# Anti-quorum sensing activity of plants

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Quorum sensing (QS) plays an important role in infections and virulence of pathogen microorganisms. The definition of mechanisms and disruption of quorum sensing in pathogen microorganisms currently is a high point in microbiology. QS can be blocked by antimicrobial chemotherapy. Bioactive components are extracted from plants and some of them affect the mechanism of QS. Increasing demands to find alternatives to antibiotic induces researches about QS and disruption of this mechanism. Inhibition of QS mechanism is an effective method to avoid infections. Many plants, spices, essential oils, and polyphenols, which naturally occurs, have antimicrobial properties. These antimicrobial agents have an importance to fight pathogen microorganisms since multidrug resistant microorganisms pose danger for human health. There are many reports about the anti-QS activity and chemical composition of essential oils of plants. The aim of this chapter is to summarize the literature findings of the anti-QS properties of medicinal plants and mechanisms of their actions.

**Keywords**: Quorum sensing (QS); pathogen; bioactive components; plants; anti quorum sensing activity

## 1. Introduction

Plant extracts have some antimicrobial components and they have been used as antimicrobial agents for many years. The last researches showed that the microbial biofilms are formed after the cell-to-cell communications (quorum sensing-QS) among the microbial species. Some plant extracts affect and prevent the biofilm formation in the microbial species with their blockage systems on the QS molecules. QS can be defined as a mechanism allows the perception and awareness the microbial cell population and when the density of the cells reaches the sufficient level the gene expressions appear to response the density of the microbial cells. This perception is provided by small signalling molecules termed as auto-inducers (AIs). According to the environmental conditions the stress resistance, toxin productions and secondary metabolite productions as well as the pathogeny, swarming and biofilm formation are the common phenotypic behaviours in microorganisms by the communication with signal molecules [1,2,3]. Plants have alternative defence systems unlike human or mammals which include the production of compounds prevent the QS mechanism and they are called anti-QS compounds that could be used as pathogen prevention agents. Eukaryote microorganisms can manipulate the bacterial QS system and therefore they protect themselves from the pathogen bacterial contaminations [1,3].

In some countries, the traditional medicinal plants having different properties have been researched to determine their anti-QS mechanisms and the efficiencies on the signalling systems of the microbial communities. Signalling molecules vary according to the microbial species and groups. In bacterial systems, QS mechanism is controlled by different AIs such as acylated homoserine lactones (AHL) in Gram negative bacteria and oligopeptides and amino acids in Gram positive bacteria. The QS system in fungi has been researched recently and it has been reported that farnesol and tyrosol are the most signal molecules that are faced in the fungal studies [1,3]. Small molecules are known as a good source of quorum sensing inhibitors (QSIs). Thus, QS mechanism of pathogens can be blocked by such antimicrobial compounds extracted from plants. Terpenoids are the main constituents of essential oils of plants and they have a low molecular weight which provides their transportation across the cell membranes easily. According to the main findings, plant phenolics which are known as flavonoids, benzoates, stilbenes, coumarins, phenyl propanoids, gallotannins, and proanthocyanidins are important QS-blocking agents. Besides, organosulfur and quinones and some of the alkaloids have anti-QS activities. When all these anti-QS activities considered, multidrug resistant pathogens could be inhibit with alternative methods of producing a new drug-like compounds prepared by plant extracts.

## 2. Quorum Sensing (QS) mechanism

Cell to cell communication has been observed widespread in microbial strains. The communication results in the changes in microbial phenotype changes. The behaviours are shaped according to the environmental conditions that microorganisms found in. The basis of the QS mechanism in the microbial life cycle is becoming more resistant to survive under inadequate conditions such as intolerable pH and temperature or lacking nutrition. QS is not only a perception of the population density but also a control system of cell maintenance, proliferation, cell behaviours, the gene transfers, and the interaction between host and other microorganisms [4,5].

QS was first determined and introduced in 1994. The AIs and their secretions and the understanding of the mechanism have become significant [4]. During the microbial growth, the signal molecules have been continued to produce and release to the medium where microorganism found and when the AIs amounts reach the threshold level, the gene expressions are regulated.

