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Quorum Sensing in Bacteria; Cell-to-Cell Communication and Signaling Mechanism.

Rameen Atique[1], Hafiza Arshi Saeed[2], Bushra Anwar[3], Aqsa Perveen[4], Javeria Sharif[5], Ayesha Haidar[6], Areesha Naveed[7], Tehreem Rana[8], Hafiza Rida Fatima[9], Abdul Samad[10]*

1,2,3,4,5,6,7,9 Department of Pathobiology and Biomedical Sciences, FVAS, MNS University of Agriculture, Multan Pakistan

[8]Department of Human Nutrition and Dietetics, MNS University of Agriculture, Multan Pakistan

[10] Division of Applied Life Science (BK21 Four), Gyeongsang National University, Jinju 52852, Korea

Corresponding Address: buzdarabdulsamad@gmail.com

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Abstract

Quorum sensing is a signaling mechanism in which bacteria coordinate with one another through chemical mediators. This system allows bacteria to communicate with the help of signals and work together to enlarge population density. The actual mechanism of quorum sensing depends on the secretion of auto-inducers (chemical signals) which are tiny molecules discharged by bacteria. In gram-positive bacteria, the chemicals that serve for quorum sensing are auto-inducer peptides (AIPs). At the same time, gram-negative bacteria induce quorum sensing by acylated homoserine lactone (AHL) molecules. In the beginning, the concentration of autoinducers boosts relatively and the population becomes dense. When the level of auto-inducers arrives at a threshold concentration, the transcription of genes occurs. The expression of genes exhibits characteristics such as biofilm development, symbiotic relationships, and pathogenic factors. The assortment of quorum sensing enables bacteria to adapt to various environmental developments. To lessen the intensity and virulence of quorum sensing, a strategy of quorum quenching is formulated. A set of enzymes is used to decrease the activity of quorum-sensing regulated bacterial species. Besides all this, quorum sensing has vast applications in the fields of medicine and agriculture. It is used to synthesize antibacterial treatments (quorum sensing inhibitors QSI) to disrupt various bacterial infections. In the agricultural department, quorum sensing can improve plant-bacteria symbiotic associations, enhancing crop development and protection against disease. The manipulation of bacterial interactions can provide various benefits to modern scientific research and applications. This review is a brief overview of the mechanism of quorum sensing in bacteria which describes the aspects of Quorum sensing.

Keywords: Bacteria, Quorum Sensing, QSI, Protection Against Disease

1. Introduction:

Quorum sensing is a process of cell-to-cell interaction in bacteria. It is a condition in which bacteria correspond with one another by using chemical signal particles. Quorum-sensing bacteria synthesize and oust chemical molecules named auto-inducers (tiny molecules released by bacteria to estimate population density). The surface concentration of auto-inducers increases with the expanding density of the cell denizens. The proliferation of auto-inducers is easily detected by bacteria and in reaction, they change the gene expression and the behavior of bacteria. The various sorts of signals, stimulants, and mechanisms of signal regulation

contemplate the unique science of bacterial species. The first-ever learned quorum sensing system is the biofluorescent marine bacterium *Vibrio fischeri*. It is evaluated as the model or example for quorum sensing in gram-negative bacteria (Nealson & Hastings 1979). The bacteria *V.fischeri* lives in the light tissue of *Euprymna scolopes* (the Hawaiian squid). The bacteria grow in the light organ of the squid to high cell concentration and yield the manifestation of genes for bioluminescence. The squid utilizes the light produced by the bacteria to disguise their shade and prevent predation (Visick et al. 2000).

The bacteria obtain benefits from squid because its light organ contains a lot of nutrients that bacteria can accumulate in large quantities. Two expression proteins, LuxI and LuxR are present in bacteria that are important for the exposition of light. These two proteins control the articulation of luciferase operon (luxICDABE). The protein, LuxI acts as an auto-inducer synthase, which stimulates the production of acyl-homoserine lactone (AHL) which is an auto-persuader 3OC6- homoserine lactone (Engebrecht & Silverman 1984). Whereas, the protein LuxR is the cytoplasmic auto-inducer signaling site (Engebrecht et al. 1983). The acyl-homoserine lactone can easily move in and out of the cell and therefore, increases cell density (Kaplan & Greenberg 1985). As soon as the signal catches up with the threshold concentration bounded by the LuxR protein, the transcription of the operon encoding luciferase is triggered (Stevens et al. 1994). The complex LuxR-AHL also triggers the declaration of LuxI, as it is also inscribed in the luciferase operon. This positive feedback induces the whole population of bacteria to swap to "quorum-sensing mode" and create light. On the other hand, Gram-positive bacteria establish cell-to-cell connections by using amended oligopeptides as impulses and two-component type membrane-covered detector histidine kinase as stimuli. Cell signaling is triggered by a phosphorylation process that affects the workout of DNA-binding functional proteins.

