AHL-Lactonase	AHLs	66-68
Arthrobacter sp. IBN110	AHL-Lactonase	AHLs	55
Alteromonas sp. strain 168	Acylase	C4HSL and 3OC12-HSL	56
Bacillus sp. strain 240B1	Lactonase	AHLs	62
Bacillus thuringiensis	Lactonase	AHLs	69
Burkholderia strain GG4	AHL -oxidoreductase	3OC6HSL	70
Bacillus megaterium	AHL-oxidase	C4HSL and 3OC12HSL	71-72
Bacillus circulans strain 24	Different from Lactonase	C4HSL and 3OC12HSL	56
Bacillus pumilus S8-07	AHL-acylase	3OC12HSL	73
Halomonas sp. strain 33	Lactonase	AHLs	56
Hyphamonas sp. DG895	Acylase/Lactonase	C4HSL and 3OC12-HSL	56
Oceanobacillus strains 30, 172, and 97-2	Lactonase	AHLs	56
Pseudomonas aeruginosa PAO1	AHL-acylase	Long chain AHLs	58
Ralstonia sp. XJ12B	AHL-acylase	Long-chain AHLs	59
Stappiaa sp. strains 5, 176 and 97-1	Lactonase	AHLs	56
Tenacibaculum discolor strain 20J	Acylase/Lactonase	AHLs	56

Animal Based: Generally, in mice, rats, and zebrafish, QQ enzymes are found. Acylase was effective moderately to reduce the formation of biofilm by *Pseudomonas putida* and *A. hydrophila* [75]. Mammalian paraoxonas (PON), related to drug metabolism, detoxification to nerve agents enable hydrolytic activity on esters and lactones [52, 76].

In mammals like a mouse, goat, bovine horse, and rabbit, QS signal- 3OC12HSL inactivate in serum [77]. Foods like turkey patties, breast of chicken, cheeses reduce 84–99% AI-2 activity [78]. Hall *et al.*, designed PP7 virus-like particle and alleviated the animal's infection [79]. Moutan Cortex disrupted the QS system of *Pseudomonas fluorescens*, which gave the freshness of fishery products [80].

Plant-Based QSI: For similarities in chemical structure to QS signals (AHL) and the ability to degrade signal receptor (LasR/ LuxR), plant extracts can act as QSI [81, 82]. A promoter GABA (γ-aminobutyric acid) decompose AHL signal OHC8HSL by the lactonase of *A. tumefaciens* [83]. Pyrogallol from *Emblica officinalis* (medicinal plant), exhibits antagonistic property against AI-2 [84]. *Curcuma longa,* which produces curcumin inhibit *P. aeruginosa* [85]. Zhao *et al.* showed that the pharmaceutical composition of herbal organisms has the potential to treat bacterial infections with low resistance [86].

Marine Organism Based QSI: *Delisea pulchra* produces halogenated furanone that inhibits QS mediated activity in bacteria. It is done when they compete with consanguineous AHL signal [88-92]. Bromoperoxidase enzymes may act like QSI to deactivate the signal of AHL (3OC6HSL) by oxidation [93]. In *P. aeruginosa*, 8 -epi-malygamide and malyngamide C are inhibited the QS activity [94].

Fungus Based QSI: Secondary metabolites like antibiotics are produced by fungi *Penicillium spp*. which produced penicillin controlled bacterial infections [1]. Around 33 type *Penicillium spp*. will produced patulin and penicillin as QSI [45]. Fungi decompose association of C6HSL and 3OC6HSL

with rhizosphere plant through lactonases activity [95]. Natural pigment from *Auricularia auricular* inhibits production of violacein in *C. violaceum* [96].

Antibody-Based QSI: Among eukaryotes, antibodies generated from mammal's immune system have a response to allergen [81].

TABLE2: QSI POTENTIAL OF THE TESTED PLANT EXTRACTS [87]

Plant	Part used	Anti-QS zone (mm)	Anti- QS potential
Anethum graveolens	Fruits	-	-
Cucumis melo	Seeds	-	-
Carum carvi	Fruits	-	-
Citrus sinensis	Seeds	20	++
Pimpinella anisum	Fruits	-	-
Foeniculum vulgrae	Fruits	-	-
Trigonella foenumgraecum	Seeds	-	-
Coriandrum sativum	Fruits	10	++
Laurus nobilis	Leaves	10	++
Psidium guajava	Leaves	3	+
Allium cepa	Outer scales	20	++
Eugina aromatic	Flowers	-	-
Mentha longifolia	Aerial part	5	+
Elettaria cardamomum	Seeds	10	++
Senna italic	Aerial part	-	-
Valantia hispida	Aerial part	-	-
Tephrosia purpurea	Aerial part	-	-
Teucrium polium	Aerial part	-	-
Commophora molmol	Bark	-	-
Tribulusa rabicus	Aerial part	-	-
Allium sativa (positive control)	Bulbs	10	++

+: Moderate anti quorum sensing activity, ++: Potent anti quorum sensing activity

Antibody XYD-11G2 has the ability to degrade 3OC12HSL of *P. aeruginosa* [97].

QS Inhibition Mechanism: Most of the QS inhibitors working principle is based on the following strategies: (a) QS signals degradation, (b) Biosynthesis of inhibited QS signal, (c) Detected QS signal inhibition, and (d) Antibiotics as QS inhibitors [98].

