Antimicrobial and Anti-quorum Sensing Activities of Medicinal Plants

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Angela E. Peter, Pola Sudhakar, B. V. Sandeep, and B. Ganga Rao

Abstract

Medicinal plants have been used for several centuries for prevention, treatment, and cure of diseases. The study of many of these traditional medicinal plants has led to the isolation and characterization of bioactive compounds. Some of these compounds have been chemically modified and used as drugs to mitigate ailments. Several commercially available antibiotics are derived from plants. The rise of multidrug-resistant strains of pathogens has led to an intensive search for compounds that can curb this alarming trend. The phenomenon of quorum sensing sheds a whole new light on the process of mitigation of microbial infection, where the plant-derived compounds block essential pathways (like virulence factor expression and biofilm formation) controlled by quorum sensing. Since the discovery that halogenated furanones produced by red marine algae *Delisea pulchra* can interfere with the process of quorum sensing in several Gram-negative bacteria, several medicinal plants (*Mentha piperita*, *Syzygium aromaticum*, *Rosmarinus officinalis*, *Jasminum sambac*, *Lilium brownii*, *Ocimum sanctum*, etc.) have been assessed for anti-quorum sensing potential. Some of them possess only anti-quorum sensing activity, and a few others possess both antimicrobial and anti-quorum sensing activity. Some studies have also identified the compounds responsible for inhibition of quorum sensing pathways. This chapter discusses the study of medicinal plants for their anti-quorum sensing activity.

A. E. Peter · P. Sudhakar (✉) · B. V. Sandeep
Department of Biotechnology, College of Science and Technology, Andhra University, Visakhapatnam, Andhra Pradesh, India
e-mail: sudhakarpola@gmail.com

B. G. Rao
College of Pharmaceutical Sciences, Andhra University, Visakhapatnam, Andhra Pradesh, India

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Medicinal plants · Quorum sensing · Quorum quenching · Anti-QS activity

14.1 Introduction

There are numerous medicinal plants in the world, some of which are found to be widely distributed, while others are endemic. The geographic and demographic conditions of that area determine the kind of phytochemicals and secondary metabolites produced by plants inhabiting the area. These various phytochemicals confer the plant with specific medicinal properties. Sometimes, the entire plant is medicinally important, while at other times, certain parts of the plant are used for the treatment of some medical conditions. Numerous traditionally acclaimed medicinal plants have been scientifically evaluated, and the specific bioactive compounds have been identified. In some cases, when the bioactive compounds are highly potent, they have even been chemically synthesized and marketed as drugs for the treatment and cure of specific medical conditions.

Antibiotics vary in their mode of action. Some inhibit protein or nucleic acid synthesis, while others disrupt membrane structures, and some interfere with the synthesis of peptidoglycan, a necessary constituent of microbial cell walls. One major concern with the use of antibiotics is the development of antibiotic-resistant strains. Antibiotic-resistant strains can develop naturally or by the improper use of antibiotics. These are mutants of the susceptible strains that have acquired the capacity to escape destruction by the antibiotic. As a result, the focus has shifted from developing antimicrobial agents to a more promising strategy in recent times.

14.2 Quorum Sensing

Quorum sensing is a kind of cell-to-cell communication in bacteria. In this process, bacteria communicate with each other by the secretion of some chemical signaling molecules known as autoinducers (AIs). These autoinducers are produced by the bacteria and released, and subsequently the amount of the autoinducer is assessed. The level of the autoinducer increases with the population of the autoinducer-producing bacteria. Once a sufficient number of cells, called a "quorum," are present, the extracellular autoinducer reaches a threshold level. This results in a widespread alteration in the gene expression, in all the autoinducer-producing bacterial cells. This communication may occur within a species, between two species, or between bacteria and their host. This process enables groups of bacteria to coordinate their functions and act as multicellular organisms. Thus, quorum sensing enables bacteria to regulate the gene expression depending on its population

density. Most of the quorum sensing-controlled mechanisms do not account for much when undertaken by an individual bacterium but can have exceptional results when a group of bacteria is involved. Virulence factor expression, biofilm formation, bioluminescence, sporulation, and conjugation are some quorum sensing-controlled mechanisms.

This phenomenon opens up a whole new revolutionary field for the treatment of microbial infections. While antimicrobial activity infers inhibition of growth or killing of the microorganism, anti-quorum sensing activity disturbs the bacterial communication system, thus attenuating microbial pathogenicity. Anti-quorum sensing agents were first characterized in red marine algae (*Delisea pulchra*) (Zahin et al. 2010a). Since this, several studies have been undertaken on terrestrial plants to ascertain if they also possessed such properties. Traditional medicinal plants from different regions of China (Siew-Mian and Tham 2012), India (Singh et al. 2009a), South Florida (Adonizio et al. 2008), and Egypt (Zaki et al. 2012), different spices (cloves, cinnamon), fruits (mango, pomegranate), and essential oils (lavender, sandalwood) have been tested for anti-quorum sensing activity. Some of these studies yielded a positive result, with the particular plant exhibiting anti-quorum sensing activity. This is, however, still a developing field in the nascent stages, which holds much promise for the future.

14.3 Mechanisms of Quorum Sensing

There are primarily three mechanisms of quorum sensing in bacteria, based on the type of autoinducer molecule involved and the mode of gene expression. One mechanism is seen in most Gram-negative bacteria and another in most of the Gram-positive bacteria. A third mechanism is also observed, having few similarities to both Gram-negative and Gram-positive bacteria-mediated quorum sensing, and some features different from both.

14.3.1 Model I: Quorum Sensing in Gram-Negative Bacteria(Waters and Bassler 2005)

The model organism for quorum sensing in Gram-negative bacteria is *Vibrio fischeri*, which lives as a symbiont of a squid. This bacterium resides in the luminous organ of the squid and stimulates the production of luminescence, helping the squid, while it is benefited as the light-producing organ is rich in nutrients.

This method of quorum sensing, which controls the expression of the luciferase gene, which is responsible for luminescence of the squid, was the first quorum sensing mechanism discovered, which was later found to exist in the majority of the Gram-negative bacteria.

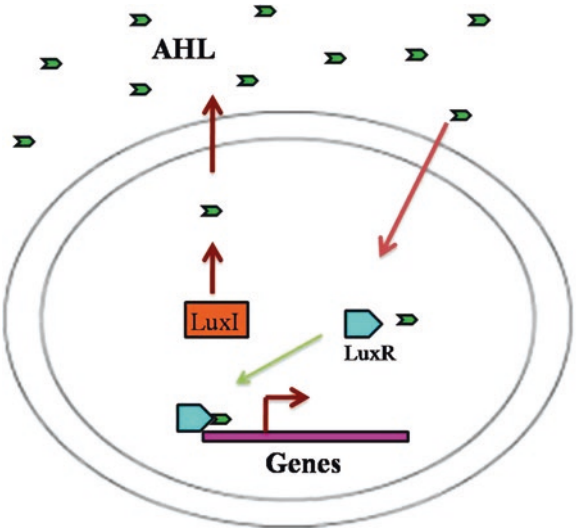

Fig. 14.1 Mechanism of quorum sensing in Gram-negative bacteria

Protein LuxI, which is a synthase, produces AHL (acyl-homoserine lactone autoinducer 3OC6-homoserine lactone). This AHL molecule can freely pass through the membrane; and when the amount of AHL reaches a threshold limit, the AHL binds to LuxR, a receptor and a DNA-binding transcriptional activator. This AHL-bound LuxR complex then activates the lux*I*CDABE operon which produces luciferase, responsible for light emission, and induces the expression of *lux*I, responsible for creating a positive feedback loop amplifying the entire process, causing the entire population to produce light.

Though other Gram-negative bacteria have similar mechanisms of activation of gene expression, they differ in the structure of AHLs produced. It was also found that the LuxR of each bacterium is highly specific for the AHL produced by that particular bacterial strain. Figure 14.1 explains the mechanism of quorum sensing in Gram-negative bacteria.

This hence helps in intraspecies communication.