The mechanism shown by gram-negative bacteria is similar to that of gram-positive bacteria in which each bacteria uses a distinct signal from the other. As we know, in Gram-positive bacteria, the signals are in the form of oligopeptides so they do not pass through the membrane. The biochemistry of transmitting signals is not defined properly, but large peptide molecules are used to split the peptide encoding quorum sensing signals. The large prototype oligopeptides are converted to lactone, lanthionines, and isoprene groups (Booth et al. 1996, Nakayama et al. 2001, Ansaldi et al. 2002). A good epitome of peptide quorum sensing is present in *Staphylococcus aureus.* It causes a lethal infection in the host tissues. At low cell concentrations, *S. aureus* represents protein elements that facilitate attachment and proliferation, and at high cell viscosity, the bacteria suppress these characteristics and instigate the release of toxins and protease enzymes (Lyon & Novick 2004).

The gene expression is formulated by the Agr quorum-sensing program. The strategy mainly constitutes an auto-inducer peptide of *Staphylococcus aureus* encrypted by *agrD.* This system also contains a two-component kinase receptor pair, AgrC, and AgrA (Novick et al. 1995). Another protein AgrB transports and supplies thiolactone spirals to *S. aureus* auto-inducing peptides. When auto-inducing peptides of *Staphylococcus aureus* fix with ArgC, they tend to the phosphorylation of ArgA. The complex phospho-ArgA influences the presentation of RNAIII which inhibits the expression of cell cohesive components while enhancing the impression of perspire factors (Novick et al. 1993). The elevated levels of auto-inducing peptides of *Staphylococcus aureus* (AIP) induce the whole bacterial population to change from low-cell density to high-cell concentration conditions.

Many interesting systems are under consideration that use intra- and inter-species quorum sensing. The communication among bacterial cells plays a significant role in the enhancement of the survival of bacterial species and allows them to construct specialized congregations to provide benefits to the entire population. Quantum-sensing bacteria have a mechanism by which they produce virulence factors in the late stage of infection to avoid alerting the host immune system about their existence. After the

high density of bacterial cells is achieved, they secrete virulence proteins that will result in a deadly infection (Fuqua et al., 1994, Passador et al., 1993, Schell 1996, Winans et al., 1999, Novick & Muir 1999).

The quorum sensing performed by acylated homoserine lactone (HSL) autoinducer imparts an essential role in the outgrowth of distinct bacterial biofilms (Davies et al., 1998 & Allison et al., 1998). Biofilms are the aggregation of bacteria on the surfaces of cells of organs. In biofilms, single and multiple species of bacteria are classified into complicated structures. Bacterial species colonize different organs and show specific imprints of gene indication and differentiation. Moreover, biofilms contain aqueous tracks that increase the transportation of nutrients and protect cells from heat and drying off. Biofilm-forming bacteria are favorably resistant to antibiotics and therefore, soar the prospects of survival and accumulation of bacteria community (Costerton et al., 1995, O'Toole & Kolter 1998). Some recent investigations have demonstrated that the bacteria and host can trace and respond to every signal (Miller & Bassler 2001). The enteric bacteria *Escherichia coli* produces an autoinducer named AI-3, which can switch on genes for intestinal colonization for attachment of bacteria to the intestinal walls.