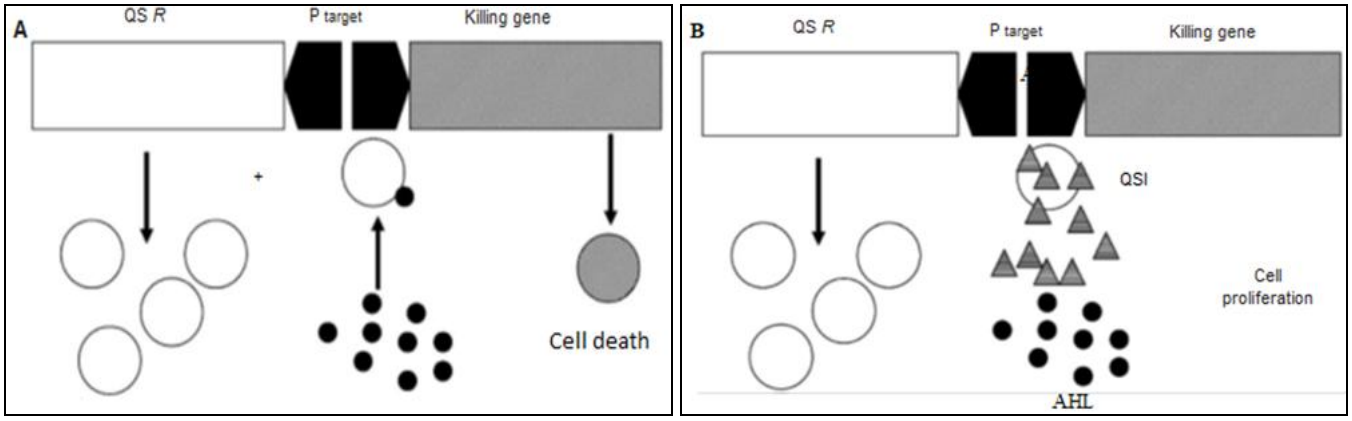

FIG. 2: LAYOUT OF THE QSIS SCREENING SYSTEMS: (A) An AHL receptor/response regulator is activated by exogenously supplied AHL. The activated LuxR homolog (QS R) upregulates expression from a QS-regulated promoter (PTarget) which controls the expression of a gene (killing gene) encoding a toxic protein leading to growth arrest or cell death. (B) If a QSI compound is present, the reception of the AHL signal is blocked, and expression of the killing gene is prevented, allowing for the growth of the screening bacterium [4].

QS Signals Degradation: QS signal may be degraded either by non-enzymatically or enzymatically. Three types of enzymes targeted the AHL signals. AHL-lactonase hydrolyzed the ester bond of the homoserine lactones ring in AHL[53, 98]. Lactonase from the gene aiiA of *Bacillus* sp. 240B1 inactivate AHL [99]. QS Signals have been degraded by acylase that also degraded AHL and forms 3-

oxodecanoic acid and homoserine lactone (HSL) [59]. The third class of enzyme named as oxidoreductase causes AHL degradation. The bpib09 enzyme can deactivate the 3-oxo C-12 homoserine lactone (3OC12HSL) [100]. Catalytic antibodies will also hydrolyze AHL signal [101].

Biosynthesis of Inhibited QS Signal: AHL production may be suppressed theoretically by one of the mechanism: acyl-ACP generation obstructing, SAM biosynthesis hampering, or inactivation of synthase enzyme [98]. Enzyme FabI can catalyze the final step of biosynthesis of acyl-ACP, *i.e*., to provide acyl chain for biosynthesis of AHL [98]. Triclosan can lower the lactone production [102]. MTAN will produced both AHL and AI-2 auto-inducers directly [98]. Anthranilate analog in *P. aeruginosa* may inhibit PQS production [103]. Recently, Ishii *et al.,* examined that quench *S. mutans* QS can inhibit the peptidase activity of Com A cassettes [104].

Detected QS Signal Inhibition: Non-productive signal-receptor complex inhibits the QS signal [98]. QS Probes are developed with the help of crystal structures that target LasR. Two isothiocyanate-based probes such as Itc-11 and Itc-12 covalently modify the nucleophilic cysteine-containing a ligand-binding pocket of LasR, and thereby inhibit QS [105].

Antibiotics as QS Inhibitors: The alternative target behavior of antibiotics found in some species, are suggested by evidence [98]. There is an indication of the reduced expression of intensive *P. aeruginosa* factors, decreased making of exotoxin A, elastase, proteases, DNase, leukocidin, and phospholipase C without inhibiting the growing *P. aeruginosa* [98, 106, 107].

QS Inhibitors from Endophytic Bacteria: There are many known bacteria which coordinate with each other's behavior and interact through quorum sensing. Endophytic bacteria behave as biocontrol agents. The QQ activity of endophytic bacteria (*Bacillus megaterium* strain B4, *Bacillus sp.* strain B3, *Bacillus sp.* strain B11 and *Brevibacillus borstelensis* strain B8) unbounded from plant of *Cannabis sativa* L. are inquired by Kusari *et al*. [100] Endophytic bacteria like *Bacillus sp.* will break up cell to cell QS signal in gram-negative *Chromobacterium violaceum* (DSM 30191) [108]. The endophytic *B. amyloliquefaciens* coming from poplar tree has its antagonist activity to *B. dothidea* [109].

Biotechnological Applications:

Aquaculture: Aquaculture, a well establish food industry, is significantly affected by disease outbreaks [110]. *Brachionus plicatilis*, which is valuable and indispensable as food, rotifer has its important for the aquaculture industry. Pathogens such as *Vibrio sp*., *Aeromonas sp*., and *Pseudomonas sp*. influence fish larvae and when used as feed cause detrimental effects [111]. Synthetic and natural brominated furanone has protected gnotobiotic sea shrimp from pathogenic of *Artemia sanfranciscana*. *Vibrio spp*. has a very effective application of QSI in the field of aquaculture. Kojic acid from *Aspergillus sp.* formless into non-toxic paint for regulating bacteria and diatoms has also been biotechnological application [112]. These will be preserved food and increase the safety of food [20, 113, 114].