14.3.2 Model II: Quorum Sensing in Gram-Positive Bacteria (Waters and Bassler 2005; Winzer and Williams 2001)

The autoinducer molecules of Gram-positive bacteria are small inducer peptides (oligopeptides, <10 amino acids). Quorum sensing in Gram-positive bacteria is well studied in *S. aureus.* The general mechanism is described in Fig. 14.2.

*agr*D codes for the AIP (autoinducing peptide) in *S. aureus*. These are impermeable to the bacterial membrane and require the assistance of ArgB protein to be exported from the bacterial cell. Once the level of the modified AIP reaches the

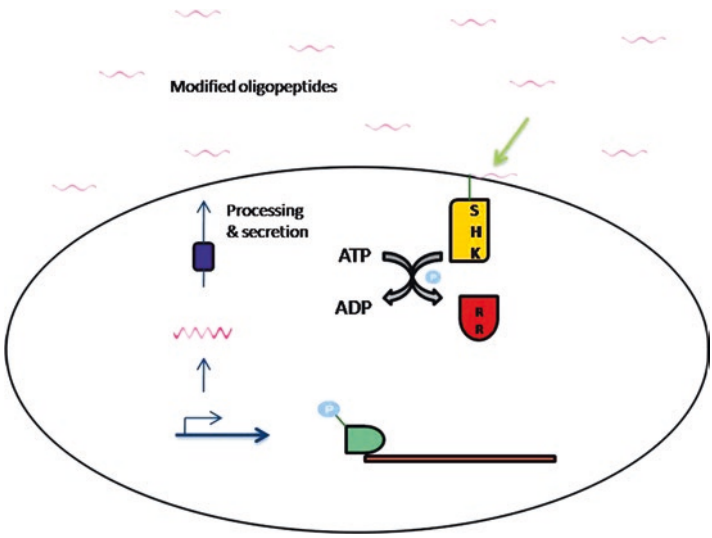

Fig. 14.2 Mechanism of quorum sensing in Gram-positive bacteria. *RR* response regulator, *SHK* sensor histidine kinase

threshold levels, they bind to AgrC receptor, which causes the phosphorylation of AgrA. This phosphorylated AgrA induces the expression of a regulatory RNA, RNA III, responsible for the production of various cell adhesion factors. This phosphorylated AgrA also activates the *agr*BDCA which stimulates the production of more AIP, hence shifting the equilibrium from cell adhesion to production of virulence factors, when there are an increased number of bacterial cells.

The signaling cassette of *S. aureus* is similar to peptide signaling cassettes of other Gram-positive bacteria.

14.3.3 Model III: Quorum Sensing in Other Bacteria (Bassler 2002)

This method was observed in *Vibrio harveyi.*

In this method, two kinds of autoinducer molecules are produced by the bacteria: one is HAI-I, which is similar to the autoinducer produced by other Gram-negative bacteria. The second autoinducer is AI-2, which is entirely different from AI of either Gram-negative or Gram-positive bacteria. It is a furanosyl borate diester. Once the threshold limits of AI are achieved, the expression of genes is induced by a mechanism similar to Gram-positive bacterial quorum sensing, by phosphorylation, causing the transcription of genes coding for quorum sensing-controlled mechanisms (Fig. 14.3).

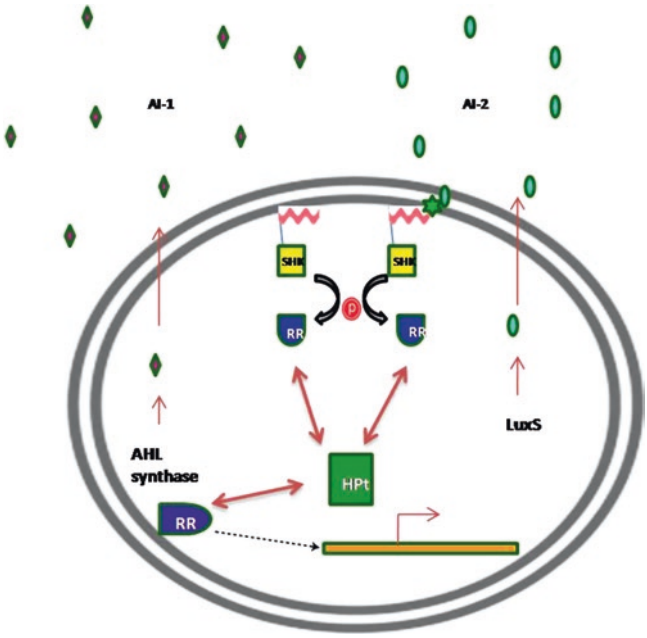

Fig. 14.3 Mechanism of quorum sensing in some bacteria. *RR* response regulator, *SHK* sensor histidine kinase, *HPt* histidine phosphotransfer protein

14.3.4 Model IV: Quorum Sensing in Fungi (Albuquerque and Casadevall 2012)

Quorum sensing was first discovered in the pathogenic fungus, *Candida albicans.* Since then, however, there has been a steady increase in the knowledge of quorum sensing systems in fungi. The autoinducers responsible for mediating the process in fungi are farnesol, tyrosol, phenylethanol, and tryptophol, the latter three being alcohols derived from aromatic amino acids, tyrosine, phenylalanine, and tryptophan. The signaling cascades that are operating in response to the autoinducer molecules that cause the expression of specific genes in fungi are poorly understood, due to their complexity. Farnesol from *C.* albicans, however, regulates filamentation and biofilm formation, reduces oxidative stress, specifically modulates drug efflux, and has detrimental effects on other microbes including bacteria (*S. aureus*) and other fungi (*Aspergillus* sps., *S. cerevisiae*). In other fungi, quorum sensing mediates differentiated expression of genes; however, the autoinducer molecules are not yet purified or identified.

14.4 Importance of Quorum Sensing

The field of quorum sensing holds impetus and relevance, in various fields like medicine, agriculture, industry, and aquaculture, as quorum sensing-mediated mechanisms render the bacteria susceptible to its consequent inhibition. In the case of human pathogens, biofilm formation and virulence expression are critical for the growth, multiplication and ability to cause disease. Since quorum sensing controls these critical steps for rendering them pathogenic, it is envisioned that the inhibition of quorum sensing can help in attenuation of a pathogen and render it noninfectious.

14.5 Quorum Quenching

The process of quenching or extinguishing the cell-to-cell communication mediated by small signaling molecules is known as quorum quenching. Following are some of the methods of quorum quenching.

14.5.1 Quorum Quenching in Gram-Negative Bacteria(Hentrez and Givskov 2003)

I. *Blocking the Signal Generation*

A critical step in the production of acylated homoserine lactones (autoinducer molecules) is the generation of homoserine lactone ring moiety, for which SAM (S-adenosyl methionine) acts as the amino group donor. It was observed that the presence of various analogs for SAM, such as S-adenosyl homocysteine, S-adenosyl cysteine, and sinefungin, led to the ability to block the production of the AHL signaling molecule.

II. *Inhibition of Signal Propagation*

Since the concentration of AHL is critical for the propagation of the signal, both enzymatic (AiiA from *Bacillus* sps. Catalyze the hydrolysis of AHL molecules) and nonenzymatic (alkaline hydrolysis at high pH) methods for degradation were studied. This line of analysis is of substantial clinical interest.

III. *Thwarting Receptor Binding*

Another method that is of interest in the blocking of quorum sensing signaling is the possibility of blocking of the binding of the AHL molecule to its receptor. This can be done either by competitive inhibition, where analogs structurally similar to AHLs are used, or by noncompetitive inhibition, where analogs that bind to other binding sites on the receptor are employed (Fig. 14.4).

