Biofilm Inhibitory Efficacy of herbal extracts

Evaluation of Biofilm Inhibitory Efficacy of Bacopa monnieri, Acalypha indica and Calotropis gigantea Extracts and their Combination Against Wound Colonizing Bacteria Pseudomonas aeruginosa and Staphylococcus Aureus

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Abstract: Key factors in compromised wound healing primarily include bacterial colonization and infection. Extensive use of systemic antibiotics, preferred choice of treatment for clinically infected wounds, is often accompanied with emergence of bacterial resistance. Quorum sensing (QS), density dependent chemical communication, is emerging as a promising area of research since most infectious microorganisms operate this mechanism to realize their pathogenic potential. Foregoing research indicates the potential of studying medicinal plant extracts/components and their combinations as vital inhibitors of QS regulated virulence factors’ production. Our study aims to understand the potential of three plant extracts and their combinations as vital inhibitors of QS regulated virulence factor’s production by two wound pathogens and to achieve this our objectives are to perform their violacein inhibitory (on C. violaceum) and biofilm inhibitory properties (on Pseudomonas aeruginosa and Staphylococcus aureus). Minimum inhibitory concentration (MIC) of aqueous plant extracts against P. aeruginosa and S. aureus was performed (two-fold serial microdilution). Violacein inhibition was assayed using agar well diffusion while biofilm inhibition by crystal violet method. Organisms presented 5mg/ml (Bacopa monnieri), 2.5mg/ml (Acalypha indica), and 2.5mg/ml (Calotropis gigantea) as MIC. Three sets of individual extract concentrations (sub-MIC in µg/ml) and their corresponding combinations were used for this study. Extracts exhibited more significant (P<0.0001) violacein inhibition in combination than individually. Biofilm inhibition by extracts’ combination was also significantly (P<0.001) higher than that of individual extracts indicating a possible positive herb-herb interaction of phytoconstituents (synergistic or complementary). The relative decrease in response to individual extracts in higher concentrations (set ‘c’) by both organisms point to possible recalcitrance behavior generally exhibited by bacteria on exposure to higher antibacterial agents. The improved antibiofilm efficacy exhibited by this novel combination may serve as an alternative approach in managing wound colonization by biofilm-producing bacteria and hence faster-wound healing.

Key words: Biofilm, Antibiotic resistance, Plant extract, Quorum sensing, Extract combination, Synergistic effect.