Industrial Applications:

A. Waste Water Treatment: Membrane bioreactor is used as a wastewater treatment technology for reclamation and desalination of brackish. It will develop a pressure of transmembrane, caused permeability, and results costly in higher treatment [75]. *A. hydrophila* and *P. putida* form these types of biofilms [115].

B. Biotransformation: Like different molecules as QSIs, synthetic biology has better control over QS based bacterial biofilms without any external supervision. For chemical transformations, biofilms behave as important platforms in biorefineries. The disperser cells had 14% slower growth rate compared to the initial colonizers.

But they had ability than the planktonic cells to produce a 14-fold higher amount of the cognate QS signal molecule (3OC12HSL). *E. coli*, as an industrial workhorse, produce therapeutic proteins due to its rapid growth and high-yield of product [116]. There is a risk of contamination of the biotransformation reactors, which lead to huge economic losses. It is based on the information that (i) *E. coli* can produce indole, and (ii) indole and its derivatives can reduce the virulence of *P.*

aeruginosa, the impact of indole was evaluated in the mixed cultures [117, 118].

Plant Cultivation: Epiphytic bacteria, the cognate QS signal molecule induced premature induction of QS expression. It resulted in the compression of swarming motility and disease on tobacco plants [119, 120]. For these unique characteristics, epiphytic bacteria has advantages for controlling diseases. *M. testaceum*, AHL-degrading bacterium which occurs naturally on the surface of potato leaf can protect the plant from bacterial pathogens like *P. carotovorum*, which causes soft rot disease [121].

Transgenic plants produced by introduction of lactonase into tobacco and potato plants and Aiia enzyme in *E. carotovora* reduced pathogenicity towards, tobacco, Chinese cabbage, cauliflower and potato plants [53, 62]. *M. tranculata* and *Pisum sativum* plants deflate QS mimics in response to bacterial infections [122].

Animals: Transgenic *Drosophila* harboring human paraoxonases 1 reduce the lethality induced by *P. aeruginosa* pathogen. It was seen that PON1 protect files from bacteria. Discovery of human–pathogen interaction through QQ studies provides therapeutic modalities for infection/inflammation and cardiovascular disease [123].

Human Health: Adenosine plays an important role to regulate the secretion of electrolytes, regulate down of inflammation, disrupt epithelial cells to enable *Bacillus anthracis* and *S. aureus* to release phagocytic activity [124]. By repressing the iron acquisition, adenosine has an important role for bacterial growth [125]. QS Signal of *P. aeruginosa* (3-OC12HSL) is inhibited breast cancer cell lines of human body [126]. This has been proposed that synthetic AHL homologs may be exploited as QSIs [127].

CONCLUSION: Our future finding will be the treating of the largest number of medicinal plants as a natural source of quorum sensing inhibitors which will control the unfavorable interaction of these QSIs with our human body. Nowadays, the QSIs are used as inhibitors basically on the basis of experimental observations with trial and error method. In this regard, if we employ the DFT calculations in association with other drug like parameters obtained from theoretical calculations on these QSIs, we will be able to synthesis more specific QSIs which will act as a better drug in a very short time and at low cost. This study has enlarged the scope of producing more specific and effective drugs for Quorum Sensing.

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REFERENCES:

1. Kalia VC, Rani A, Lal S, Cheema S and Raut CP: Combing databases reveals potential antibiotic producers. Expert Opin Drug Discov 2007; 2(2): 11-24.
2. Ciofu O, Giwercman B, Pedersen SS and Høiby N: Development of antibiotic resistance in *P. aeruginosa* during two decades of antipseudomonal treatment at the Danish CF Center. APMIS 1994; 102: 674-80.
3. Bjarnsholt T, Jensen PØ, Rasmussen TB, Christophersen L, Calum H and Hentzer M: Garlic blocks quorum sensing and promotes rapid clearing of pulmonary *Pseudomonas aeruginosa* infections. Microbiology 2005b; 151: 3873-80.
4. Rasmussen TB, Bjarnsholt T, Skindersoe ME, Hentzer M, Kristoffersen P and Köte M: Screening for quorum-sensing inhibitors (QSI) by use of a novel genetic system, the QSI selector. J Bacteriol 2005a; 187: 1799-14.
5. Lewis K: Persister cells, dormancy and infectious disease: Nat Rev Microbiol 2007; 5: 48-56.
6. Koch C and Høiby N: Diagnosis and treatment of cystic fibrosis. Respiration 2000; 67: 239-47.
7. Olson ME, Ceri H, Morck DW, Buret AG and Read RR: Biofilm bacteria: formation and comparative susceptibility to antibiotics. Can J Vet Res 2002; 66: 86-92.
8. Bhargava N, Sharma P and Capalash N: Quorum sensing in *Acinetobacter*: an emerging pathogen. Crit Rev Microbiol 2010; 36: 349-60.
9. Miller MB and Bassler BL: Quorum sensing in bacteria. Annu Rev Microbiol 2001; 55: 165-99.
10. Romero M, Acuña L and Otero A: Patents on quorum quenching: interfering with bacterial communication as a strategy to fight infections. Recent Pat Biotechnol 2012a; 6: 2-12.
11. Waters CM and Bassler BL: Quorum sensing: cell-to-cell communication in bacteria. Annu Rev Cell Dev Biol 2005; 21: 319-46.
12. Choo JH, Rukayadi Y and Hwang JK: Inhibition of bacterial quorum sensing by vanilla extract. Lett Appl Microbiol 2006; 42: 637-41.
13. de Nys R, Givskov M, Kumar N, Kjelleberg S and Steinberg PD: Furanones. Prog Mol Subcell Biol 2006; 42: 55-86.
14. Huma N, Shankar P, Kushwah J, Bhushan A, Joshi J and Mukherjee T: Diversity and polymorphism in AHL-lactonase gene (aiiA) of Bacillus. J Microbiol Biotechnol 2011; 21: 1001-11.