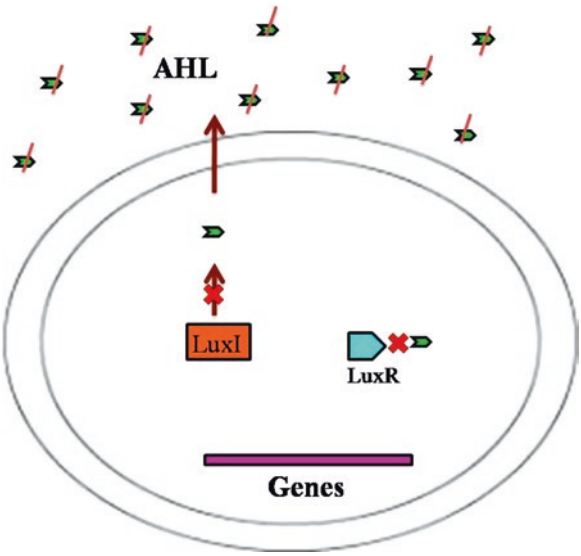

Fig. 14.4 Mechanism of quorum quenching in Gram-negative bacteria

14.5.2 Quorum Quenching in Gram-Positive Bacteria (Kalia 2013)

Different peptide blocking agents have been identified that inhibit quorum sensing-mediated gene expression in Gram-positive bacteria. Siomycin I is a peptide antibiotic that selectively inhibits the growth of Gram-positive bacteria by disruption of biofilm of *Enterococcus faecalis*. RNA III inhibiting peptide (RIP) affected the adhesion of *S. aureus* and *S. epidermis*. Truncated AIP II affected the cognate receptor AgrC-II and also inhibited virulence in four different strains of *S. aureus* (Fig. 14.5).

14.5.3 Quorum Quenching in Fungi (Hogan 2015)

The use of some chemical molecules achieves inhibition of quorum sensing in fungi. The mechanisms of inhibition are not well defined, as the process of quorum sensing in fungi is not so well understood. Nevertheless, few chemical molecules have been identified to quell the quorum signal in certain specific fungi.

14.6 Anti-quorum Sensing Activity

The molecules that act as antagonists for the inhibition of quorum sensing are of great interest, as they represent highly attractive targets for the development of novel therapeutics. It is speculated that this method of controlling microbial infections will circumvent the existing problem of antibiotic resistance. It was contemplated that some phytochemicals produced by plants might inhibit quorum sensing.

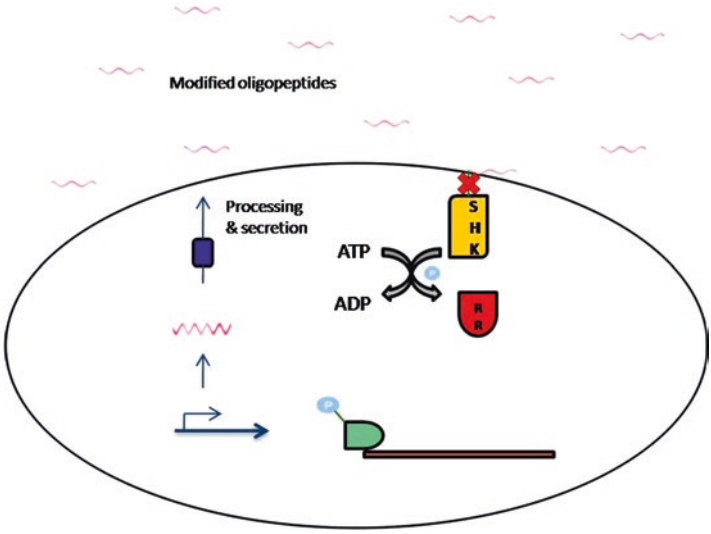

Fig. 14.5 Mechanism of quorum quenching in Gram-positive bacteria

Anti-quorum sensing compounds (halogenated furanones) were first characterized from Australian macro (red) algae *Delissea pulchra* (Zahin et al. 2010b). Spurred on by this discovery, there was a new interest in the discovery of more such quorum sensing inhibitors from other algae and plants in the scientific community. This led to the screening of several seaweeds, marine sponges, edible fruits and vegetables, essential oils (Packiavathy et al. 2012), and in particular plants already known to possess medicinal properties. Another factor that led to this accelerated screening of different terrestrial and marine sources for anti-quorum sensing activity was the development of fast and straightforward assay systems using biosensor strains that enabled the easy and efficient detection of anti-quorum sensing activity. This led to the unearthing of anti-quorum sensing ability of several algae, sponges, and plants.

This chapter focuses on the anti-quorum sensing properties of medicinal plants in particular.

14.7 Methods for Assessment of Anti-quorum Sensing Activity (McLean et al. 2004; Bacha et al. 2016; Khan et al. 2008)

A simple and rapid screening method was developed by McLean and his coworkers, to assess anti-quorum sensing activity of bacterial or plant samples. This method employs either one of the indicator cultures: *Pseudomonas aureofaciens* 30–84 or *Chromobacterium violaceum* ATCC 12472. This technique is a soft agar overlay protocol, based on the inhibition of pigment formation. In the case of plant samples, the test sample (leaf/flower/stem) is directly placed on LB agar plates. Subsequently,

the plates are overlaid with LB soft agar, which contains an inoculum of either one of the reporter bacterial strains. The plates are incubated overnight. Detection is facilitated as the reporter bacterial strains regulate pigment production by quorum sensing and are readily inhibited by AHL analogs and other antagonists. Inhibition of quorum sensing is indicated by a lack of pigmentation of the indicator culture in the vicinity of the tested sample. If there is lack of pigmentation coupled with an inhibition of the growth, the plant sample under study exhibits both anti-quorum sensing and antimicrobial properties.

This method of assay is rapid and accurate and can be quickly followed and mastered. As a result, this is commonly used, with slight modifications, wherever necessary by several researchers to ascertain anti-quorum sensing properties of different plant samples. Among the two reporter bacterial strains mentioned, *Chromobacterium violaceum* ATCC 12472 is more frequently used. This synthesizes a violet-colored pigment called violacein. The quorum signaling molecule involved is N-hexanoyl-L-homoserine lactone (HHL) produced by the autoinducer synthase CviR. The binding of this HHL to its receptor CviR triggers the expression of genes for the production of the violet pigment violacein.

Instead of placing whole plant samples, plant extracts can be pipetted onto sterile paper disks which are put on the agar plates (disk-diffusion method). Alternatively, wells can be made in the agar plates to hold the sample extracts (cup-plate method). The colorless, opaque but viable halo around the disks/well indicates the inhibition of quorum sensing (Figs. 14.6 and 14.7).

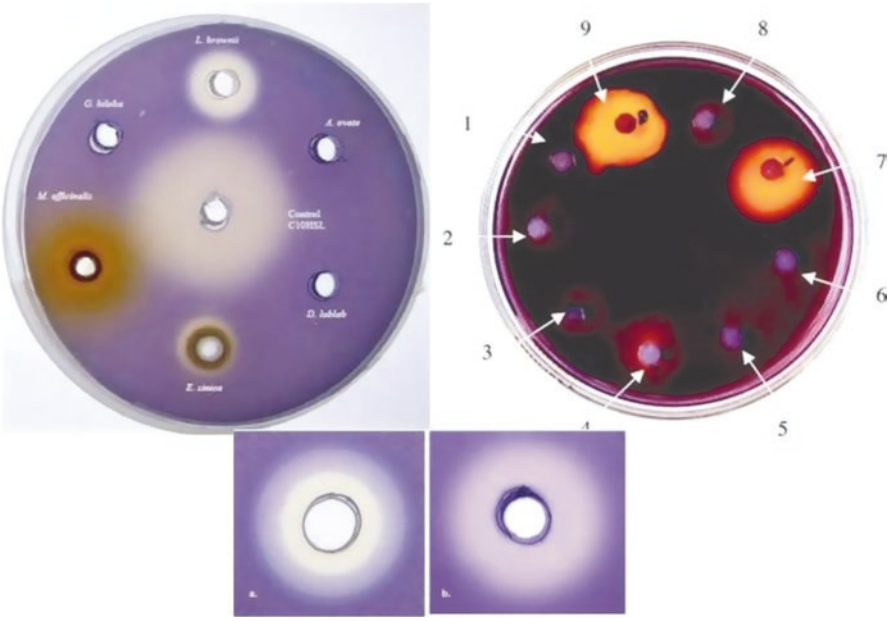

Fig. 14.6 Anti-QS activity indicated by clear zone/halo due to inhibition of violacein formation (Siew-Mian and Tham 2012; Singh et al. 2009c)