The AI-3 signaling route is also initiated by adrenaline and adrenaline through which *E.coli* can scrutinize the host's catecholamine levels to change the gene expression (Reading et al., 2007). Quorum sensing helps *Pseudomonas aeruginosa* to react to endogenous host derivatives, dynorphin. Auto inducers of *Pseudomonas aeruginosa* are significant in stimulating infection and also, some auto inducers corresponded with eukaryotic cells to boost disease. New strategies of quorum sensing have been discovered by scientists to impede the formation of biofilms in bacteria. These techniques enable to control of diseases caused by pathogenic species of bacteria. In the antimicrobial research sector, quorum-sensing inhibiting agents are now able to replace antibiotics as bacteria have become resistant to a diverse range of antibiotics. The following methods have recently been used by investigators to utilize innovative quorum-sensing inhibitors (1) production of known quorum-sensing inhibitor derivatives. (2) improvement in subsisting quorum quenching enzymes. (3) inquiry for quorum sensing inhibiting components in naturally occurring products. (4) identification of accepted drugs as quorum sensing inhibiting mechanisms (Chang et al., 2019 & Koch et al., 2014).

Quorum-sensing inhibiting elements are alternatives to antibiotics and have vast applications the in the fields, of medicine, agriculture, the food industry, and water restorative techniques. *Pseudomonas aeruginosa* is a major cause of pulmonary infection in public health. These microorganisms are highly resistant to antibiotics and are a major concern nowadays. A quorum-sensing inhibitor acylase PvdQ can irreversibly hydrolyze acylated homoserine lactone (AHL) molecules. These alternatives are effective in the treatment of pulmonary infections (Utari et al., 2018). Currently, scientists are facing the challenges of biofilm-forming pathogenic bacteria. A multifunctional layer of polyethylene glycol (PEG) is integrated with quorum sensing instructor 5-methylene-1- prop-2-enoyl-4-(2-fluorophenyl)-dihydropyrrol-2-one in the surface (Ozcelik et al., 2017). Quorum-sensing inhibitors are also important in the food-producing industry. When biofilm formation occurs in foods, bacteria proliferate on the surface of food packs and containers (Shi & Zhu., 2009).

The extraction of basic oils from *Murraya koenigii* is obtained and they have a robust ability to quorum sensing inhibition. These oils can hamper biofilm formation, and lessen cell expansion and disintegration of frozen milk by *psychrophila* PSPF19 (Bai & Vittal., 2014). The application of quorum sensing is also important in water treatment plants. Wastewater is purified by using membrane bioreactors coupled with membrane filtration procedures (Lee et al., 2018; Oh & Lee., 2018). The usage of membrane bioreactors leads to the problem of biofouling. It is a process in which a thick layer of biofilm forms which results in the accumulation of bacterial cells (Kose-Mutlu et al., 2019). For this, quorum quenching enzymes are employed to stave off biofouling

in membrane bioreactor. A quorum-quenching enzyme, acylase is used to inhibit the formation of mature mushroom-shaped biofilm formed by biofouling (Kim et al., 2011). Nanotechnology is a strategy that was developed in the 1990s to treat and inhibit human-associated infections. They aim to reduce the intensity of disease and enhance the efficacy of the human immune system. Nanotechnology products are used as transporters to improve the delivery, target site, and safety of drugs (Doane & Burda., 2012; Zhang et al., 2020). In medicine, nanotechnology is used to build nanoparticles and nanocapsules that incorporate quorum sensing to prevent biofilm formation. Silver nanoparticles have been launched as a new nanomaterial that displays an amazing quorum-sensing inhibition scheme (Qais et al., 2021; Qais et al., 2018; Vanlalveni et al., 2021). Nanoparticles of gallium and bismuth show effective quorum-sensing inhibition against bacterial biofilms of *Pseudomonas aeruginosa* (Halwani et al., 2008; Alhariri & Omri 2013).

2. Quorum sensing in gram-negative bacteria:

(Miller & Bassler.,2001) elaborate that the phenomenon of quorum-sensing was uncovered and illustrated in two illuminating marine bacterial species, *Vibrio fischeri,* and *Vibrio harveyi.* Over 25 years ago, researchers found out that the enzymes present in both marine bacterial species can elicit light when encoded by luciferase operon *luxCDABE*. In the quorum sensing system, a group of bacteria communicates by releasing chemical signals and coordinating cell-to-cell mechanisms. In the past few decades, quorum sensing has been recognized in 25 different species of gram-negative bacteria. The mechanism of many gram-negative bacteria matches the quorum-sensing course of *Vibrio fischeri.*