The QS system is correlated directly with the crucial elements which are [6];
1. The AIs
2. The signal synthesizing
3. The signal receptor
4. The signal response regulator
5. The regulated genes [6,7].

In bacterial strains, the signal molecules are typical for G-(+) and G-(-) bacteria cells. The derivatives of the peptides and derivatives of the fatty acids are known signal molecules of G-(+) and G-(-) bacteria respectively. It has been reported that the genera *Bacillus, Enterococcus, Staphylococcus, Streptococcus* and *Streptomyces* can exploit the QS mechanism to survive under the insufficient conditions, for this aim, they develop their genetic competence ability and form biofilm layer to produce effective seconder metabolites such as antimicrobial peptides and toxins. The best known QS mechanism is which observed in G-(-) bacteria [4]. The QS system in G-(-) bacteria is based on LuxI/LuxR homologues. N-acyl-homoserine lactone (AHL) synthase are carried out by encoding in LuxI homologues, on the other hand, the transcription of regulatory protein depending on the cognate signal molecules and activities about the transcription of the QS target genes have been encoded and organised by LuxR homologues [5,8]. The signal molecules produced and released by G-(-) bacteria are in the family of AHLs. The AHL dependent QS mechanism was first determined and termed in the bacterium *Vibrio fischeri*. The determination of the QS system in the bacteria had been detected after the recognition of the bioluminescence with the increase in density of the population [4,9]. In G-(+) bacteria, the auto inducers are amino acids and secreted short peptides unlike the system observed in G-(-) bacteria for QS. In yeast strains, biocarbonate, acetaldehyde and ammonia are well known signal molecules [6,10,11].

The microorganisms as well as plants respond to QS signals. OC12-HSL is one of the molecule produced by *Pseudomonas aeruginosa* that affects *Candida albicans*. On the other hand, curcumin, the phytochemical molecule, obtained from *Curcuma longa* has the capability of inhibition of signalling system of *Esherichia coli, Salmonella typi, Candida albicans* and *Sachharomyces cerevisiae* [3,5,12]. Moreover, farnesol is one of the signal molecule which is found in the biofilm matrix produced by *Pseudomonas aeruginos*a, and it can degrade the pathway of the QS system of *Candida albicans* [6,8,10,11].

The quorum sensing mechanism is an advantage for microbial communities for adaptation to the rapid changes in environmental conditions. Farnesol is the most known molecule for communication in between fungi species. Besides, aromatic alcohols, tyrosol, dodecanol and ɣ-butyrolactone are other molecules which have been identified as mediators of QS processes in eukaryotic organisms. The filamentous fungi have QS mechanism as well and the signal molecules found in the filamentous fungi such as *Aspergillus* and *Penicillium* species are secondary metabolites in general. Penicillin is one of a QS molecule as well as the secondary metabolite that regulates growth profile of *Aspergillus nidulans* [13]. The cell to cell communications could be also observed in the different genus of microorganisms such as bacteria-fungi, yeast-fungi interaction [14].

The microbial infections are associated with QS of the pathogens and in this regard, the microbial infection follows the pathway;

**Adhesion** is the first and the crucial step of the infection. The pathogen microorganism adheres to the host cell and tissue by their fimbria, pili, etc.

**Penetration** is the second step and in this part, the microorganism penetrates the host cell or tissue.

**Multiplication** is another step and the penetration is followed by multiplication. In this part, the microorganisms take the control of the host cell to produce the molecules which they need for growth and accelerating the accumulation in the host cell or tissue.

**Evasion** step provides the getting free from the host cell,/tissue. The toxin production and releasing of the toxins have been carried out at this stage [15,16].

The QS and the biofilm formation, the causation of the infections and becoming more resistant against harsh conditions are the results of the cumulative behaviours of the microorganisms. The pathogeny can not be thought without the QS mechanism. In this circumstance, the orchestrated activity of the microorganisms is a key research area to describe the QS mechanism [15,17].