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1. INTRODUCTION

One of the major causes of delayed wound healing is the colonization of wounds by bacteria and if left untreated can lead to a chronic wound.\(^1\) Persistence of infections in chronic wounds is the most common cause that hinders its healing, resulting in increased patient morbidity and mortality.\(^2\)\(^,\)\(^3\) The manifestation of bacterial biofilms in chronic wounds is more critical in delaying the wound healing process than in the more treatable planktonic forms.\(^4\)\(^,\)\(^5\) Biofilm formation, a quorum sensing (QS) regulated mechanism, provides physical protection to the enclosed bacterial colonies from a hostile external environment. This facilitates survival and communication among the bounded bacteria, which enhances their virulence.\(^6\) Biofilms reduce the uptake of antibiotics leading to resistant bacterial strains. Biofilm-forming bacteria, \(P.\) aeruginosa and \(S.\) aureus, are the most frequently isolated pathogens from chronic wounds.\(^7\) These bacteria are highly invasive and have developed resistance to a wide range of commonly prescribed antibiotics, leading to treatment failure of many infected wounds.\(^8\)\(^,\)\(^9\) Consequently, there is a need to identify alternative therapeutic strategies to manage the wound infections caused by these multidrug resistant pathogens.\(^10\)\(^,\)\(^11\) One of the effective options to tackle the issue of antibiotic resistance is, to reduce the pathogenicity rather than the direct killing of the micro-organisms. This has prompted researchers to identify methods that target specific receptors/activators of QS to combat biofilm-associated infections.\(^12\)\(^,\)\(^13\) Recently, research on the use of medicinal plants in wound care has been given serious importance as new treatment option for acute and chronic wounds.\(^14\)\(^,\)\(^15\) Phytoconstituents from diverse medicinal plants have been reported to exhibit significant anti-QS activity.\(^16\)\(^,\)\(^17\) Combination of medicinal plants brings together phytoconstituents from individual plants to synergistically and complementarily achieve the desired therapeutic effect/s through the phenomenon of positive herb-herb interaction.\(^18\)\(^,\)\(^19\) The complex nature of QS regulated mechanism requires a composite drug approach such as an herbal combination as an improved option for treating multidrug resistant wound colonizing bacteria.\(^20\) Treatment of wound colonizing bacteria using PHF is gaining acceptance in the field of scientific research. Some of the patents have been patented, while a few are commercially available.\(^21\)\(^,\)\(^22\) \(Bacopa\) monnieri (L.) Wettst. also called Brahmi, a plant species belonging to \(Plantaginaceae\) family, has been used extensively in Ayurveda and Chinese medicine as a memory enhancer.\(^23\) It is mostly found in wetlands and swamps. Most of the medicinal uses of \(Bacopa\) monnieri include treatment of asthma \\& arthritis.\(^24\) As antibacterial agent\(^22\) it is also known for its anxiolytic effect,\(^25\) anti-depressant effect,\(^26\) anticonvulsant action,\(^27\) antiallergic and wound healing properties.\(^28\)\(^,\)\(^29\) Bacopasides, basically triterpene saponins, are the most important active compounds in \(B.\) monnieri.\(^30\)\(^,\)\(^31\) \(Acalypha\) indica also called Indian acalypa belonging to the family \(Euphorbiaceae\) has been reported to have significant medicinal properties for the treatment of various diseases. Extracts from all parts of this plant have been extensively used in Ayurveda and Siddha for managing several ailments such as rheumatism, diabetes mellitus, skin diseases and wounds.\(^32\) It is commonly found in wet, temperate, and tropical areas of Asia, Africa, Europe, Australia and South and North America and used as antimicrobial agent.\(^33\) \(Calotropis\) gigantea also known as ‘Giant shallow wort’ or ‘Madar’ is a latex producing plant that is found in India, Africa, Bangladesh and Sri Lanka. \(C.\) gigantea belongs to the family of \(Apocynaceae.\) This plant is widely used in Ayurveda to treat various human diseases.\(^34\)\(^,\) Screening studies revealed the presence of numerous potent phytoconstituents in this plant which are responsible for its broad pharmacological activities.\(^35\)\(^,\)\(^36\) Medicinal activity of \(C.\) gigantea includes its anti-asthmatic, antibacterial, anti-arthritis, wound healing and antiscarring effects.\(^37\) The present study aimed at evaluating the anti-QS activity of \(B.\) monnieri, \(A.\) indica and \(C.\) gigantea extracts and their combinations against wound colonizing bacteria \(P.\) aeruginosa and \(S.\) aureus.

2. MATERIALS AND METHODS

2.1 Media and Chemicals

All the media and chemicals used in this research were of analytical grade procured from HiMedia laboratories Pvt. Ltd, Mumbai, India and Thermo Fisher Scientific India Pvt Ltd Mumbai India. Luria Bertani (LB) agar, LB broth, Muller Hinton Broth (MHB) and Tryptic Soy Broth (TSB) are culture media used for experiment and maintenance of bacterial cultures. Ammonium oxalate, ethanol, glycerol, crystal violet, gentamicin, methanol, yeast, cinnamon oil, tryptone, yeast extract, glucose, soy, potassium chloride, sodium chloride, disodium hydrogen phosphate \(\text{Na}_2\text{HPO}_4\), and potassium dihydrogen phosphate \(\text{KH}_2\text{PO}_4\) are the other chemicals used in this experiment.