However, two species of bacteria *Vibrio harveyi* and *Myxococcus xanthus* follow different quorum-sensing pathways. Gram-negative bacteria contain two homologous regulatory proteins of *Vibrio fischeri,* LuxI, and LuxR. The function of LuxI proteins is the biosynthesis of a specially designed acylated homoserine lactone (HSL) molecule. These signaling molecules are known as auto-inducers and their concentration increases as the cell density increases. While LuxR proteins bind with acylated homoserine lactone auto-inducers to attain a threshold level. The formation of the LuxR-HSL complex highlights the target gene for expression. Using LuxI/LuxR pathways of quorum sensing, gram-negative bacteria can achieve maximum cell density population. *Vibrio fischeri* and *Pseudomonas aeruginosa* is a species of gram-negative bacteria that intervene in quorum sensing by using LuxI/LuxR circuits. The most detailed studied quorum sensing mechanism is of the marine bacterium *Vibrio fischeri.* This bacteria can form symbiotic associations with most of the eukaryotic hosts. The host develops a specific light organ in which *V. fischeri* lives and attains a very high cell density. The host provides habitat and nutrition for bacteria to survive while in return the microorganism furnishes the host with light. When *V. fischeri* forms a symbiotic association with squid (*Euprymna scolopes),* it uses light from the bacteria as an antipredation scheme to avoid its shadow on bright nights. Whereas, the fish *Monocentris japonicus* establishes a relationship with *V. fischeri* which helps the fish attract its mate by creating luminescence.

The emission of light in the organ is related to the high-cell concentration, normally 10^{11} cells per ml, and this process is governed by quorum sensing. When *V. fischeri* increases in number they secrete auto-inducers that allow the bacteria to communicate and give a sign to bacteria to produce light. As we discussed earlier, luciferase enzymes are present in *Vibrio. fischeri* that are responsible for light production. The enzymes are encoded by the *luxICDABE* operon and two functional proteins LuxI and LuxR. When the concentration of cells is low, a low amount of autoinducers is produced by encoding luciferase, and as a result, less quantity of light is delivered. As the cells of *V. fischeri* proliferate in the host, signaling chemicals reach threshold concentration and bind LuxR protein with *luxICDABE* initiating transcription.

3. The phenomenon of quorum sensing in *Pseudomonas* :

(De Kievit. 2009) explains the quorum sensing phenomenon of gram-negative bacteria, *Pseudomonas aeruginosa.* This bacteria is pathogenic and causes biofilm formation. *Pseudomonas aeruginosa* comprises two acylated homoserine lactone quorum-sensing mechanisms, Las and Rhl. The Las system consists of a transcriptional controller LasR which is interconnected with an acylated homoserine lactone (AHL) signal, N-(3-oxododecanoyl)-L-homoserine lactone, activated by the hormone acylated homoserine lactone synthase Lasl. Likewise, the Rhl system is a combination of RhlR with linked acylated homoserine lactone (N-butyryl-L-homoserine lactone), stimulated by the enzyme Rhll AHL synthase. An additional autoinducer is produced by *P. aeruginosa, Pseudomonas* Quinolone Signal (2-heptyl-3-hydroxy-4(1H).

The quorum sensing manipulated genes of *Pseudomonas aeruginosa* greatly leverage the biofilm formation. Scientists found out that the Las quorum sensing system can develop mature and transformed biofilms. The extracellular matrix of biofilm mainly consists of polysaccharides, DNA, and proteins. The pel biosynthetic operon (PA3058-PA3064) has been identified as an optimistic factor for quorum sensing modulation. As the biofilm develops, extracellular DNA plays a key role in the accumulation of bacterial cells. In *P. aeruginosa* biofilms, extracellular DNA is extracted by the degradation of a small concentration of cells. Decreased levels of extracellular DNA are shown by the quorum sensing of proteins *laslrhll* and *pqsa.* So the mutants of biofilms become susceptible to sodium dodecyl sulfate (SDS) and DNA assists in the stability of biofilm. Furthermore, rhamnolipids are glycolipids that play a role as biosurfactants and maintenance of biofilms. They are produced by the operons *rhlAB* and *rhlC.* The biofilms of *P. aeruginosa* can create open channels in the surface of a solid matrix and these channels or routes help in the uptake of nutrients and expulsion of waste materials. *P. aeruginosa* can move with the help of pili on solid surfaces by twitching or swarming movement. Switching movement is associated with type IV pili while swarming is governed by quorum sensing. The *rhlAB* genes are believed to control swarming activity by quorum sensing regulated proteins. Some genes are involved that help the bacteria to move by flagella in glucose media. Swarming motility helps *P. aeruginosa* to designate the biofilms in the early stage of life. Cells of *P. aeruginosa* cultivated on a medium of citrate, benzoate, and casamino acids lead to the formation of uniform biofilms. Moreover, the presence of iron affects the escape of DNA and the construction of biofilms. When the concentration of iron is low, biofilm formation and expression of *Pseudomonas* quorum sensing are at the maximum level and vice versa.