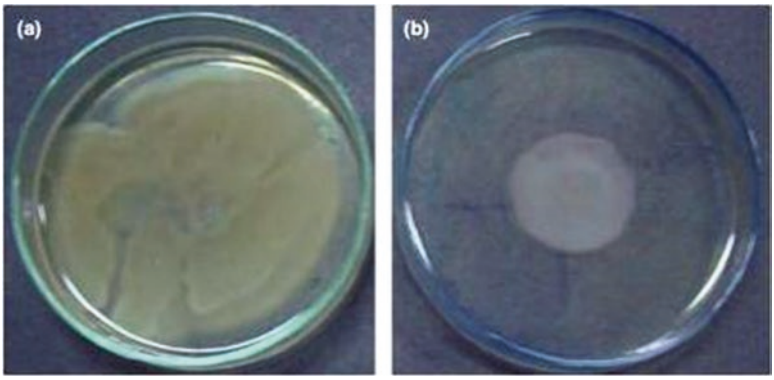

Fig. 14.7 Inhibition of swarming motility in the plate (**b**) when compared to control plate (**a**) using reporter strain PAO1 (Khan et al. 2008)

Another reporter strain of *E. coli*, AI1-QQ.1, is also used to assess anti-QS activity. This reporter consists of a gene encoding a lethal protein fused to a promoter induced in the presence of quorum sensing signaling molecule AHL. Consequently, the strain is unable to grow in the presence of AHL signaling molecules, unless a nontoxic QS-inhibiting compound is present.

Another method to strengthen the assumption of anti-QS activity of a plant uses a bioreporter strain *P.* aeruginosa, PAO1. The phenomenon of swarming in bacteria is considered to be a virulence factor as it is involved in the process of biofilm formation due to mass translocation of cells and this relies on the expression of biosurfactant molecules, the expression of which is under quorum sensing control in PAO1. Hence, any compound inhibiting the swarming motility in PAO1 is expected to interfere with quorum sensing and its regulated traits.

14.8 Anti-quorum Sensing Activities of Medicinal Plants

Several medicinal plants of different regions have been screened for their anti-quorum sensing activity. Some studies are a preliminary screening of medicinal plants; others extend to the detection of the compounds responsible. Some medicinal plants exhibiting anti-quorum sensing activity are discussed below (Fig. 14.8).

Cinnamomum verum is widely distributed in the tropical regions of the world. The bark is an important spice and a flavoring agent. It is known to exhibit antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and anticancer properties. It is also used for neurological disorders, cardiovascular diseases, and the improvement of lipid profile (Rao and Gan 2014).

The anti-QS activity of essential oil of cinnamon against reporter strains CV12472 and CV026 in the presence of natural C_6-AHL was assayed. A slightly

Fig. 14.8 Some plants possessing anti-QS activity

higher anti-QS activity was observed against CV12472 (zone of inhibition 12 mm) when compared to CV026 (zone of inhibition 11 mm) (Waters and Bassler 2005).

Mentha piperita is an important aromatic and medicinal crop. It is initially native to Europe, Canada, and the USA but is now cultivated in different parts of the world. The oil obtained is strongly scented and has medicinal and high commercial value as it is also used as a flavoring agent. The plant is used as an antiemetic, antispasmodic, and nasal decongestant. It is known for its antimicrobial and anti-inflammatory activity. It is also used in different gastrointestinal and hepatic disorders.(Shah and D'Mello 2004)

The commercially available essential oil of *M. piperita* was subjected to anti-QS activity against reporter strains CV12472 and CV026 in the presence of natural C_6-AHL. A higher zone of inhibition (11 mm) was obtained in the case of CV12472, when compared to that of CV026 (10 mm), showing that the essential oil of *M. piperita* possesses anti-QS activity.(Waters and Bassler 2005)

Syzygium aromaticum is native to East Indonesia but is produced in several regions like India, Malaysia, Sri Lanka, Indonesia, Madagascar, and Tanzania. It is an important spice. It is rich in several phenolic compounds and essential oils. It is well known for numerous pharmacological properties, which render it invaluable in a broad spectrum of medical conditions. It is known to possess antimicrobial, antioxidant, antiviral, antinociceptive, and larvicidal activity (Cortes-Rojas et al. 2014).

The ability of clove essential oil to inhibit quorum sensing was assayed using bioreporter strains CV12472 and CV026 in the presence of natural C_6-AHL. The essential oil of clove showed greater quorum sensing inhibition ability for CV12472 (zone of inhibition 19 mm) when compared to CV026 in the presence of natural C_6-AHL (zone of inhibition 17 mm). At higher concentration, clove oil showed inhibition of pigment formation of CV12472, indicating that the inhibition of quorum sensing is a function of the concentration of sample used. Inhibition of swarming motility by clove oil was also studied with reporter strain PAO1. It was observed that swarming motility was inhibited by clove oil, thus strengthening its anti-QS behavior. GC-MS analysis of clove oil was further studied. Major ingredient eugenol was individually tested for anti-QS activity and inhibition of swarming activity. Pure eugenol showed no anti-QS activity or inhibition of swarming motility. This implies that the anti-QS activity and inhibition of swarming motility exhibited by clove oil are due to the other compounds, like α-caryophyllene and β-caryophyllene of clove oil, either in isolation or combination with the various other compounds (Waters and Bassler 2005).

Moringa oleifera, commonly known as drumstick tree, is native to India but found in other tropical and subtropical regions of the world. It is known to possess antidiabetic and anticancer properties. The leaves, fruits, roots, and seeds are used for the treatment of abdominal tumors, scurvy, paralytic attacks, helminthic, bladder, prostate troubles, sores, and skin infections (Singh et al. 2009b).

The anti-quorum sensing potential of aqueous extract of leaf, fruit, and seed was studied using biomonitor strain *C. violaceum* (ATCC 12472) by disk diffusion assay. Strong anti-QS activity was observed for both leaf and fruit extracts. No activity was observed for seed extract (Singh et al. 2009a).

Tecoma capensis is commonly referred to as Cape honeysuckle. It is found in warm and cold regions of the world. It is known to possess antiplasmodial activity, relieve pain, and induce sleep (Saini and Singhal 2012).

Anti-QS activity was determined using *C. violaceum.* The ethanolic extract of both flower and leaf exhibited anti-QS activity with a zone of inhibition 11 ± 1.0 mm and 13 ± 0.5 mm, respectively (Al-Hussaini and Mahasneh 2009).

Lavandula angustifolia is commonly called as lavender; it is known for its carminative, antiflatulence, and anticolic properties. It is a sedative and possesses spasmolytic activity (Lis-Balchin and Hart 1999).

C. violaceum was used to determine the anti-QS potential of flowers (ethanolic extract) of *L. angustifolia.* An opaque zone of 9.5 ± 0.5 mm was observed, indicating that the flowers possess anti-QS activity (Al-Hussaini and Mahasneh 2009).

Rosmarinus officinalis (rosemary) is a popular perennial culinary herb cultivated all over the world. It is known for its antimicrobial, anticancer, antidiabetic, anti-inflammatory, antioxidant, antidiuretic, antiulcerogenic, and antithrombotic activity (Habtemariam 2016).

The ethanolic extracts of both flowers and leaves of *R. officinalis* exhibited anti-QS activity (zone of inhibition 9.0 ± 0.5 mm and 13 ± 0.5 mm, respectively) when assayed using *C.* violaceum (Al-Hussaini and Mahasneh 2009).

Jasminum sambac, commonly called Jasmine, is widely cultivated in several tropical regions like India and Malaysia. Traditionally, the oil extracted is used to treat cancer and heart disease, as an antidepressant, to soothe pain and anxiety, and to make skin smooth (Sabharwal et al. 2013).

The ethanolic extract of leaves and flowers was tested for their anti-QS activity using *C. violaceum*. Both extracts exhibited anti-QS activity with zone of inhibition 10.5 ± 0.9 mm and 9.0 ± 0.5 mm, respectively (Al-Hussaini and Mahasneh 2009).