15. Kalia VC and Purohit HJ: Quenching the quorum sensing system: potential antibacterial drug targets. Crit Rev Microbiol 2011; 37: 121-40.
16. Kalia VC, Raju SC and Purohit HJ: Genomic analysis reveals versatile organisms for quorum quenching enzymes: acyl-homoserine lactone-acylase and -lactonase. Open Microbiol J 2011; 5: 1-13.
17. Niu C and Gilbert ES: Colorimetric method for identifying plant essential oil components that affect biofilm formation and structure. App Env Micro 2004; 70: 6951-6.
18. Ponnusamy K, Paul D and Kweon JH: Inhibition of quorum sensing mechanism and *Aeromonas hydrophila* biofilm formation by vanillin. Environ Eng Sci 2009; 26: 1359-63.
19. Ren D, Sims J and Wood TK: Inhibition of biofilm formation and swarming of *Escherichia coli* by (5Z)-4-bromo-5-(bromomethylene)-3-butyl-2(5H)-furanone. Env Microbiol 2001; 3: 731-6.
20. Jamuna Bai A and Rai VR: Bacterial quorum sensing and food industry. Compr Rev Fd Sci Fd Saf 2011; 10: 184-94.
21. Geske GD, O'Neill JC, Miller DM, Wezeman RJ, Mattmann ME and LinQ: Comparative analyses of N-acylated homoserine lactones reveal unique structural features that dictate their ability to activate or inhibit quorum sensing. Chembiochem 2008; 9: 389-00.
22. Geske GD, Wezeman RJ, Siegel AP and Blackwell HE: Small molecule inhibitors of bacterial quorum sensing and biofilm formation. J Am Chem Soc 2005; 127: 12762-3.
23. Janssens JC, Steenackers H, Robijns S, Gellens E, Levin J and Zhao H: Brominated furanones inhibit biofilm formation by *Salmonella enterica Serovar Typhimurium*. Appl Environ Microbiol 2008; 74: 6639-48.
24. Lönn-Stensrud J, Petersen FC, Benneche T and Scheie AA: Synthetic bromated furanone inhibitsautoinducer-2-mediated communication and biofilm formation in oral *Streptococci*. Oral Microbiol Immunol 2007; 22: 340–6.
25. Rasch M, Buch C, Austin B, Slierendrecht WJ, Ekmann KS and Larsen JL: An inhibitor of bacterial quorum sensing reduces mortyalities caused by Vibriosis in Rain bowtrout (*Oncorhynchus mykiss*, Walbaum). Syst Appl Microbiol 2004; 27: 350-9.
26. Rasch M, Rasmussen TB, Andersen JB, Persson T, Nielsen J and Givskov M: Well-knownquorum sensing inhibitors do not affect bacterial quorum sensing-regulated beansprout spoilage. J Appl Microbiol 2007; 102: 826-37.
27. Welch M, Mikkelsen H, Swatton JE, Smith D, Thomas GL and Glansdorp FG: Cell-cell communication in gram-negative bacteria. Mol Biosyst 2005; 1: 196-202.
28. Rasmussen TB and Givskov M: Quorum sensing inhibitors: a bargain of effects, review. Microbiology 2006; 152: 895-904.
29. Jiang TY and Li MY: Quorum sensing inhibitors: a patent review. Expert Opin Ther Patents 2013; 23(7): 867-94.
30. Hastings JW and Nealson KH: Bacterial bioluminescence. Annual review of microbiology 1977; 31: 549-95.
31. Hense BA and Schuster M: Core principles of bacterial autoinducer systems. Microbiol Mol Biol Rev 2015; 79(1): 153-69.
32. Rutherford ST and Bassler BL: Bacterial quorum sensing: its role in virulence and possibilities for its control. Cold Spring Harb Perspect Med 2012; 1; 2(11).
33. Hentzer M, Wu H, Andersen JB, Riedel K, Rasmussen TB, Bagge N, Kumar N, Schembri MA, Song Z, Kristoffersen P, Manefield M, Costerton JW, Molin S, Eberl L, Steinberg P, Kjelleberg S, Hoiby N and Givskov M: Attenuation of *Pseudomonas aeruginosa* virulence by quorum sensing inhibitors. EMBO J 2003; 22: 3803-15.