4. Quorum sensing in Gram-positive bacteria:

(Bhatt. 2018) defines the process and mechanism of quorum sensing in gram-positive bacteria. The gram-positive bacteria mainly utilized two routes for quorum sensing. Primarily, auto-inducers are manufactured by ribosomes as pro peptides and translated into proteins. Then, they are released by ABC transporters and proteases break them up to mature into auto-inducer peptides(AIPs). When the concentration of AIPs catches up with the maximum level, kinases (cell receptors) are secreted by the cell surface that recognizes them. The AIPs operate the kinases by phosphorylation. The activated receptor encodes the transcription of target genes.

5. Pathways of quorum sensing inducers in gram-positive bacteria:

The two primary elements of this quorum-sensing pathway are the His kinase and the intracellular regulatory receptor. Because of the two constituents, it is called a two-component pathway and is significant in *Lactococcus lactis* and *Streptococcus pneumoniae.*

5.1. Primary pathway

The quorum sensing mechanism of gram-positive bacteria is different from that of gram-negative bacteria, in former quorum sensing implicates an indirect regulation of genes via phosphorylation. Thus, the high concentration of cells is achieved by the integration of kinase signals. However, in, gram-negative quorum sensing, chemical signals directly attach to the transcription factors. *S. pneumoniae* follows a competence system in which an ABC transporter transfers the recognized 17 auto-inducer peptides termed competence stimulating peptides. After attaining the threshold concentration, activation of the kinase is initiated by auto-inducer peptides. The activated kinase goes through phosphorylation and transfers intracellular regulatory stimuli for transcription. The phosphate stimulates the particular sigma factor for the transcription of the target genes. *Staphylococcus aureus* and *Clostridium perfringens* exhibit quorum sensing by using an accessory gene regulator system (Agr system). The Agr system contains various proteins such as AgrA, AgrB, AgrC, and AgrD on the gene locus.

The protein AgrD encodes a precursor peptide (autoinducer peptide) which is sliced up by AgrB and as a result, thiolactone is secreted. As soon as a threshold level is achieved after the secretion of thiolactone, a receptor histidine kinase (AgrC) is turned on. After that, the phosphorylation of ArgC occurs and activates the intracellular receptor AgrA. AgrA then elevates the level of RNAIII in the cell and undergoes the transcription of all *age* genes. In the end, the transcription of RNAIII tends to the presentation of sigma toxins of virulence factors of bacteria.

5.2. Secondary pathway:

(Rocha-Estrada et al., 2010) describe the second pathway procedure of quorum sensing in Gram-positive bacteria. In this bacteria, proteins of quorum sensing bind directly with the auto-inducer peptides. These signaling proteins consist of aspartyl phosphate phosphatases (Rap proteins), neutral protease regulators (NprR), and phospholipase C regulators (PlcR). The family called RNPP stands for Rap, NprR, PlcR and PrgX. This family consists of all gram-positive bacteria that bind to the receptor peptides. The regulatory signal remains inside the cell, but a pro-peptide signaling fragment is exported. The study on RNPP quorum sensing mainly focuses on the sequence of amino acids, the interaction of proteins with chemical peptides, and the interaction of proteins and peptides with target DNA. The RNPP system of quorum sensing has been researched in *Bacillus subtilis, Staphylococcus pneumoniae, Enterococcus faecalis,* and *Bacillus cereus.* In the RNPP family system, when auto-inducers reach the threshold concentration they are delivered inside the cells with the help of an oligo peptide transporter. Therefore, the stimulated phosphate regulator (Phr) autoinducer peptides can turn off Rap-phosphatases.