## 3. Quorum quenching (QQ) mechanism of the plants

Quorum quenching (QQ) is an approach that can be described as interrupting/preventing the microbial communication instead of killing the microorganism [8]. QQ strategies are based on the disruption of the signal molecules that produced and secreted by the microorganisms. The disruption of the QS mechanism has been provided with small QS inhibitors (QSI), AHL-lactonase, AHL-acylase and paraoxonase enzymes [15]. The usage area of the natural products increases recently, because of the many beneficial properties of natural products. Plant food extracts and phytochemicals have been used in the food science and medicine due to their wide range beneficial effects against many diseases as well as antimicrobial effects [8]. Natural products are the common demand of the consumers in the food industry because of the therapeutic values in traditional applications. In recent years, biological functions and the

therapeutic effects of natural food products and their interactions between the microorganisms have been considered as the rising interest industrially. The biologically-active components found naturally in the plants have been opened a new door into the exploration of new-generate drugs and antimicrobial agents which might be used in the food industry as natural preservatives. Moreover, the synergistic effect of the extracts has been observed in the researches and the crude plant extracts have more efficacy than their isolated components individually. This synergy might be provided by active components existed together [8,12]. According to the several researches, the quorum quenching mechanism has been found in the natural plant-derived products as well as microorganisms. For example, N-acylhomoserine lactonase enzyme termed as AiiA could be isolated from *Bacillus* sp., and the enzymatic activity has been observed with the hydrolysation of the lactone bond found in the AHL signalling molecule. Several AIs inhibits many microbial strains such as *Bacillus, Agrobacterium, Rhodococcus, Streptomyces, Pseudomonas, and Klebsiella*. The acylase activity has been also observed in *Pseudomonas* and *Streptomyces* [18]. On the other hand, QS antagonist components which are isolated from plants are well-known flavonoids found in almost all parts of the plants. It has been known that the flavonoids impart the relevant colours to the flowers and fruits. The colour provider components act a key role in the protection of the plant from insect pests. The flavonoids have also the QQ mechanism against the communication among the microbial [1,3]. In general, the target of biological components is the microbial QS system and the effect of the compounds are carried out with inactivating, degrading or modifying the signal molecules. QQ system blocks the completion of QS mechanism in a correct way. The basis of QQ mechanism is a requirement of the plant to protect itself against the pathogen attacks [3]. Some of the antagonist plant extracts could be listed as; *Vaccinium macrocarpon, Rubus idaeus, Origanum vulgare, Rosemarinus officinalis, Ocimum basilicum, Brassica oleracea, Curcuma longa, Zingiber officinale*. The extracts have QQ mechanism against *Pseudomonas aeruginosa* and *Esherichia coli* O157:H7 which are important foodborne pathogens in the food industry. Furthermore; *Rosa canina, Ballota nigra, Juglans regia, Castanea sativa, Rosemarinus officinalis* are some plant-derived extracts having QQ ability against *Staphylococcus aureus*. It has been also reported that the orange extract could prevent the communication among *Yersinia enterocolitica* strains. It has been reported that tannin-rich fractions of some plants could inhibit the swarming and virulence factors, especially in pathogen bacterial strains. In the future, the plant extracts which capable of QQ might replace the drugs in medicine and chemical/synthetic preservatives/additives in the food industry. The definite taking the synthetic food additives from the industry might be observed in time but the in medicine the combined application of drugs and natural extracts can be more common in the future because of the synergistic effects to each other. The use of the anti-QS agents might enhance to development the new biocontrol strategies [1,11,19].

The QS is defined mainly in bacterial strains because their signal molecules and the QS mechanism could be understood more easily compared to the yeast and fungi strains. Bacterial QS has been considered as a therapeutic target to decrease the virulence of bacteria and therefore the infection controlling can be provided by degradation of QS signalling molecules or inhibiting the perception system of signal molecules [2]. In this regard, the bacterial strains are used to inhibit each other. Because of the small, diffusible signal molecules accumulate in the medium and this density of the signal molecules can coordinate the behaviour of the microbial community and therefore release some toxins and toxin-like seconder metabolites synchronously. On the other hand, QQ enzymes to stop the QS mechanism are another controlling method for protection from pathogen bacteria that threatens the human health. The QQ systems have been determined in various prokaryotic and eukaryotic microorganisms, however, AHL-degrading enzyme was first determined in *Bacillus* species [4,18]. It has been reported that three types of enzymes including AHL-lactonase, AHL-acylase, and AHL-oxidoreductase. The enzymes degrade the pathways of signalling AHL molecules [2]. The microbial activities could be regulated by QQ mechanism instead of QS mechanism because the signalling molecules are inhibited [18].