2.2 Bacterial Strains and culture conditions

The Bacterial cultures of \(C.\) violaceum (MTCC2656), \(P.\) aeruginosa (MTCC3541) and \(S.\) aureus (MTCC737) were purchased from Microbial Type Culture Collection Centre (MTCC), Institute of Microbial Technology (IMTECH) Chandigarh, India. The lyophilized cultures were activated by inoculating in LB broth and incubated in a shaking condition at \(37^\circ\)C for 24hrs. The 24hr cultures of \(P.\) aeruginosa and \(S.\) aureus in (TSB) supplemented with 1% glucose were used for biofilm inhibition assay. The cultures were preserved in glycerol and stored at -80°C for further use.

2.3 Plant Material authentication and voucher reference

Fresh leaves of the selected plants, \(B.\) monnieri (Brahmi), \(A.\) indica (Indian acalypha), with voucher number 65 and 50, respectively were procured from Department of Horticulture, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra (GKVK), Bangalore, Karnataka India. They were authenticated by Professor M. Vasundhara, Head, Department of Horticulture, GKVK, C. gigantea, (Giant shallow wort) with voucher number SMPU/NADRI/BNG/2010-11/490 was obtained from National Ayurveda Dietetics Research Institute, Jayanagar, Bangalore, Karnataka, India. It was authenticated by Dr. Shiddamallayya N. Assistance Research Officer (Botany). The leaves were thoroughly washed, shade dried, and made into a coarse powder using an electric homogenizer.

2.4 Preparation of the Extracts

Crude extracts were prepared by dissolving 25g of the powdered plant sample in a flask containing 250ml of distilled water. The flask was kept in a shaker at room temperature for 24 hours after which the extracts were filtered using Whatman No. 1 filter paper. The filtrates were lyophilized using Labconco Freeze dryer -105°C by LABQUIP India Private limited, Hyderabad. The dried extracts were packed in a closed container and stored at -20°C for further analysis.\(^38\)
2.5 Minimum Inhibitory Concentration (MIC) Determination

Broth microdilution method was used to estimate the MIC of each extract.34,37 96-well plate was used to prepare a two-fold serial dilution of the extracts. MHB (50 μL) was added into the 1st – 10th well. Then 50 μL of 10mg/mL of each plant extract was added to the corresponding first well. A serial two-fold dilution was performed by transferring 50 μL of the suspension in each well to the subsequent well until the 10th well. The final 50 μL suspension taken out from the last well was discarded. MHB broth and bacteria alone served as a positive control. Bacterial suspension was adjusted to 0.5 McFarland (1-2 ×10^8 CFU/mL) and bacteria served as a negative control, while gentamicin 10 μg/mL was discarded. MHB broth and bacteria alone served as well. The final 50 μL suspension in each well to the subsequent well until the 10th well was discarded. MHB broth and bacteria alone served as a positive control. Bacterial suspension was adjusted to 0.5 McFarland (1-2 ×10^8 CFU/mL). The adjusted broth inoculum was diluted in the ratio of 1:100, and 50 μL was dispensed into respective wells (1-12) to attain the final inoculum size of 5 × 10^3 CFU/mL per well.34,37 The final concentrations of the extracts ranged from 0.0195 to 10mg/mL. The plate was incubated for 24 hrs at 37°C. The MIC for each extract was determined by adding 40μL of 10mg/mL. The plate was incubated for 24 hrs at 37°C. The MIC of the extracts was determined by measuring the diameter (in mm) of the zone of pigment inhibition formed around the well. Experiment was performed in a triplicate of three independent trials.

2.6 Violacein inhibition assay using C. violaceum (MTCC2656)

Agar well diffusion assay was used to detect violacein inhibition activity of the plant extract adopting standard method described by Ahmed et al.41. Overnight cultures of C. violaceum (MTCC2656) in LB broth were diluted to 0.5 McFarland. 100μL of diluted culture was spread on LB agar plates and was smeared uniformly. Wells were made on the LB agar plates with a standard cork borer of 6 mm diameter. 100μL of the optimized aqueous plant extracts, concentrations as indicated in table 2, were added to each well. Water and 1% DMSO were used as vehicle controls while 2μ g/mL cinnamon oil was used as a positive control. The plates were incubated at 33°C for 24hrs. A colorless opaque zone with loss of purple pigment around the treated wells indicated violacein inhibition confirming anti-QS activity. The violacein inhibitory activity of the plant extracts were determined by measuring the diameter (in mm) of the zone of pigment inhibition formed around the well. Experiment was performed in a triplicate of three independent trials.