The pro-peptide is treated by proteases and converted to mature peptides. Phosphate regulator peptides will interfere with regulator aspartate phosphatases and express genes. Several types of Rap proteins RapA, RapB, RapE, and RapH can inhibit signaling through phosphorylation. Then, Rap proteins are suppressed by a series of Phr proteins termed PhrA, PhrB, PhrE, and PhrH. RapC-PhrC quorum system can regulate hereditary competence in which PhrC hinders RapC by the influence of ComA. Competence system A regulated gene expression directly with ComP and indirectly with ComK. They play an essential role in controlling stress, nutrition, and, defense of *Bacillus subtilis* in the stationary phase and sporulation. PlcR encodes virulence particles and the *plcA* gene (phospholipase C). PapR combines with PlcR to activate it and PlcR fixes with the target sequences. The activated PlcR incorporates DNA called PlcR-box and it is used for the transcription of genes. Some virulence factors of *B. cereus* are directly manipulated by PlcR. The quorum sensing of *Enterococcus faecalis* is regulated by the repressor PrgX. It has two auto-inducer peptides for quorum sensing, one is a chromosomally localized gene cCF10 and the other is a plasmid localized gene pCF10. Both of these auto-inducers act together to suppress the activity of PrgX and help in the conjugation process.

6. Quorum quenching enzymes:

(Grandclément et al., 2016) explain the mechanism and role of quorum quenching enzymes. Quorum quenching involves all the techniques that disrupt the pathway of quorum sensing. Quorum-quenching molecules contain enzymes, chemical mediators, and inhibitory compounds. The enzymes involved in quorum quenching can inhibit or inactivate quorum-sensing signals. The first-ever quorum-quenching molecules were studied in soil bacterial recluses of *Variovorax* and *Bacillus* genera. These bacteria were able to degrade acylated homoserine lactone (AHL) molecules responsible for quorum sensing. The quorum quenching enzymes contain four classes of catalytic enzymes;(1) lactonases that open up the homoserine lactone coil. (2) the amidases that cut the calculated homoserine lactone molecules at the amide bond and lay off fatty acids and homoserine lactone. (3) the reductases that transform 3-oxo-substituted AHL to their interlinked 3-hydroxyl-replaced AHL. (4) cytochrome oxidase that catalyzes the oxidation of the acyl chain. The amino acid sequence and structure of acylated homoserine lactone-disrupting enzymes are different.

The members of the lactose family are metallo-beta-lactamase-like lactonases, phosphodiesterase-like lactonases, and paraoxonases-hydrolase fold lactonases. These three members of the family use metallic ions for catalytic mechanisms. In this process, the lactone substrate molecule combines with the metal action and provides electrons to the carbonyl carbon. Then, an active site of the metal removes a proton from the charged water molecule. In the following tetrahedral intermediate, the molecule is unstable and broken down to give a hydrolyzed derivative. Bacterial enzymes AiiD, AiiC, PvdQ, QuiP, and the porcine kidney acylase I relate to the amidohydrolase collection of beta-lactam acylase. The PvdQ enzyme (crystal amidase) is derived from *Pseudomonas aeruginosa* and demonstrates a typical hydrolase fold with an extraordinarily large hydrophobic binding site. It depicts a covalently bound interpose which belongs to the long act chain of AHL. The primary crystal structure of reductase BpiBo9 is associated with the short-chain reductase lineage and the cytochrome P450 oxidase CYP102A1 of bacteria *B.megaterium* induces the oxidation of three carbon atoms of the acyl chain.