Populus nigra is known for its antioxidant and anti-inflammatory properties (Dudonné et al. 2011).

The ethanolic extract of the leaves of *P. nigra* exhibited anti-QS activity, with a zone of inhibition of 8.5 ± 0.5 mm, when tested using *C. violaceum* (Al-Hussaini and Mahasneh 2009).

Populus alba, the white poplar tree, is widely distributed in Europe, Asia as well as North Africa. It is known to possess antifungal, antioxidant, antitumor, antiseptic, and antiviral activity (Haouat et al. 2013).

The ethanolic extract of the leaves of *P. alba* exhibited anti-QS activity, with a zone of inhibition of 10 ± 1.0 mm, when tested using *C. violaceum* (Al-Hussaini and Mahasneh 2009).

Sonchus oleraceus, commonly called sow thistle, is native to Asia and Europe. It possesses high antioxidant activity and is commonly used for alleviation of pain (Vilelathor et al. 2009a).

The ethanolic extract of the aerial parts of *S. oleraceus* was assayed for anti-QS activity (using *C. violaceum*). A zone of inhibition of 18 ± 0.5 mm indicated that it possessed an excellent anti-QS activity (Al-Hussaini and Mahasneh 2009).

Laurus nobilis is commonly referred to as the sweet bay tree and is a native to southern Europe. It is known to possess neuroprotective, antioxidant, antiulcerogenic, anticonvulsant, analgesic, anti-inflammatory, antimicrobial, insect-repellant, immunostimulant, and antimutagenic activity (Patrakar et al. 2012).

Ethanolic extract of the leaves, flowers, fruits, and bark was tested for anti-QS activity using *C. violaceum.* The highest activity was exhibited by the flowers (zone of inhibition 24 ± 0.9 mm), followed by the leaves (zone of inhibition 17.5 ± 0.5 mm) and bark (zone of inhibition 19 ± 0.5 mm), and the least activity was exhibited by the fruits (zone of inhibition 15 ± 0.9 mm) (Al-Hussaini and Mahasneh 2009).

Adhatoda vasica Nees is found in many parts of India and several regions of the world. It is a traditional medicinal plant of India, used in Ayurveda for treating various ailments. Pharmacognostic activities include antiulcerogenic, anti-allergy, antitubercular, abortifacient, antimicrobial, insecticidal, uterotonic, anti-asthmatic, bronchodilatory, and wound-healing activity (Gangwar and Ghosh 2014).

The anti-QS activity of hydroalcoholic leaf extract of *A. vasica* was checked using reporter strain *C. violaceum* CV12472. Anti-QS zone of 12 ± 0.3 mm was observed (Zaki et al. 2012).

Bauhinia purpurea L. is not only native to Asia but also found in some areas of America. It possesses antipyretic, anti-inflammatory, antinociceptive, antimicrobial, analgesic, antidiabetic, antioxidant, and antidiarrheal activity. It is also known for its wound-healing, nephroprotective, and hormone regulation capacity (Kumar and Chandrashekar 2011).

The hydroalcoholic extract of *B. purpurea* leaves was evaluated for inhibition of quorum sensing. A zone of 10 ± 0.1 mm indicated that the leaf extract possessed the ability to inhibit quorum sensing (Zaki et al. 2012).

Lantana camara L. is commonly known as Lantana or Wild Sage. It is an ornamental plant that is initially from America; now found in several parts of the world, including Africa and New Zealand. The plant possesses antimicrobial, antiulcerogenic, hemolytic, hypoglycemic, anti-inflammatory, antifilarial, anticancer, antifertility, and wound-healing properties (Kalita et al. 2012).

The leaf extract (hydroalcoholic) of *L. camara* was subjected to anti-QS assay using bioreporter strain CV12472. Anti-QS zone of 9 ± 0.6 mm was obtained, suggesting that the leaf of *L.* camara possesses mild quorum sensing-inhibitory properties (Zaki et al. 2012).

Myoporum laetum G. Forst. is found in South America, California, New Zealand. It is a shrub or small tree found in open grasslands or coastal regions. It is used traditionally as a medicinal plant in different parts of the world, like Egypt (Preston 2012).

The hydroalcoholic leaf extract of *M. laetum* when tested for anti-QS gave an inhibitory zone of 15 ± 0.4 mm, indicating that it may possess good ability to inhibit the expression of genes controlled by quorum sensing (Zaki et al. 2012).

Piper longum L. (long pepper) is native to Indo-Malaysian region. Though it can be commonly found growing wild in the tropical rainforests of India, Nepal, Indonesia, Malaysia, Sri Lanka, and the Philippines, it is also widely cultivated as it is a commercial crop of great value. It is used as a spice and as a traditional medicine. Pharmacognostic activities include stimulant effects, immunomodulatory, hepatoprotective, anti-inflammatory, antiamoebic, hypocholesterolemic, and antimicrobial activity (Khushbu et al. 2011).

The fruit extract of *P. longum* was subjected to quorum sensing-inhibitory assay, using CV12472 bioreporter strain. A zone of inhibition of 6 ± 0.1 mm indicated that the fruits possess mild ability to inhibit quorum sensing (Zaki et al. 2012).

Taraxacum officinale F. H. Wigg, commonly called dandelion, is distributed in several regions across the globe. It has been widely used in traditional medicinal systems. The root is considered as a gastrointestinal remedy, aiding in the liver and digestive function, while the leaf is used as a diuretic. Pharmacological activities include anti-inflammation and hypoglycemic activity (Yarnell and Abascal 2009).

A study of the anti-QS ability of the hydroalcoholic extract of the aerial parts of *T. officinale* exhibited its ability to quench the quorum sensing process for the production of violacein in reporter bacterial strain CV12472 (zone of inhibition observed 7 ± 0.4 mm) (Zaki et al. 2012).

Hemidesmus indicus (L.) Schult is a climbing plant that grows in different parts of India and is used by native healers for nephric complaints, syphilis, and sore mouth. It has antibacterial, anticancer, antidiabetic, antidiarrheal, anti-inflammatory, antioxidant, antiulcerogenic, antivenom, renoprotective, cardioprotective, and hepatoprotective effects (Weissner 2014).

The hydroalcoholic extract of the root of *H. indicus* was assayed for anti-QS activity at three different concentrations, 400 µg, 800 µg, and 1200 µg, using two bioreporter strains, CV 12472 and CV026. The highest activity was observed against CV 12472 at 800 µg, followed by the other two concentrations (zone of inhibition 800 µg, 16.0 ± 0.4 mm; 400 µg, 14.0 ± 0.4 mm; 1200 µg, 11.0 ± 0.3 mm). A similar trend was observed for using CV026 strain (zone of inhibition 800 µg, 14.0 ± 0.4 mm; 400 µg, 12.0 ± 0.4 mm; 1200 µg, 6.0 ± 0.3 mm). The extract also exhibited the ability to reduce swarming motility of PAO1 reporter strain (Zahin et al. 2010b).

Holarrhena antidysenterica is found in tropical and subtropical regions of Asia and Africa. It is used in Indian Ayurvedic medicine to treat diarrhea and dysentery. It is known for its antidiabetic, antidiarrheal, diuretic, antihelminthic, antimalarial, antimicrobial, antimutagenic, and antihypertensive activity (Sinha et al. 2013).

The bark of *H. antidystenterica* was assessed for anti-QS activity at three different concentrations, with two reporter strains, CV 12472 and CV026. More significant inhibition was observed with CV 12472 than CV026. In the case of CV 12472, a very high zone of inhibition was observed at the highest concentration, which consequently reduced with a decrease in concentration (zone of inhibition 1200 μg, 21.0 ± 0.5 mm; 800 μg, 15.0 ± 0.4 mm; 400 μg, 12.0 ± 0.3 mm). Relatively lesser anti-QS activity was exhibited against CV026 strain (zone of inhibition 800 μg, 11.0 ± 0.4 mm; 400 μg, 10.0 ± 0.4 mm; 1200 μg, 5.0 ± 0.2 mm). The extract also reduced the swarming motility of PAO1 reporter strain (Zahin et al. 2010b).