Andrographolide, a labdane diterpenoid *Andrographis paniculata* plant, and curcumin, a yellow chemical component produced by some plants which are the member ginger family, are known as the repressors that affect the QS-regulated virulence of *Pseudomonas aeruginosa*. Besides, another plant-derived active ingredient ellagic acid and fisetin have some attenuation effects on biofilm formation of *Streptococcus dysgalactiae*. Another active component is a salicylic acid which has an ability on repressing AHL production in *P.aeruginosa* and tannic acid which is a kind of a tannin is commonly used as an antimicrobial and anti-inflammatory agent. According to the researches, salicylic acid, tannic acid and trans-cinnamaldehyde might be a potential for inhibiting AHL-synthase [2].

## 4. Quorum Quenching (QQ) and Phytochemicals

In recent years, the role of QS among the microbial strains in the food industry has been researched and according to the reports of the studies, some signalling molecules have been detected in different concentrations in the food products such as meat and vegetables and milk products. The food processing periods and storage conditions might affect the secretion of the QS molecules. Food products are available for growth and biofilm formation of microorganisms because they are rich in nutrients. The growth of the spoilage or pathogen microorganisms in the food matrix might be influenced by the communication among the different microbial strains found in the food, and the ability of signal molecule production is affected because of the cell-to-cell interactions. The targeting the QS mechanism is the new strategy for prevention from the pathogen and spoilage microorganisms and the biofilm matrix produced by them which

could be found in the food products. Phytochemicals naturally found in the fruits and vegetables have the abilities of inactivation the QS mechanism. The diet containing plant derived foods and vegetables might influence the intestinal microbiota to prevent the colonization and biofilm formation of pathogen microorganisms in the intestinal system [6,20].

The QQ mechanism can be defined as given below:

**Small QSIs** can bind to the relevant signal receptor and control the gene expression in the microbial metabolism. Therefore, the signal molecules could not reach to the receptors and the cumulative behaviours could not be regulated by the signalling mechanism. Besides, some QSIs have the ability to inhibit enzymatic reactions carried out during the communication among the microbial strains.

**AHL-lactonases** influence the homoserine lactone ring of AHL signals and the efficacy has been observed because of the hydrolysing of the chemical structure of AHL signals.

**AHL-acylase** is known as another QS inhibit group that effects amide bond of AHLs and the efficacy of the QQ enzyme is provided by hydrolysing of the chemical bonds.

**Paraoxonase** is the inactivation enzymes which have efficacy on AHL. The inactivation has been performed depending on $Ca^{2+}$ ion and the mode action has been like lactonase activity [15,21].

Some plant and natural food products, their phytochemicals, and the microorganisms which are inhibited by the relevant phytochemicals are demonstrated in **Table 1**.

**Table 1** QSIs identified from plants and affected microorganisms by phytochemical molecules

| Sources | Phytochemical molecules | Affected Microbial strain | References |
|---|---|---|---|
| *Aframomum corrorima* | Sabinene<br>Nerolido<br>1,8-Cineole | *Aspergillus flavus*<br>*Penicillium expansum*<br>*Esherichia coli*<br>*Salmonella* spp.<br>*Klebsiella* spp. | [3,12] |
| *Curcuma longa* (Turmeric) | Curcumin | *Salmonella typhi*<br>*Listeria monocytogenes*<br>*Clostridium* spp.<br>*Staphylococcus aureus*<br>*Esherichia coli*<br>*Bacillus cereus*<br>*Bacillus subtilis*<br>*Yersinia enterocolitica*<br>*Saccharomyces cerevisiae*<br>*Penicillium notatum* | [3,6,12] |
| *Ocimum canum* | α-Terpineol<br>Chavicol<br>Chavibetol | Food spoilage bacteria | [12] |
| *Ocimum basilicum* (Basil) | 1,8-Cineole<br>Linalool<br>Methyl chavicol | *Bacillus subtilis*<br>*Esherichia coli*<br>*Salmonella typhimurium*<br>*Candida albicans*<br>*Clostridium botulinum*<br>*Listeria monocytogenes*<br>*Staphylococcus aureus* | [12] |
| *Vaccinium macrocarpon* | Ursolic acid | *Staphylococcus mutans* | [22] |
| *Salvia officinalis* | Oleanolic acid | *Staphylococcus mutans* | [22] |
| *Emblica officinalis*<br>*Terminalia belerica* | Gallic acid | *Staphylococcus mutans* | [22,23] |
| *Acacia nilotica*<br>*Terminalia arjuna*<br>*Eugenia jambolana*<br>*Aloe vera* | Quercetin | *Staphylococcus mutans* | [22,24] |
| *Terminalia chebula*<br>*Terminalia belerica* | Tannic acid | *Staphylococcus mutans* | [22,23] |
| *Coffee and tea trees* | Pyrogallol<br>(1,2,3-trihydroxybenzene) | *Vibrio harveyi* | [6,25] |