34. Parsek MR, Val DL, Hanzelka BL, Cronan JE and Greenberg EP: Acyl homoserine-lactone quorum-sensing signal generation. Proc Natl Acad Sci USA 1999; 96: 4360-65.
35. Chen X, Zhang L, Zhang M, Liu H, Lu P and Lin K: Quorum sensing inhibitors: a patent review (2014-2018). Expert Opinion on Therapeutic Patents 2018; 849-65.
36. Anwar H, Dasgupta MK and Costerton JW: Testing the susceptibility of bacteria in biofilms to antibacterial agents. Antimicrob Agents Chemother 1990; 34: 2043-6.
37. Dell'Acqua G, Giacometti A, Cironi O, Ghiselli R, Saba V and Scalise G: Suppression of drug-resistant *Staphylococcal* infections by the quorum-sensing inhibitor RNAIII-inhibiting peptide. J Infect Dis 2004; 190: 316-20.
38. Balaban N, Giacometti A, Cirioni O, Gov Y, Ghiselli R and Mocchegiani F: Use of the quorum-sensing inhibitor RNAIII-inhibiting peptide to prevent biofilm formation *in-vivo* by drug-resistant *Staphylococcus epidermidis*. J Infect Dis 2003a; 187: 625-30.
39. Balaban N, Goldkorn T, Gov Y, Hirshberg M, Koyfman N and Matthews HR: Regulation of *Staphylococcus aureus* pathogenesis *via* target of RNAIII-activating protein (TRAP). J Biol Chem 2001; 276: 2658-67.
40. Balaban N, Gov Y, Bitler A and Boelaert JR: Prevention of *Staphylococcus aureus* biofilm on dialysis catheters and adherence to human cells. Kidney Int 2003b; 63: 340-5.
41. Giacometti A, Cirioni O, Ghiselli R, Dell'Acqua G, Orlando F and D'Amato G: RNAIII-inhibiting peptide improves efficacy of clinically used antibiotics in a murine model of *Staphylococcal* sepsis. Peptides 2005; 26: 169-75.
42. Giacometti A, Cirioni O, Gov Y, Ghiselli R, Del Prete MS and Mocchegiani F: RNA III inhibiting peptide inhibits *in-vivo* biofilm formation by drug-resistant *Staphylococcus aureus*. Antimicrob Agents Chemother 2003; 47: 1979-83.
43. Zeng Z, Qian L, Cao L, Tan H, Huang Y and Xue X: Virtual screening for novel quorum sensing inhibitors to eradicate biofilm formation of *Pseudomonas aeruginosa*. Appl Microbiol Biotechnol 2008; 79: 119-26.
44. Bjarnsholt T, Jensen PØ, Burmølle M, Hentzer M, Haagensen JAJ and Hougen HP: *Pseudomonas aeruginosa* tolerance to tobramycin, hydrogen peroxide and polymorphonuclear leuckocytes is quorum-sensing dependent. Microbiology 2005a; 151: 373-83.
45. Rasmussen TB, Skindersoe ME, Bjarnsholt T, Phipps RK, Christensen KB and Jensen PO: Identity and effects of quorum-sensing inhibitors produced by *Penicillium species*. Microbiology 2005b; 151: 1325-40.
46. Hentzer M and Givskov M: Pharmacological inhibition of quorum sensing for the treatment of chronic bacterial infections. J Clin Invest 2003; 112: 1300-7.
47. Brackman G, Cos P, Maes L, Nelis HJ and Coenye T: Quorum sensing inhibitors increase the susceptibility of bacterial biofilms to antibiotics *in-vitro* and *in-vivo*. Antimicrob Agents Chemother 2011; 55: 2655-61.
48. Reverchon S, Chantegrel B, Deshayes C, Doutheau A and Cotte Pattat N: New synthetic analogues of N-acyl homoserine lactones as agonists or antagonists of transcriptional regulators involved in bacterial quorum sensing. Bioorg Med Chem Lett 2002; 12: 1153-57.
49. Castang S, Chantegrel B and Deshayes C: N-Sulfonylhomoserine lactones as antagonists of bacterial quorum sensing. Bioorg Med Chem Lett 2004; 14: 5145-49.
50. Olse, JA, Severinsen R, Rasmussen TB, Hentzer M, Givskov M and Nielsen J: Synthesis of new 3- and 4-substituted analogues of acyl homoserine lactone quorum