Mangifera indica, mango, is grown in many parts of the world. The plant is known for its antidiabetic, antitetanus, analgesic, antipyretic, antimicrobial, antiulcerogenic, antimalarial, cardioprotective, and bronchodilatory properties (Parvez 2016).

The ability to inhibit quorum sensing was assessed using hydroalcoholic leaf extract. The extract more efficiently inhibited quorum sensing against CV 12472 than CV 026 reporter strain (zone of inhibition CV 12472 1200 μg, 14.0 ± 0.4 mm; 800 μg, 12.0 ± 0.3 mm; 400 μg, 8.0 ± 0.2 mm; CV026 1200 μg, 11.0 ± 0.4 mm; 800 μg, 9.0 ± 0.4 mm; 400 μg, NIL). The inhibition of swarming motility was also good (65.9% reduction at a concentration of 800 μg/ml, determined using PAO1) (Zahin et al. 2010b).

Psoralea corylifolia is an important Indian and Chinese medicinal plant, widely distributed in the Asian subcontinent. It is known for its immunomodulatory, anti-inflammatory, antitumor, and antibacterial activity. The seed extract is used for a variety of diseases like leukoderma and impotence (Mounika 2016).

The anti-QS activity of hydroalcoholic seed extract was studied against reporter strains CV 12472 and CV026. The extract was more potent against CV 12472 than CV026. In the case of both extracts, the inhibitory capacity increased with increase in the concentration of extract (zone of inhibition CV 12472 1200 μg, 17.0 ± 0.5 mm; 800 μg, 11.0 ± 0.4 mm; 400 μg, 9.0 ± 0.2 mm; CV026 1200 μg, 14.0 ± 0.6 mm; 800 μg, 11.0 ± 0.5 mm; 400 μg, 8.0 ± 0.3 mm). The extract also exhibited an excellent ability (69.5% reduction, at a concentration of 1000 μg/ml) to reduce the swarming motility of PAO1 bioreporter strain. This signifies that the extract is potent and can control quorum sensing-mediated expression of genes (Zahin et al. 2010b).

Punica granatum is found in India and more arid regions of Southeast Asia, the East Indies, and tropical parts of Africa. It is known to possess high antioxidant activity and anticarcinogenic and anti-inflammatory activity. It is also used for dental conditions, in diabetes, and in male infertility (Jurenka 2008).

The hydroalcoholic extract of pomegranate rind was assayed for anti-QS properties with bioreporter strains CV 12472 and CV026. The extract was more potent on CV026 than CV 12472. The highest activity was observed at the highest concentration employed, 1200 µg, and no inhibition was observed at the minimum concentration in the case of both the reporter strains (zone of inhibition CV026 1200 µg, 12.0 ± 0.4 mm; 800 µg, 10.0 ± 0.4 mm; 400 µg, NIL; CV 12472 1200 µg, 7.0 ± 0.1 mm; 800 µg, 9.0 ± 0.2 mm; 400 µg, NIL). The extract was also tested for its capacity to inhibit swarming motility of PAO1 strain. It was found that the extract was potent and there was a 65.9% reduction in the swarming motility at an extract concentration of 500 µg/ml. This proves that the extract of pomegranate rind has a good anti-QS activity (Zahin et al. 2010b).

Aloe barbadensis is a well-known important medicinal plant. It improves the digestive system, protects the immune system, and helps fight stress. It is known for its wound-healing, anticancer, anti-arthritic, antidiabetic, and antimicrobial properties (Nandal and Bhardwaj 2012).

The anti-QS activity of hydro-acetone of aloe leaf extract was assessed using CVO26 bioreporter strain. There was no inhibition of violacein pigment production. Inhibition of swarming activity of reporter strain PAO1 was observed, the percent of reduction being 79.9%. This indicated that aloe could have anti-QS activity, as it showed inhibition of swarming activity. It is recommended that another assay be performed using other reporter strains like CV 12472 to establish the anti-QS activity (Siew-Mian and Tham 2012).

Angelica sinensis is a herb found in China, Japan, and Korea. The dried root is used traditionally to strengthen heart, liver as well as lubricate the bowel. It is considered as a blood tonic and is used for regulating the menstrual cycle. It is known for its anticoagulant, antispasmodic, and antifibrotic activity. It is also used for dysmenorrheal, cardiovascular disease, immune support, and hematopoiesis (Head 2004).

The root extract was studied for anti-QS activity. There was an inhibition of pigmentation; zone of inhibition of 13.5 ± 0.3 mm was observed for 50 µl of extract used. There was no inhibition of swarming when checked with PAO1 reporter strain; the extract promoted swarming when compared to the control (Siew-Mian and Tham 2012).

Astragalus membranaceus is a herbal immunomodulator and an antidiabetic drug. The roots have been used in many herbal formulations in China for the treatment of diabetes (Agyemang et al. 2013).

The root extract exhibited a very high inhibition of violacein production (zone of inhibition 34.0 ± 0.0 mm for 50 µl of extract used) when assayed for anti-QS

activity with CV026 strain.). No inhibition of swarming motility was detected when assayed with PAO1 reporter strain (Siew-Mian and Tham 2012).

Cnidium monnieri is a plant commonly used in the traditional Chinese system of medicine. The plant is a source of osthole (7-methoxy-8[3-methyl-2-butenyl]-2H-1-benzopyran-2-one), which is known for its anticancer, anti-inflammatory, antioxidant, immunomodulatory, antimicrobial, and antiparasitic properties. It is also well known for its neuroprotective, hepatoprotective, and cardiovascular benefits (Zhang et al. 2015).

50 µl of a hydro-acetone extract of the seed was subjected to anti-QS assay using reporter strain CV026. No inhibition of pigmentation was observed. The extract was however found to inhibit swarming of reporter strain PAO1 to a great extent (percent of reduction- 78.8%). This indicated that *C. monnieri* could have anti-QS activity, as it showed inhibition of swarming activity. It is recommended that another assay be performed using other reporter strains like CV 12472 to establish the anti-QS activity (Siew-Mian and Tham 2012).

Crataegus cuneata is widely distributed throughout the Northern temperate regions of the world. It is known for its activity on the reproductive system (Kumar et al. 2012).

A study of the anti-QS activity of the fruit extract using CV026 revealed that the extract was able to inhibit pigmentation (zone of inhibition 14.2 ± 0.4 mm). No inhibition of swarming motility was detected when assayed with PAO1 reporter strain (Siew-Mian and Tham 2012).

Dioscorea nipponica is used for rheumatoid arthritis, asthma, and bronchitis. It is also known for its anticancer activity (Ho et al. 2011).

The tuber extract of *D. nipponica* was assayed for anti-QS activity using CV026. A considerable zone of inhibition of pigment formation of 13.8 ± 0.2 mm indicates that it could possess anti-QS activity. There was no inhibition of swarming when checked with PAO1 reporter strain; the extract promoted swarming when compared to the control (Siew-Mian and Tham 2012)

Ephedra sinica is found in Asia, Europe, and some areas of America. It is used in Chinese and Indian traditional medicinal systems. It is known to have anti-inflammatory activity. It is a source of the neurotransmitter epinephrine (Abourashed et al. 2003).

A 50 µl hydro-acetone branch extract of *E. sinica* was subjected to anti-QS assay with reporter strain CV026. There was inhibition of violacein production (zone of inhibition 12.0 ± 0.0 mm). The extract promoted swarming, as there was an increase

in the colony of PAO1 (compared to control) which was used as a reporter strain (Siew-Mian and Tham 2012).

Lilium brownii is a traditional medicinal plant native to China and India, but has been cultivated in different countries of Europe also. It is used in the treatment of backaches, dizziness, impotence, urinary disorders, and fever. It is known for its antipyretic and antidiabetic properties (Okubo et al. 2012).