7. Functions of different quorum quenching enzymes

(Sikdar & Elias., 2020) they explained the biological roles of different types of AHL lactonases. Phosphodiesterase like lactonases is commonly found in bacteria and archaea. These are metalloenzymes and heat stable. PLLs are a useful type of lactonase enzymes that prefer long acyl chains. For example, SsoPox is a characteristic form of the phosphodiesterase-like lactonases from *Saccharolobus solfataricus.* The Metallo-beta-lactamase-like lactonases are present in prokaryotes and eukaryotes. They display specific alpha-beta/beta-alpha overlaps with two metal cations. They also prefer long chains of acylated homoserine lactone substrates. For example, AiiA from *Bacillus cereus* is a representative arrangement of the metallo-beta-lactamase-like lactonases. The third type of AHL lactonases are the alpha/beta hydrolase fold lactonases that are separate from bacteria. They also ascertain the wide range of AHL substrates. An example of this type of lactonase enzyme is AidH from the soil bacterium *Ochrobactrum species.* The lactose enzyme paraoxonases take their name from their capacity to cut paraoxon. PONs can hydrolyze substrates of long-chain AHL. Quorum-sensing inhibitor molecules are capable of suppressing the mechanism of bacterial quorum sensing by (i) inhibiting the action of AHL synthesis, (ii) diminishing the production of quorum-sensing chemical mediators, (iii) disrupting the acylated homoserine lactone (AHL) molecules, and (iv) employing artificial substances that imitate the signal molecules. Antibiotics and quorum-sensing inhibitors work synergistically to destroy the biofilms of bacteria. They attack the

exopolysaccharide layer of the biofilms and make bacteria vulnerable to antibiotics. As we all know, bacteria have become resistant to multiple antibiotics, so quorum quenching is a more favorable technique in this regard.

8. Uses and applications of quorum sensing

(Amara et al., 2011) explains that although the wonder of quorum quenching has spread among prokaryotes and eukaryotes it can reduce the risk of bacterial infections. Therefore, investigators are utilizing quorum-quenching mechanisms to eliminate the hazards of quorum-sensing-regulated bacterial species. Techniques of quorum quenching are operated by the Department of Agriculture, medical, and water treatment. The manifestation of quorum quenching enzymes has been revealed to be influential in bacterial and plant samples. Insertion of AiiA into the potato and tobacco plants can destroy the 3-oxo-C6-homoserine lactone molecule and the plant is malnourished by *E. carotovora.* When the AiiA is expressed in the mutated plant, the size of the infected area becomes smaller in about 20 hours after inoculation. The higher the amount of enzyme inoculated, the smaller the size of transgenic plants. Other plants also show similar results when infected with *E. carotovora*. Another example includes the establishment of a symbiotic association between the nitrogen-fixing bacterium *Sinorhizobium meliloti* and plants of the legume family (peas, beans). These plants can fix nitrogen for bacteria and convert nitrogen into ammonia while in return, the bacteria increase the surface area of roots for the uptake of nutrients. The root nodules formed by bacteria are oriented by quorum sensing. When we inoculate AiiA lactonase quorum quenching enzyme in the nodules, there will be a reduction in the production of acylated homoserine lactone receptors, and as a result lower efficiency of *S. meliloti.* When AiiA is expressed in the legume plant *Medicago truncatula* (seedling), then it will yield less than 50% of the nodules. Genes related to quorum quenching are inserted into the host system to evaluate the efficacy of quorum sensing of bacteria species. The benefit of articulating quorum quenching enzymes in the host can disclose the effects of virulent pathogens such as *P. aeruginosa.*

Conclusion:

Bacteria inhabit different ecosystems and environments and can regulate a series of activities. In the mechanism of quorum sensing, bacteria can communicate and interact with other species of bacteria. The study of quorum sensing is now raising heads in modern technology. It is the fundamental study of bacterial coordination. The mechanism of quorum sensing controls different functions such as the expression of genes. The auto-inducers released by bacterial species facilitate the intra and inter-species with cell-to-cell communication. Some auto-inducers are host-specific (species-specific) and others are genus-specific. The compounds related to quorum sensing are naturally produced by eukaryotic cells and are used in genetic engineering for transgenic plants. Quorum-quenching enzymes (synthases and lactonases) are useful in deterring plant infections. Some plants establish associated behavior with bacteria and a single bacterium can stimulate many types of chemical signals to elicit ordinary phenotypes. The study of quorum sensing specifically targets the areas of agriculture, medicine, and industry for drug development. However, eukaryotes have evolved an effective mechanism to exploit quorum sensing and defend themselves from pathogenic disorders. It is now clear that the bacteria exist in niches and continuously communicate with each other. Researchers are busy investigating new species of quorum-sensing controlled bacteria to expose their unseen mechanisms and communication.

Conflict of Interest

The authors declare that there is no conflict of Interest

Acknowledgment

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