sensing auto-inducers. Bioorg Med Chem Lett 2002; 12: 325-28.
51. Kalia VC: Quorum sensing inhibitors: An overview. Biotechnology Advances 2013; 31: 224-45.
52. Dong YH and Zhang LH: Quorum sensing and quorum-quenching enzymes. J Microbiol 2005; 43: 101-9.
53. Dong YH, Wang LH, Xu JL, Zhang HB, Zhang XF and Zhang LH: Quenching quorum-sensing dependent bacterial infection by an N-acyl homoserinelactonase. Nature 2001; 411: 813-7.
54. Huma N, Shankar P, Kushwah J, Bhushan A, Joshi J and Mukherjee T: Diversity and polymorphism in AHL-lactonase gene (aiiA) of *Bacillus*. J Microbiol Biotechnol 2011; 21: 1001-11.
55. Park SY, Lee SJ, Oh TK, Oh JW, Koo BT and Yum DY: AhlD, an N-acylhomoserinelactonase in *Arthrobacter sp.*, and predicted homologues in other bacteria. Microbiology 2003; 149: 1541-50.
56. Romero M, Martin-Cuadrado A, Roca-Rivada A, Cabello AM and Otero A: Quorumquecnching in cultivable bacteria from dense marine coastal microbial communitites. FEMS Microbiol Ecol 2011; 75: 205-17.
57. Uroz S, Dessaux Y and Oger P: Quorum sensing and quorum: the yin and yang of bacterial communication. Chembiochem 2009; 10: 205-16.
58. Huang JJ, Han JI, Zhang LH and Leadbetter JR: Utilization of acyl-homoserine lactone quorum signals for growth by a soil pseudomonad and *P. aeruginosa* PAO1. Appl Environ Microbiol 2003; 69: 5941-9.
59. Lin YH, Xu JL, Hu J, Wang LH, Ong SL and Leadbetter JR: Acyl-homoserine lactone acylase from *Ralstonia* strain XJ12B represents a novel and potent class of quorum-quenching enzymes. Mol Microbiol 2003; 47: 849-60.
60. Park SY, Kang HO, Jang HS, Lee JK, Koo BT and Yum DY: Identification of extracellular N-acyl homoserine lactone acylase from a *Streptomyces sp*. and its application toquorum quenching. Appl Environ Microbiol 2005; 71: 2632–41.
61. Chan KG, Wong CS, Yin WF, Sam CK and Koh CL: Rapid degradation of N-3-oxoacylhomoserine lactones by a *Bacillus cereus* isolate from Malaysian rainforest soil. Antonie Van Leeuwenhoek 2010a; 98: 299-305.
62. Dong YH, Xu JL, Li XZ, Zhang LH and Aii A: An enzyme that inactivates the acyl-homoserine lactone quorum-sensing signal and attenuates the virulence of *Erwinia carotovor*a. Proc Natl Acad Sci USA 2000; 97: 3526-31.
63. Liu D, Momb J, Thomas PW, Moulin A, Petsko GA and Fast W: Mechanism of the quorum-quenching lactonase (AiiA) from *Bacillus thuringiensis*. 1. Product-bound structures. Biochemistry 2008; 47: 7706-14.
64. Momb J, Wang C, Liu D, Thomas PW, Petsko GA and Guo H: Mechanism of the quorum-quenching lactonase (AiiA) from *Bacillus thuringiensis*. 2. Substrate modeling and active site mutations. Biochemistry 2008; 47: 7715-25.
65. Kang BR, Lee JH, Ko SJ, Lee YH, Cha JS and Cho BH: Degradation of acyl-homoserinelactone molecules by *Acinetobacter sp*. strain C1010935-941. Can J Microbiol 2004a; 50: 935-41.
66. Zhang HB, Wang LH and Zhang LH: Genetic control of quorum-sensing signal turnover in *Agrobacterium tumefaciens*. Proc Natl Acad Sci USA 2002; 99: 4638-43.
67. Zhang LH and Dong YH: Quorum sensing and signal interference: diverse implications. Mol Microbiol 2004; 53: 1563-71.
68. Carlier A, Uroz S, Smadja B, Fray R, Latour X and Dessaux Y: The Ti plasmid of *Agrobacterium tumefaciens* harbors an attM-paralogous gene, aiiB, also encoding N-acyl homoserine lactonase activity. Appl Environ Microbiol 2003; 69: 4989-93.
69. Lee J, Attila C, Cirillo SL, Cirillo JD and Wood TK: Indole and 7-hydroxyindole diminish *Pseudomonas aeruginosa* virulence. Microb Biotechnol 2012; 2: 75-90.
70. Chan KG, Atkinson S, Mathee K, Sam CK, Chhabra SR and Cámara M: Characterization of N-acylhomoserine lactone-degrading bacteria associated with *Zingiber officinale* (ginger) rhizosphere: co-existence of quorum quenching and quorumsensing in *Acinetobacter* and Burkholderia. BMC Microbiol 2011; 11: 51.
71. Chowdhary PK, Keshvan N, Nguyen HQ, Peterson JA, González JE and Haines DC: *Bacillus megaterium* CYP102A1 oxidation of acyl homoserine lactones and acyl homoserines. Biochemistry 2007; 46: 14429-37.
72. Cirou A, Uroz S, Chapelle E, Latour X, Orange N and Faure D: Quorum sensing as a targetfor novel biocontrol strategies directed at *Pectobacterium.* Recent Developments in Management of Plant Diseases. Dordrecht: Springer 2009; 121-31.
73. Nithya C, Arvindraja C and Pandian SK: *Bacillus pumilus* of Palk Bay origin inhibits quorum-sensing-mediated virulence factors in gram-negative bacteria. Res Microbiol 2010a; 161: 293-04.
74. Kalia VC: Quorum sensing inhibitors: An overview. Biotechnology Advances 2013; 31: 224-45
75. Paul D, Kim YS, Ponnusamy K and Kweon JH: Application of quorum quenching to inhibit biofilm fermentation. Environ Eng Sci 2009; 16: 1319-24.
76. Teiber JF, Horke S, Haines DC, Chowdhary PK, Xiao J and Kramer GL: Dominant role of paraoxonases in inactivation of the *Pseudomonas aeruginosa* quorum-sensing signal N-(3-oxododecanoyl) -L -homoserine lactone. Infect Immun 2008; 76: 2512-9.
77. Yang F, Wang LH, Wang J, Dong YH, Hu JY and Zhang LH: Quorum quenching enzyme activity is widely conserved in the sera of mammalian species. FEBS Lett 2005; 579: 3713-7.
78. Lu LG, Hume MF and Pillai SD: Autoinducer-2-like activity associated with foods and its interaction with food additives. J Food Prot 2004; 67: 1457-62.
79. Hall P, Chackerian B, Peabody DS, Daly SM, Elmore B and Triplett K: Vlp-based vaccines for targeting *Staphylococcus aureus* secreted virulence factors patent WO2017136400A1. 2017.
80. Li J, Chen G, Li X, Yi S, Li T and Li Y: Quorum-sensing inhibitor of aquatic *Pseudomonas fluorescens* and preparation method thereof patent CN105432766(A). 2016.
81. Teplitski M, Mathesius U and Rambaugh KP: Perception and degradation of N-acyl homoserine lactone quorum sensing signals by mammalian and plant cells. Chem Rev 2011; 111: 100-16.
82. Vattem DA, Mihalik K, Crixell SH and McLean RJC: Dietary phytochemicals as quorum sensing inhibitors. Fitoterapia 2007; 78: 302-10.
83. Chevrot R, Rosen R, Haudecoeur E, Cirou A, Shelp BJ and Ron E: GABA controls the level of quorum-sensing signal in *Agrobacterium tumefaciens*. Proc Natl Acad Sci USA 2006; 103: 7460-4.
84. Ni N, Choudhary G, Li M and Wang B: Pyrogallol and its analogs can antagonize bacterial quorum sensing in *Vibrio harveyi*. Bioorg Med Chem Lett 2008; 18: 1567-72.
85. Rudrappa T and Bais HP: Curcumin, a known phenolic from *Curcuma longa*, attenuates the virulence of *Pseudomonas aeruginosa* PAO1 in the whole plant and