The bulb extract of *L. brownii* was checked for anti-QS activity. A zone of inhibition of 17.3 ± 0.3 mm indicated that there was an inhibition of pigment formation. The extract was also able to inhibit swarming greatly; a reduction percent of 64.8% was observed on reporter strain PAO1. This suggests that the plant has potent anti-QS activity (Siew-Mian and Tham 2012).

Magnoila officinalis is a common Chinese medicinal plant. It possesses antioxidant, anti-inflammatory, antitumor, and antimicrobial activity (Shen et al. 2010). The bark extract of *M. officinalis* was screened for anti-QS activity.

There was a high inhibition of violacein production; a creamy-white halo (diameter 23.7 ± 0.3 mm) was observed. The extract promoted swarming, as there was an increase in the colony of PAO1 (compared to control) which was used as a reporter strain (Siew-Mian and Tham 2012).

Panax pseudoginseng is commonly called false Ginseng or Indian Ginseng. It is found in India, China, Tibet, Nepal, Bhutan, and Myanmar. It is a conventional folk medicine. It is known for its anticancer, anti-asthma, and anticonvulsive effects. Traditionally, it is used for the treatment of headaches, hemorrhagic disease, dyspepsia, and palpitations (Nayar and Sastry 1990; Selvam 2012).

Screening of the root extract for anti-QS activity using CV026 revealed the ability to inhibit pigmentation (zone of inhibition 12.7 ± 0.3 mm). The extract was also able to inhibit swarming greatly; a reduction percent of 60.2% was observed on reporter strain PAO1. This suggests that the plant has potent anti-QS activity (Siew-Mian and Tham 2012).

Albiza schimperiana is traditionally used as a medicine for the treatment of bacterial infections like pneumonia and other parasitic infections such as malaria (Kokila et al. 2013).

The methanol extract of the root of *A. schimperiana* displayed quorum sensing activity, when screened using *E. coli* reporter strain AI1-QQ.1, suggesting the presence of AHL interfering molecules in the extract (Bacha et al. 2016).

Justicia schimperiana is known to be used in the traditional system of medicine in Ethiopia. The leaves are popularly used for the treatment of liver disease, diarrhea, dysentery, and other stomach disorders (Correa and Alcantara 2011).

Petroleum ether extract of the seed of *J. schimperiana* revealed the ability to quench quorum signaling, hinting that the extract possibly possesses AHL interfering molecules (Bacha et al. 2016).

Prunus armeniaca is commonly known as apricot. It is a deciduous tree that is native to the continental regions of the globe but is also widely cultivated in other areas. The antimicrobial, anticancer, antioxidant, and hepatoprotective activity of *P. armeniaca* have also been reported. It is consumed as a fruit and is used in the traditional system of medicine for asthma, constipation, and cough and to soothe irritated skin (Raj et al. 2012).

No zone of inhibition was observed when the plant extract (seed kernel) was tested with reporter strain CV026 for quorum sensing activity. However, inhibition of swarming was identified with PAO1 reporter strain, as exhibited by a 29% reduction in colony area (Koh and Tham 2011).

Prunella vulgaris belongs to the mint family and is very popularly used in European, Chinese, and Indian traditional medicinal system. It is used to treat fever and throat infections and for wound healing. Its antimicrobial, anti-inflammation, antidiabetic, and antistress activity has also been scientifically evaluated (Rasool and Ganai 2013).

Anti-quorum sensing activity was assessed using reporter strain CV026 and a zone of inhibition of 15.5 mm was observed indicating the ability of *P. vulgaris* to inhibit quorum sensing. No inhibition in swarming motility was identified; on the contrary, the whole plant extract was observed to promote swarming motility when tested with PAO1 (Koh and Tham 2011).

Nelumbo nucifera, commonly known as the lotus, is an aquatic plant found in Asia, known for its medicinal properties. Traditionally, it is used in the treatment of tissue inflammation, cancer, diarrhea, skin diseases, nervous disorders, and leprosy. Several bioactive compounds like β-sitosterol, quercetin, ginnol, and nuciferine have been reported and characterized from lotus plant (Paudel and Panth 2015).

Leaf extract of lotus possesses the ability to inhibit quorum sensing, as a zone of inhibition of 16 mm was observed when CV026 reporter strain was used. Promotion of swarming motility was observed compared to the control when PAO1 reporter strain was used (Koh and Tham 2011).

Panax notoginseng is a Chinese medicinal herb widely cultivated in different parts of China. It is used to promote blood circulation, for the treatment of fractures, injuries, vertigo and reduces swelling and pain. Its anti-inflammatory, antioxidant, antitumor, antimicrobial, antidiabetic, renal protective, and hepatoprotective activity has been scientifically evaluated (Ng 2006).

The hydro-acetone flower and root extract of *P. notoginseng* exhibited anti-QS activity against both CV026 and PAO1 reporter strains. A zone of inhibition of pigmentation of 20 mm was observed for CV026 strain, and 32% inhibition of swarming motility was observed in the case of flower extract. The root extract exhibited higher activity, a zone of inhibition of 24 mm was observed for CV026, and 50% inhibition of swarming motility was observed with PAO1 (Koh and Tham 2011).

Areca catechu is a variety of palm plant grown extensively in Asian countries as a seed crop. The alkaloids present in the seed are intoxicating and addictive when chewed. It is an antidepressant, a sedative, and a narcotic-analgesic. It is proved to possess antioxidant, antivenom, anticancer, antihelminthic, and molluscicidal activity. Several alkaloids, like guvacine, guvacoline, isoguvacine, arecaidine, arecolidine, norarecaidine, and norarecoline, have been reported to form seeds of *A. catechu (*Jaiswal et al. 2011*)*.

The seed extract of *A. catechu* showed the ability to inhibit QS when tested with two reporter strains: CV026 and PAO1. A clear zone of 18 mm (absence of pigmentation) was observed in the case of CV026. Efficient inhibition of swarming motility was observed, with a high percentage of 79% against reporter strain PAO1 (Koh and Tham 2011).

Imperata cylindrica is commonly known as Cogon grass and is a perennial monocot plant. It is traditionally used in the treatment of diabetes, gout, common cold and cough, anemia, and urinary calculi. It possesses antihelminthic, antibacterial, anticancer, antidiuretic, antidiarrheal, and anti-arthritic activity (Parvathy et al. 2012).

The hydro-acetone extract of the underground stem exhibited the ability to inhibit QS as illustrated by the study on reporter strain CV026, where pigmentation inhibition was depicted by a zone of inhibition of 20 mm. When the reporter strain PAO1 was used for analysis, no inhibition of swarming motility was observed; in fact, the plant extract was found to promote swarming (Koh and Tham 2011).

Myristica cinnamomea is a folk medicine in many regions of Asia like Malaysia, Singapore, and Sumatra. It is known for its antimicrobial, nematocidal, and anti-ulcerogenic activity.

QS inhibition was observed with reporter strain CV026. In particular, malabaricone C from the methanolic bark extract was found to inhibit violacein production

by CV026. Similarly, anti-QS activity was observed with reporter strain PAO1; malabaricone C was found to decrease the production of pyocyanin by PAO1. However, no adverse effects on the viability of PAO1 were observed (Chong et al. 2011).

Acacia nilotica L. is widely distributed in the tropical and subtropical regions. It is used traditionally for the treatment of cancer, diarrhea, tuberculosis, leprosy, bleeding piles, cold, cough, and fever. Antioxidant activity, inhibition of lipid peroxidation, and prevention of DNA damage of *A. nilotica* have also been scientifically evaluated.

The hydrolyzed crude extract and the hydrolyzed ethyl acetate fraction of the pods of *A. nilotica* exhibited a dose-dependent inhibition of violacein production by the biomonitor strain CV 12472. Among the two extracts, the hydrolyzed ethyl acetate fraction showed higher QS inhibition. The inhibitory effect of hydrolyzed ethyl acetate fraction ranged from 15.24 ± 0.82 to 100 ± 4.04%, while the inhibitory effect of hydrolyzed crude extract ranged from 11.11 ± 0.73 to 91.26 ± 4.62% (Singh et al. 2009c).