2.7 Biofilm inhibition assay

The anti-biofilm activity against P. aeruginosa and S. aureus was evaluated using crystal violet assay.42 Bacterial cultures were grown in TSB containing 1% glucose overnight. Optimized sub-MIC concentrations of the plant extracts as shown in table 2, were used in this experiment. A combination of these plants' extracts was made for each set of the above concentrations in a respective manner. Bacterial suspension (50μl) of 0.5 McFarland was added into 96 well culture plates. Plant extracts (50μL) of the respective concentrations were added to the corresponding wells. Bacterial culture and TSB served as positive control while TSB alone served as negative control. The plates were kept in a shaker incubator for 24hrs at 37°C. After 24hrs, the planktonic suspension was aspirated and each well was washed three times with distilled water and stained with 200 μl of 0.1% crystal violet. The plate was allowed to stand for 20 min. The crystal violet was removed, and excess stain was rinsed three times with tap water. The plates were allowed to dry and 200 μl of 96% (v/v) ethanol was added to each well to solubilize the crystal violet and the formed biofilm. The plate was read spectrophotometrically at 595 nm using a microplate reader (Varioskan™ lux multimode plate reader Thermo Scientific United states). Experiment was performed in a triplicate of three independent trials. Percentage biofilm inhibition was calculated using the formula below.

Biofilm inhibition (%) = OD_{Control} - OD_{Sample} / OD_{Control} × 100

2.8 Statistical analysis

All the experimental data of replicates were reported as mean ± standard error of the mean (SEM). Statistical significance in the difference between various treatments and that of the control was evaluated by applying one-way ANOVA (Tukey’s test). Graph pad Prism (Version 8.0) was used and P value ≤ 0.05 was considered statistically significant.

3. RESULTS

3.1. Determination of MIC

MIC of the individual plant extracts against P. aeruginosa and S. aureus are presented in table 1. The three plant extracts exhibited similar MIC values against the two strains of bacteria used in this experiment.

| Table 1. MIC (mg/ml) of the plant extracts tested against P. aeruginosa and S. aureus |
|---|---|---|
| S/No | Plant extracts | P. aeruginosa | S. aureus |
| --- | --- | --- | --- |
| 1 | B. monnieri | <5mg/ml | <5mg/ml |
| 2 | A. indica | <2.5mg/ml | <2.5mg/ml |
| 3 | C. gigantea | <2.5mg/ml | <2.5mg/ml |

Table 1 shows the MIC of the three plant extracts (B. monnieri, A. indica, C. gigantea) used in this study on P. aeruginosa and S. aureus. The results indicated that all the three plant extracts showed similar MIC on both the organism tested. This served as the basis for determining the extract concentrations that has been used in this research.

3.2. Preparation of plant extracts’ combinations

Different sub-MIC concentrations of each plant extract were optimized and three sets of individual plant extract concentrations and their corresponding combinations were prepared as per Table 2.
Table 2. The concentration of plant extracts used for the study

| Extract combination (µg/ml) | B. monnieri (µg/ml) | A. indica (µg/ml) | C. gigantea (µg/ml) |
|-----------------------------|---------------------|-------------------|---------------------|
| Set a                       | 150                 | 116               | 10                  |
| Set b                       | 750                 | 580               | 50                  |
| Set c                       | 1500                | 1160              | 100                 |

Based on the MIC results (Table 1), three sets of sub MIC concentrations labelled set ‘a’, set ‘b’ and set ‘c’ for each of the plant extracts and their respective combinations were chosen for this study. B. monnieri, A.indica and C.gigantea have initial concentrations of 150, 116 and 10µg/ml, respectively (set ‘a’). These concentrations were increased 5 times (set ‘b’) and 10 times (set ‘c’) to test for the anti-quorum sensing activity of lower, middle, and higher sub MIC concentrations.