animal pathogenicity models. J Agric Food Chem 2008; 56: 1955-62.
86. Zhao Y, Ma Q, Zhou L, Kong F, Xie Q and Dai H: Bacterial infection resistance pharmaceutical composition and application thereof patent CN107296858 (A). 2017.
87. Al-Haidari: Anti-quorum sensing activity of some medicinal plants. Afr J Tradit Complement Altern Med 2016; 13(5): 67-71.
88. deNys R, Wright AD, König GM and Sticher O: New halogenated furanones from the marine alga *Delisea pulchra* (cf. fimbriata). Tetrahedron 1993; 49: 11213-20.
89. Gram L, de Nys R, Maximilien R, Givskov M, Steinberg P and Kjelleberg S: Inhibitory effects of secondary metabolites from the red alga *Delisea pulchra* on swarming motility of *Proteus mirabilis*. Appl Environ Microbiol 1996; 62: 4284-7.
90. Ren D, Bedzyk LA, Ye RW, Thomas SM and Wood TK: Differential gene expression shows natural brominated furanones interfere with the autoinducer-2 bacterial signaling system of *Escherichia coli*. Biotechnol Bioeng 2004; 88: 630-42.
91. Ren D, Sims J and Wood TK: Inhibition of biofilm formation and swarming of *E. coli* by (5Z)-4-bromo-5-(bromomethylene)- 3-butyl- 2(5H)- furanone. Environ Microbiol 2001; 3: 731–6.
92. Manefield M, Harris L, Rice SA, de Nys R and Kjelleberg S: Inhibition of luminescence and virulence in the black tiger prawn (*Penaeus monodon*) pathogen *Vibrio harveyi* by intercellular signal antagonists. Appl Environ Microbiol 2000; 66: 2079-84.
93. Borchardt SA, Allain EJ, Michels JJ, Stearns GW, Kelly RF and McCoy WF: Reaction of acylated homoserine lactone bacterial signaling molecules with oxidized halogen antimicrobials. Appl Environ Microbiol 2001; 67: 3174-9.
94. Kwan JC, Teplitski M, Gunasekara SP, Paul VJ and Luesch H: Isolation and biological evaluation of 8-epi-malyngamide C from the Floridian marine cyanobacterium *Lyngbya majuscula*. J Nat Prod 2010; 73: 463-6.
95. Uroz S and Heinonsalo J: Degradation of N-acyl homoserine lactone quorum-sensing signal molecules by forest root-associated fungi. FEMS Microbiol Ecol 2008; 65: 271–8.
96. Zhu H, He CC and Chu QH: Inhibition of quorum sensing in *Chromobacterium violaceum* by pigments extracted from *Auricularia auricular*. Lett Appl Microbiol 2011; 52: 269-74.
97. De Lamo Marin S, Xu Y, Meijler MM and Janda KD: Antibody catalyzed the hydrolysis of a quorum-sensing signal found in gram-negative bacteria. Bioorg Med Chem Lett 2007; 17: 1549-52.
98. LaSarre B and Federle MJ: Exploiting quorum sensing to confuse bacterial pathogens. Microbiol Mol Biol Rev 2013; 77: 73-111.
99. Dong YH, Gusti AR, Zhang Q, Xu JL and Zhang LH: Identification of quorum-quenching N-acyl homoserine-lactonases from *Bacillus species*. Appl Environ Microbiol 2002; 68: 1754-59.
100. Bijtenhoorn P, Schipper C, Hornung C, Quitschau M, Grond S, Weiland N and Streit WR: BpiB05: A novel metagenome - derived hydrolase acting on N-acyl homoserine lactones. J Biotechnol 2011; 155: 86-94.
101. Marin SD, Xu Y, Meijler MM and Janda KD: Antibody catalyzed the hydrolysis of a quorum-sensing signal found in gram-negative bacteria. Bioorg Med Chem Lett 2007; 17: 1549-52.
102. Hoang TT and Schweizer HP: Characterization of *Pseudomonas aeruginosa*-enoyl-acyl carrier protein reductase (FabI): a target for the antimicrobial triclosan and its role in acylated homoserine lactone synthesis. J Bacteriol 1999; 181: 5489-97.
103. Calfee MW, Coleman JP and Pesci EC: Interference with *Pseudomonas* quinolone signal synthesis inhibits virulence factor expression by *Pseudomonas aeruginosa*. Proc Natl Acad Sci USA 2001; 98: 11633-37.
104. Ishii S, Fukui K, Yokoshima S, Kumagai K, Beniyama Y, Kodama T, Fukuyama T, Okabe T, Nagano T, Kojima H and Yano T: High-throughput screening of small molecule inhibitors of the *Streptococcus* quorum-sensing signal pathway. Sci Rep 2017; 7: 4029.
105. Amara N, Mashiach R, Amar D, Krief P, Spieser SA, Bottomley MJ, Aharoni A and Meijler MM: Covalent inhibition of bacterial quorum sensing. J Am ChemSoc 2009; 131: 10610-19.
106. Kita E, Sawaki M, Oku D, Hamuro A, Mikasa K, Konishi M, Emoto M, Takeuchi S, Narita N and Kashiba S: Suppression of virulence factors of *Pseudomonas aeruginosa* by erythromycin. J Antimicrob Chemother 1991; 27: 273-84.
107. Nicolau DP, Banevicius MA, Nightingale CH and Quintiliani R: Beneficial effect of adjunctive azithromycin in the treatment of mucoid *Pseudomonas aeruginosa* pneumonia in the murine model. Antimicrob Agents Chemother 1999; 43: 3033-35.
108. Kusari P, Kusari S, Lamshoft M, Sezgin S, Spiteller M and Kayser O: Quorum quenching is an antivirulence strategy employed by endophytic bacteria. Appl Microbiol Biotechnol 2014a; 98: 7173-83.
109. Lopes RB, Costa LE, Vanetti MC, de Araujo EF and de Queiroz MV: Endophytic bacteria isolated from common bean (*Phaseolus vulgaris*) exhibiting high variability showed antimicrobial activity and quorum sensing inhibition. Curr Microbiol 2015; 71: 509-16.
110. Defoirdt T, Sorgeloos P and Bossier P: Alternatives to antibiotics for the control of bacterial disease in aquaculture. CurrOpinMicrobiol 2011; 14: 251–8.
111. Skjerma J and Vadstein O: Characterization of the bacterial flora of mass cultivated *Brachionus plicatilis*. Hydrobiologia 1993; 255: 185-91.
112. Dobretsov S, Teplitski M, Bayer M, Gunasekra S, Proksch P and Paul VJ: Inhibition of marine biofouling by bacterial quorum sensing inhibitors. Biofouling 2011; 27: 893-05.
113. Craigen B, Dashiff A and Kadouri DE: The use of commercially available alpha-amylase compounds to inhibit and remove *Staphylococcus aureus* biofilms. Open Microbiol J 2011; 5: 21-31.
114. Rasch M, Buch C, Austin B, Slierendrecht WJ, Ekmann KS and Larsen JL: An inhibitor of bacterial quorum sensing reduces mortyalities caused by Vibriosis in Rainbow trout (*Oncorhynchus mykiss*, Walbaum). Syst Appl Microbiol 2004; 27: 350-9.
115. Swift S, Karlyshev AV, Fish L, Durant EL, Winson MK and Chhabra SR: Quorum sensing in *Aeromonas hydrophila* and *Aeromonas salmonicida*: identification of the LuxRI homologs AhyRI and AsaRI and their cognate N-acylhomoserine lactone signal molecules. J Bacteriol 1997; 179: 5271-81.
116. Huang CJ, Lin H and Yang X: Industrial production of recombinant therapeutics in *Escherichia coli* and its recent advancements. J Ind Microb Biotechnol 2012; 39: 383-99.
117. Chu W, Zere TR, Weber MM, Wood TK, Whiteley M and Hidalgo-Romano B: Indole production promotes *Escherichia coli* mixed-culture growth with *Pseudomonas aeruginosa* by inhibiting quorum signaling. Appl Environ Microbiol 2012; 78: 411-9.