| | | | |
|---|---|---|---|
| *Rosmarinus officinali* (Rosemary) | p-Cymene<br>Linalool<br>Thymol<br>γ -Terpinene<br>Carnosic acid<br>Carnosol | *Pseudomonas* spp | [12] |
| *Citrus aurantifolia* (Lime) | Limonene,<br>β-Pinene,<br>γ -Terpinene,<br>Citral | *Aspergillus niger*<br>*Staphylococcus aureus* | [6,12] |
| *Quercus cortex* | 1,2,3-benzenetriol<br>4-propyl-1,3-benzenediol<br>4-(3-hydroxy-<br>1-propenyl)-2-methoxy-phenol<br>3,4,5-trimethoxyphenol | *Chromobacterium violaceum* | [25] |

Many edible or non-edible plants and fruits possess inhibitory activities against adhesion and biofilm formation. One of a pathogen bacteria *Streptococcus mutans* causes infections and the polyphenolic rich extracts can prevent the signalling system and therefore biofilm formation in *Streptoccus* species. According to the previous studies, the extract of *Helichrysum italicum* could inhibit the adherence of *S.mutans* cells on the glass surface and cranberry juice powder concentration also inhibited the biofilm formation of *S. sobrinus* and *S. sanguinis* [22]. The biofilm formation of *Pseudomonas aeruginosa* has been reduced in the ranges between 20-80 % by the application of ethanolic extracts of some plants which can be listed *as Cinnamomum zeylanicum, Marrubium vulgare, Tamarix aphylla, Cuminum cyminum, Pelargonium hortorum, Lawsonia inermis, Salvia officinalis, Triticum aestivum, Artemisia absinthium, Hibiscus sabdariffa, Thymus vulgaris, Punica granatum, Agave sisalana, Mentha longifolia* and *Portulaca oleracea*, whereas it has been reported that any biofilm inhibition or reduction has not observed by the application of ethanolic extracts of *Pelargonium graveolens, Foeniculum vulgare, Solenostemon scutellarioides, Rosmarinus officinalis, Urtica dioica, Matricaria recutita, Erythrina crista-galli* and *Momordica charantia* [26]. Polyphenols are known as a group of compounds found naturally in the plants including tea and coffee and it has been reported that pyrogallol is one of a QS inhibitor. The bioluminescence has been prevented in *Vibrio harveyi* starain. The bioluminescence is directly correlated with QS in between the microbial strains [27]. According to another research *Quercus cortex* (Oak bark) has been considered as another plant-derived natural drug that is used for the treatment of skin inflammations, diarrhea and etc. Plant derived products are known as a source of polyphenolic and therapeutic metabolites and oak bark is rich in the phenolic compounds which are known as hydrolysable tannins, pyrogallol tannins, condensed tannins—proanthocyanidins. The most effective components for inactivation of the QS mechanism are tannins in oak bark. The vescalagin and castalagin which are hydrolysable tannins are first detected and isolated from *Conocarpus erectus*, and the QQ activity has been observed in the component [25,28]. The researchers have investigated the inhibition effect of bean sprout, chamomile, carrot, garlic, habanero, propolis on QS systems of microorganisms. For example, garlic extract contains at least three different QS inhibitors. The QQ activity of the garlic extracts are depending on the concentration of the extract. Moreover, the phytoalexin resveratrol (3,5,4′-trihydroxystilbene) is an antifungal agent and it is found naturally in grapes and other plants. *Coriandrum sativum* extracts are known as α-pinene, ß-bisabolene, p-cymene, hexanal and linalool and they have QQ activities on fungi species according to the previous studies [29]. The molecular mechanism and the active components which act the key role in QS should be understood clearly to design and develop the effective QQ strategies. Some of the key components in QS mechanism can be listed as proteins and enzymes which are used in biosynthesis, some indispensable proteins which are placed in long chain signal active efflux, transcription factors and regulatory enzymes carried out QS [21].