3.3. Violacein inhibition

All tested concentrations of the plant extracts and their combinations (Table 2) showed varying levels of violacein inhibition without affecting the organism’s growth (Figure 1). No pigment inhibition was observed around the vehicle control wells containing DMSO (1%) and sterile distilled water. Extracts’ combination showed more significant (P<0.001) violacein inhibition in sets ‘a’ and ‘b’ than in set ‘c’ (P<0.01) compared to the positive control. The observed violacein inhibition appears to be concentration independent as an increase in the extract dose didn’t contribute to any incremental growth in violacein inhibition.

3.4. Biofilm inhibition

Different optimized sub-MIC concentrations of plant extracts were used for this study (Table 2). Percentage biofilm inhibition...
inhibition activity of different sets of sub-MIC concentrations and their respective combinations was performed (Figure 2). Results from this experiment showed varying degrees of percentage biofilm inhibition exhibited by individual plant extracts and their combinations (Table 3). In S. aureus (Figure 2A), the percentage biofilm inhibition of extracts’ combinations was shown to be significantly higher (P<0.001) in all three tested concentrations compared to the control. For individual plant extracts, there was a general tendency of increase in biofilm inhibition from set ‘a’ to ‘b’ and then a slight reduction as the concentrations rose in set ‘c’. However, CG does not seem to follow this pattern in set ‘c’ though this was not statistically significant. BM showed percentage biofilm inhibition of 35.49±15.72, 57.63±5.07 and 47.57±14.48 in set ‘a’, ‘b’ and ‘c’, respectively, showing slight concentration-dependent pattern between set ‘a’ and set ‘b’ while the biofilm inhibition drops in set ‘c’. The same is observed in AI exhibiting percentage biofilm inhibition of 49.82±11.74, 67.36±9.81 and 52.94±15.17 in set ‘a’, ‘b’ and ‘c’ respectively. On the other hand, CG with biofilm inhibition of 41.78±17.17, 49.00±12.72 and 52.18±13.15 in set ‘a’, ‘b’ and ‘c’ respectively demonstrated a slight disproportionate concentration dependent increase in percentage biofilm inhibition. Despite these variations in percentage biofilm inhibition across the different individual plant extracts’ concentrations, the EC of set ‘a’ (72.87±7.85), set ‘b’ (76.61±5.29) and set ‘c’ (75.85±6.02) did not show any significant change in the percentage biofilm inhibition corresponding to increase in concentrations. In P. aeruginosa (Figure 2B), extracts’ combinations of the three sets of concentrations exhibited significant increase (P<0.001) in percentage biofilm inhibition compared to individual plant extracts and control. Percentage biofilm inhibition of the individual extract did not follow concentration dependent nature. BM exhibited percentage biofilm inhibition of 44.22±13.68, 48.65±9.48 and 62.76±5.68 in set ‘a’, ‘b’ and ‘c’, respectively indicating a slight concentration dependency which is not maintained with further increase in concentration. The opposite was observed for CG which show percentage biofilm inhibition of 70.29±9.30, 51.97±11.72 and 47.51±12.20 in set ‘a’, ‘b’ and ‘c’ respectively indicating a decrease in percentage biofilm inhibition with increase in extract concentrations, though the reduction was non incremental. AI showed percentage biofilm inhibition of 72.33±9.05, 62.09±17.59 and 67.10±9.61 in set ‘a’, ‘b’ and ‘c’ respectively indicating a slight increase in biofilm inhibition in set ‘c’ compared to set ‘b’ and decrease in set ‘c’ compared to set ‘a’. Percentage biofilm inhibition of EC in set ‘a’ (87.96±4.73), set ‘b’ (80.85±4.58) and set ‘c’ (78.53±6.06) did not vary significantly despite the variations in the percentage biofilm inhibition exhibited by individual plant extracts’ concentrations. The improved violacein and percentage biofilm inhibition activities exhibited by the extracts’ combinations can be attributed to a synergistic, reinforcement, potentiation or complementary interaction of the phytoconstituents present in them and not additive.\(^\text{11}\)