118. Lee J, Attila C, Cirillo SL, Cirillo JD and Wood TK: Indole and 7-hydroxy indole diminish *Pseudomonas aeruginosa* virulence. Microb Biotechnol 2012; 2: 75-90.
119. Dulla GFJ and Lindow SE. Acyl-homoserine lactone-mediated cross-talk among epiphytic bacteia modulates the behaviour of Pseudomonas on leaves. ISME J 2009; 3: 8: 25–34.
120. Quinones B, Pujol CJ and Lindow SE: Regulation of AHL production and its contribution to epiphytic fitness in *Pseudomonas syringae*. Mol Plant-Microbe Interact 2004; 17: 521-31.
121. Wang WZ, Morohoshi T, Ikenoya M, Somaya N and Ikeda T: AiiM, a novel class of N-acylhomoserinelactonase from the leaf-associated bacterium *Microbacterium testoceum.* Appl Environ Microbiol 2010; 76: 2524-30.
122. Teplitski M, Robinson JB and Bauer WD: Plants secrete substances that mimic bacterial N-acyl homoserine lactone signal activities and affect population density-dependent behaviors in associated bacteria. Mol Plant-Microbe Interact 2000; 13: 637-48.
123. Stoltz DA, Ozer EA, Taft PJ, Barry M, Liu L and Kiss PJ: Drosophila is protected from *Pseudomonas aeruginosa* lethality by transgenic expression of paraoxonase-1. J Clin Invest 2008; 118: 3123-31.
124. Thammavongsa V, Kern JW, Missiakas DM and Schneewind O: *S. aureus* synthesizes adenosine to escape host immune responses. J Exp Med 2009; 206: 2417-27.
125. Sheng L, Pu M, Hegde M, Zhang Y, Jayaraman A and Wood TK: Interkingdom adenosine signal reduces *Pseudomonas aeruginosa* pathogenicity. Microb Biotechnol 2012; 2: 560-72.
126. Li L, Hooi D, Chhabra SR, Pritchard D and Shaw PE: Bacterial Nacylhomoserine lactone-induced apoptosis in breast carcinoma cells correlated with down-modulation of STAT3. Oncogene 2004; 23: 4894-02.
127. Oliver CM, Schaefer AL, Greenberg EP and Sufrin JR: Microwave synthesis and evaluation of phenacyl-homoserine lactones as anticancer compounds that minimally activate quorum sensing pathways in *P. aeruginosa*. J Med Chem 2009; 52: 15: 69-75.

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