Each classic antimicrobial agents targets the different sites of the pathogenic microorganism. The basic action mode is known as disruption of the membrane structure, inhibition of protein synthesizing and inhibition of the pathway of the production of coenzymes, nucleic acids, and peptidoglycans. The classic antimicrobial agents can inhibit the growth of the microorganism but sometimes they remain ineffective for prevention of the biofilm formation. The signalling molecules have been produced and released to the medium and the threshold density causes the gene expression to change the behaviours of the microorganism. Thus, the classic antimicrobial agents have remained insufficient. In this regard, the action mode and the target should be changed by using the different methods. The therapeutic and phytochemicals found naturally in plants, vegetables and fruits have become a significant solution way for inhibition of the drug-resistant microorganisms. Because the biofilm forming strains have continued to grow in time and QS mechanism and the biofilm formation make them more resistant against harsh conditions results in threatening the human [22].

## 5. Conclusion

The wide range drug-resistant microorganisms have become an important menace for the human treatments with drugs in medicine. Because of the increasing resistance of the especially pathogens against active components in the drugs, there is an urgent need to search different ways to cure the microbial diseases. The previous studies show that the inhibitory system has been present in the organisms. This anti-QS mechanism has been observed both microorganisms and plant extracts. The use of plant-derived extracts having anti-QS activities for the inhibition of the biofilm formation in pathogen and food-borne microorganisms and prevention of the communication between each other with the signal molecules might be an interesting strategy in biotechnology. Moreover, the phytochemicals could be used as natural additives in the food industry. In this regard, the therapeutic properties of the plants should be researched and the QQ mechanism should be brought into the forefront in biotechnological studies.

## References


[1] Koh CL, Sam CK., Yin WF, Tan LY, Krishnan T, Chong YM, Chan KG. Plant-derived natural products as sources of anti-quorum sensing compounds. Sensors. 2013; 13.5: 6217-6228.

[2] Chang, CY, Krishnan T, Wang H, Chen Y, Yin WF, Chong YM, Chan KG. Non-antibiotic quorum sensing inhibitors acting against N-acyl homoserine lactone synthase as druggable target. Scientific reports. 2014; 4: 7245.

[3] Bacha K., Tariku Y, Gebreyesus F, Zerihun S, Mohammed A, Weiland-Bräuer N, Mulat M. Antimicrobial and anti-Quorum Sensing activities of selected medicinal plants of Ethiopia: Implication for development of potent antimicrobial agents. BMC microbiology. 2016; 16.1: 139.

[4] Czajkowski R, Jafra S. Quenching of acyl-homoserine lactone-dependent quorum sensing by enzymatic disruption of signal molecules. Acta Biochimica Polonica. 2009; 56.1: 1-16.

[5] Grandclément C, Tannières M, Moréra S, Dessaux Y, Faure D. Quorum quenching: role in nature and applied developments. FEMS microbiology reviews. 2016; 40.1: 86-116.

[6] Nazzaro F, Fratianni F, Coppola R. Quorum sensing and phytochemicals. International journal of molecular sciences. 2013; 14.6: 12607-12619.

[7] Tang K, Zhang XH. Quorum quenching agents: resources for antivirulence therapy. Marine drugs. 2014; 12.6: 3245-3282.

[8] El-Hamid MIA. A New Promising Target for Plant Extracts: Inhibition of Bacterial Quorum Sensing. Journal of Molecular Biology and Biotechnology. 2016.