**A. Staphylococcus aureus**

![Figure 2A](image)

**B. Pseudomonas aeruginosa**

![Figure 2B](image)

Figure 2. Biofilm inhibitory activity of different sets of sub-MIC concentrations of aqueous plant extracts and their combinations against (A) P. aeruginosa and (B) S. aureus, using crystal violet staining assay.
BM=Bacopa monnieri , AI=Acalypha indica, CG=Calotropis gigantea, EC=Extract combination, Bacterial culture and MHB without plant extract served as a control. Mean values of triplicate independent experiments and standard error of mean are shown. Set ‘a’, Set ‘b’ and Set ‘c’ represent lowest, intermediate and highest concentrations respectively of the optimized aqueous plant extracts chosen for this experiment.

| Table 3. Percentage biofilm inhibition of different sets of sub-MIC concentrations and their respective combinations |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | set a            | set b            | Set c            |                 |                 |                 |
| Plant extracts  | P.aeruginosa %  | S.aureus %       | P.aeruginosa %   | S.aureus %      | P.aeruginosa %  | S.aureus %      |
| BM              | 44.22±13.68*    | 35.49±15.72**   | 62.76±25.68**    | 57.63±5.07**    | 48.65±9.48*     | 47.57±14.48**   |
| AI              | 72.33±9.05**    | 49.82±11.74**   | 62.09±17.59**    | 67.36±8.91**    | 67.10±9.61**    | 52.94±15.17**   |
| CG              | 70.29±9.30***   | 41.78±11.77**   | 51.97±11.72**    | 49.00±12.72**   | 47.51±12.20*    | 52.18±13.15**   |
| EC              | 87.96±4.73***   | 72.87±7.85*     | 80.85±4.58**     | 76.61±5.29***   | 78.53±6.06***   | 75.85±6.02***   |

Table 3 showing percentage biofilm inhibition ± standard error of mean of the plant extracts selected for this study on P. aeruginosa and S. aureus. BM=B. monnieri, AI=A. indica, CG=C. gigantea, EC=Extract combination. Results of the three sets of individual plant extracts concentration (set ‘a’, set ‘b’ and set ‘c’) and their corresponding combinations are presented. It is observed that biofilm inhibitory properties of the individual plant extracts is generally higher in P. aeruginosa than in S. aureus with varying degree of significance. Percentage biofilm inhibition of extract combinations did not vary significantly with each other despite the large variations in the individual extracts concentration in them.