Allium sativum, commonly called garlic, is a small underground bulb which is native to Central Asia but is widely cultivated in several parts of the world. It is famous for its medicinal properties and as a spice used in culinary preparations. It has been used traditionally for the management of blood pressure, high cholesterol, heart attack, and coronary disease. It was found to be useful for the treatment of different cancers, diabetes, gout, microbial infections, diarrhea, and arthritis (Neeraj et al. 2014).

It possesses anti-QS activity as observed with reporter strains *C. violaceum*, *P.* aeruginosa, and *A. tumefaciens* strain NLT4 (Kalia 2013).

Ocimum sanctum, commonly referred to as holy basil or tulsi, is a native to India but cultivated in other regions. It is a folklore treatment for various conditions like cancer, diabetes, pain cough, liver conditions, and hypotension. Its antimicrobial, wound-healing, antidiabetic, antioxidant, anticancer, immunogenic, antihelminthic, antiulcerogenic, cardioprotective, and larvicidal activity has been established (Rahman et al. 2011).

Quorum quenching ability of *O. sanctum* was assessed using *C. violaceum* and PAO1 reporter strains. Inhibition of violacein production and pyocyanin pigment formation and biofilm production were observed, respectively (Kalia 2013).

Pisum sativum, commonly known as a garden pea, is used extensively as a pulse for consumption. Pharmacognostic evaluation has revealed that it possesses antidiabetic, anticancer, antioxidant, anti-inflammatory, and antimicrobial activity. Pea plant is rich in apigenin, hydroxybenzoic, hydroxycinnamic, luteolin, and

quercetin, all of which have been reported to contribute to its therapeutic properties including anticarcinogenic property (Rungruangmaitree and Jiraungkoorskul 2017).

The seed, root, and leaf extracts of *P. sativum* inhibited violacein production in the reporter strain CV0blu, indicating that it possessed anti-QS activity. In addition, the seed extract exhibited the ability to inhibit the swarming motility of *S. liquefaciens* MG1 reporter strain and C4HSL-inducible protease and N-acetylglucosaminidase in CV026 reporter strain (Kalia 2013).

Medicago sativa is commonly called alfalfa and is used as an Ayurvedic and homeopathic medicine to treat central nervous system disorders. It is reported to have antioxidant, anti-inflammatory, antidiabetic, and neuroprotective activity (Bora and Sharma 2011).

The anti-QS activity of *M. sativa* exhibited the ability of the seed extract to inhibit the production of violacein pigment by the biomonitor strain *C. violaceum (*Kalia 2013*)*.

Alyssum maritimum is commonly referred to sweet alyssum. The flower and aerial parts of the plant are used as an infusion for kidney stones. It is also known to possess hepatoprotective and antiulcerogenic activity (Parada et al. 2009).

Slight inhibition of pigment formation was observed with reporter strain *C.* violaceum CV0blu indicates the moderate ability to inhibit QS (Kalia 2013).

Ananas comosus, commonly referred to as pineapple, is one of the most important commercial fruit crops in the world. It is known to possess anti-inflammatory, antioxidant, antimicrobial, analgesic, and hypoglycemic effects (Hossain et al. 2015).

The quorum quenching ability of *A. comosus* was studied using *C. violaceum* and PAO1 biomonitor strains. With both biomonitor strains, anti-QS activity was observed. Inhibition of the production of violacein by the *C. violaceum* and inhibition in pyocyanin pigment, staphylolytic protease, elastase production, and biofilm production by PAO1 indicate the ability of the plant to act as a QS inhibitor (Kalia 2013).

Manilkara zapota, commonly known as sapota or chickoo, is a tropical widely cultivated fruit. It is known to possess antimicrobial, antitumor, anti-inflammation, antipyretic, analgesic, hepatoprotective, hypoglycemic, antidiarrheal, and hypocholesterolemic effects. Several of its phytoconstituents have been isolated and characterized like erythrodiol, lupeol acetate, D-quercitol, myricitrin, quercitrin, and manilkoraside (P. Milind and Preeti 2015).

Inhibition of pigment production by reporter strain *C. violaceum* demonstrates the anti-QS ability of the plant. With PAO1 reporter strain, the plant extract was able to obstruct pyocyanin pigment, staphylolytic protease, elastase production, and biofilm production, suggesting its ability to act as a suitable quorum quenching agent (Kalia 2013).

In addition to the plants mentioned above, there are many more medicinal plants screened for inhibition of quorum sensing. A few more plants screened for anti-QS activity are listed in the table below (Table 14.1).

Table 14.1 Plant-based quorum sensing inhibition (Kalia 2013; Koh et al. 2013)

S. no.	Plant name	Organism employed	Anti-QS activity observed
1.	*Vanilla planifolia* extract	*C. violaceum* CV026	Inhibition of violacein production
2.	Rasberry extracts	*C. violaceum*	Inhibition of violacein production
3.	Blueberry extracts	*C. violaceum*	Inhibition of violacein production
4.	Grape extracts	*C. violaceum*	Inhibition of violacein production
	Grape fruit juice	*E. coli*	Inhibition of biofilm formation
		P. aeruginosa	Inhibition of biofilm formation
		S. Typhimurium	Inhibition of biofilm formation
5.	Squash exudate: γ-hydroxybutyrate (GHB)	*A.* tume*faciens*	Inhibition of AHL signaling
6.	Tomato seedlings exudate: γ-hydroxybutyrate (GHB)	*A. tumefaciens*	Inhibition of AHL signaling
7.	*Musa paradisiaca*	*C. violaceum*	Inhibition of pigment formation
		P. aeruginosa PAO1	
8.	Tea tree	*C. violaceum* CV026	Inhibition of pigment formation
9.	*Cinnamomum zeylanicum*	*P. aeruginosa*	Inhibition of biofilm formation
	Cinnamon oil component-cinnamaldehyde	*E. coli*	Inhibition of biofilm formation
		V. harveyi	Inhibits AHL- and AI-2 mediated QS
	Cinnamaldehyde and its derivative: 4-NO2-cinnamaldehyde	*Vibrio* sps.	Inhibition of AI-2 mediated QS-bioluminescence, protease activity, pigment formation
10.	Thyme	*C. violaceum*	Inhibition of violacein production
11.	Turmeric	*C. violaceum*	Inhibition of violacein production
12.	Ginger	*C. violaceum*	Inhibition of pigment formation
13.	*Ocimum basilicum* (sweet basil): Rosmarinic acid	*P. aeruginosa*	Inhibition of protease and elastase production, biofilm formation, and virulence factors
14.	*Passiflora incarnata* leaf extract	*C. violaceum* CV0blu	Inhibition of violacein production
15.	*Ruta graveolens* leaf extract	*C. violaceum* CV0blu	Inhibition of violacein production

14.9 Conclusion

The discovery of penicillin in the early nineteenth century by Fleming fueled the drive to discover more such agents that could eradicate disease-causing microorganisms. Many plants yielded bioactive compounds which were characterized, synthetically produced on a large scale, and used as antibiotics. However, microorganisms are opportunistic and devised mechanisms to evade destruction by antibiotics. This, coupled with the indiscriminate use of these antibiotics, led to the development of multidrug-resistant pathogens. A quest to unearth new molecules that could combat these multidrug-resistant strains began.

As quorum sensing mediates gene expression of several important events that are critical to causing infections, it was envisioned that inhibition could be exploited to contain the growth and expression of virulence of pathogens. Different plants were screened for their ability to inhibit quorum sensing. This chapter deals with some of the plants that exhibited anti-quorum sensing activity on testing. It was observed that many medicinal plants have the potential to act as inhibitors for quorum sensing. Further study is required though, to identify the phytoconstituents that are responsible for inhibition.

A novel approach would be to use plants that have both antimicrobial and anti-quorum sensing activity. Many plants exhibit antimicrobial activity, but only few exhibit both antimicrobial and anti-quorum sensing activity. Identification of such plants and a detailed study of the individual compounds responsible for the activity and the mechanism of action will lead to the development of new lead molecules that can be used to give sustainability to combat microbial infections.

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