[9] Koh KH, Tham FY. Screening of traditional Chinese medicinal plants for quorum-sensing inhibitors activity. Journal of Microbiology, Immunology and Infection. 2011; 44.2: 144-148.

[10] Fleet GH. Yeast interactions and wine flavour. International journal of food microbiology. 2003; 86.1: 11-22.

[11] Mahmoudi E, Tarzaban S, Khodaygan P. Dual behaviour of plants against bacterial quorum sensing: inhibition or excitation. Journal of Plant Pathology. 2014; 96.2: 295-301.

[12] Gottardi D, Bukvicki D, Prasad S, Tyagi AK. Beneficial Effects of Spices in Food Preservation and Safety. Frontiers in Microbiology. 2016; 7.

[13] Barriuso J. Quorum sensing mechanisms in fungi. AIMS Microbiol. 2015; 1.1: 37-47.

[14] Frey-Klett P, Burlinson P, Deveau A, Barret M, Tarkka M, Sarniguet A. Bacterial-fungal interactions: hyphens between agricultural, clinical, environmental, and food microbiologists. Microbiology and Molecular Biology Reviews. 2011; 75.4: 583-609.

[15] Adak S, Upadrasta L, Kumar SJ, Soni R, Banerjee R. Quorum quenching–an alternative antimicrobial therapeutics. Science against microbial pathogens: communicating current research and technological advances. Formatex Research Center, Badajoz. 2011.

[16] Ribet D, Cossart P. How bacterial pathogens colonize their hosts and invade deeper tissues. Microbes and Infection. 2015; 17:173-183.

[17] Skandamis PN, Nychas GJE. Quorum sensing in the context of food microbiology. Applied and environmental microbiology. 2012; 78.16: 5473-5482.

[18] Chen F, Gao Y, Chen X, Yu Z, Li X. Quorum quenching enzymes and their application in degrading signal molecules to block quorum sensing-dependent infection. International journal of molecular sciences. 2013; 14.9: 17477-17500.

[19] Shukla V, Bhathena Z. Broad spectrum anti-quorum sensing activity of tannin-rich crude extracts of Indian medicinal plants. Scientifica. 2016; 2016.

[20] Williams P. Quorum sensing, communication and cross-kingdom signalling in the bacterial world. Microbiology. 2007; 153.12: 3923-3938.

[21] Dong YH, Wang LH, Zhang L. H.Quorum-quenching microbial infections: mechanisms and implications. Philosophical Transactions of the Royal Society of London B: Biological Sciences. 2007; 362.1483: 1201-1211.

[22] Abachi S, Lee S, Rupasinghe HP. Molecular mechanisms of inhibition of Streptococcus species by phytochemicals. Molecules. 2016; 21.2: 215.

[23] Gupta SP, Garg G. Quantitative estimation of gallic acid and tannic acid in bhuvnesvara vati by RP-HPLC. Der Pharmacia Lettre. 2014; 6.2:31-36.

[24] Sultana B, Anwar F. Flavonols (kaempeferol, quercetin, myricetin) contents of selected fruits, vegetables and medicinal plants. Food Chemistry. 2008; 108.3: 879-884.

[25] Deryabin DG, Tolmacheva AA. Antibacterial and anti-quorum sensing molecular composition derived from quercus cortex (oak bark) extract. Molecules. 2015; 20.9: 17093-17108.

[26] Al-Refi MR. Antimicrobial, Anti-Biofilm, Anti-Quorum Sensing and Synergistic Effects of Some Medicinal Plants Extracts. The Islamic University–Gaza. Master Thesis. 2016. Pp:150.
[27] Defoirdt T, Pande GSJ, Baruah K., Bossier P. The apparent quorum-sensing inhibitory activity of pyrogallol is a side effect of peroxide production. Antimicrobial agents and chemotherapy. 2013; 57.6: 2870-2873.
[28] Tolmacheva AA, Rogozhin EA, Deryabin DG. Antibacterial and quorum sensing regulatory activities of some traditional Eastern-European medicinal plants. Acta pharmaceutica.2014; 64.2: 173-186.
[29] Savoia D. Plant-derived antimicrobial compounds: alternatives to antibiotics. Future microbiology. 2012; 7.8: 979-990.