4. DISCUSSION

One of the major causes of delayed wound healing is an infection of the wound area by opportunistic pathogenic bacteria.44 The two opportunistic bacteria most commonly isolated from chronic wounds are S. aureus and P. aeruginosa. These bacteria are also reported to co-exist within the chronic wound environment making them more dangerous than if found separately.45 These bacteria are increasingly gaining resistance to commonly used antibiotics due to their ability to produce multiple virulence factors such as biofilm, LasB Elastase, hemolysins etc making them multidrug resistant. Most of these virulence factors are QS regulated; hence, interrupting the QS regulated mechanism of these bacteria using suitable inhibitors from plant extracts is an emerging approach to tackle the menace of wound-related infections.46-47 There is a growing need for novel antimicrobial and anti-biofilm treatment strategies to tackle this problem.48 QS-regulated attribute of C. violaceum is an easily noticeable and measurable indicator trait and therefore, this bacterium has been extensively used as a model organism for studying QS inhibitory activity of natural and synthetic compounds.49 Hence, medicinal plants which inhibit violacein production without affecting bacterial cell viability can be considered as potential QS inhibitors.50 Data suggest that bacterial biofilm was reported to be 1000 times more tolerant to wide range of antibiotics than their planktonic counterpart, which makes them persist in wound causing delay in its healing.44,51 Before testing for biofilm inhibitory efficiency of the optimized sub-MIC concentrations of the plant extracts on S. aureus and P. aeruginosa, biosensor strain of C. violaceum was used to test their anti-QS activity. Inhibition of violacein production by the three plants under investigation from this study validates the potent QS inhibitory role associated with them individually and in combination compared to the control. The same extract concentrations were used to test for their anti-biofilm activity on S. aureus and P. aeruginosa. The non-incremental pattern observed in the percentage biofilm inhibition exhibited by plant extracts used in this study can be attributed to the recalcitrance behavior of S. aureus and P. aeruginosa as reported by Lebeaux et al.,52 when exposed to higher concentration within sub-MIC. Results from this experiment revealed that the treatments in all three sets of concentrations inhibit bacteria biofilm formation and reduce the violacine production compared to the control, which is suggestive of the in vitro anti-QS activity of the extracts and their combinations. A great deal of research focuses on the newer concept of antipathogenic compounds, focusing largely on controlling different pathogens by not exerting a sharp killing effect.53,54 The significant percentage biofilm inhibition exhibited by the EC in all the three sets of extracts’ concentrations has pointed to the advantage of polyherbal combination in treating wound infection.55 The same pattern was reported by Jose et al.56 where they showed a promising percentage of biofilm inhibition of a herbal combination against toxigenic Vibrio cholerae at a relatively lower concentration compared to the individual plants extracts. Different phytoconstituents in herbal combinations have been reported to simultaneously inhibit diverse QS-regulated virulence factors’ production. This is an important attribute of herbal combinations because it renders the bacteria susceptible to the body immune system and/or any mild antibiotic.53,54 One of the advantages of targeting virulence factors in an attempt to combat bacterial resistance is that inhibitors of QS-regulated virulence factors usually target the adaptation and not the survival mechanisms of bacteria making them less likely to generate resistance against antibiotics.46 To avoid the ever-increasing prevalence of multidrug resistance tendencies of bacteria, it is necessary to shift away from the conventional antimicrobial approach where antibiotics are produced by looking at bacteria as individual free moving (planktonic form) rather than as multicellular tissue-like structures (Biofilm) that are attached to a particular surface.57

5. CONCLUSION

Even with the availability of diverse antibiotics and ongoing research to develop novel ones, bacterial multidrug resistance is still a serious medical concern. One of the mechanisms by which P. aeruginosa and S. aureus become multidrug-resistant strains is by the formation of biofilm, which make them persist in wounds causing a serious threat to individuals and public health. B. monnieri, A. indica and C. gigantea are plants known for various medicinal properties in traditional medicinal systems. The recent past has witnessed an escalating interest in studying plants for diverse medicinal properties. Advanced scientific techniques have led to the isolation of a variety of...
bioactive compounds from many such candidates, some of which have been taken even to the level of pharmacological validation. Poly Herbalism is a concept that is gaining extensive acceptance now than ever before and an increasing interest can be witnessed among the scientific community to develop and validate novel polyherbal combinations/formulations. Several phytoconstituents in herbal combinations have been reported to be effective in treating wound colonizing bacteria by simultaneously inhibiting the production of diverse virulence factors such as biofilm and exhibit significantly higher bactericidal activity in comparison to the use of a single plant. Results from this study validates the quorum modulatory potential of these three plants individually and in combination. Extracts of these plants are suitable for curbing the infection by *S. aureus* and *P. aeruginosa* in wounds. The study can be further extended towards the identification of active components of these extracts, their purification and subsequently understanding their mechanism of action on biofilm assemblies. The major findings of this study are as follows (i) All the individual plant extracts exhibit various degrees of violacein and percentage biofilm inhibition (ii) The inhibitory property of these plant extracts doesn’t seem to be fully concentration-dependent (iii) The tendency of increase in the inhibitory activity in set `b` and decreases in set `c` indicate the possible recalcitrant behavior of bacteria in higher concentration of antibacterial agents (iv) Extract combinations showed more significant violacein, and percentage biofilm inhibition than the individual plant extracts (v) Extract combinations did not show significant variation from each other despite the changes in concentrations of individual plant extracts in them. This indicates one of the advantages of extract combination over individual plant extracts. Study observations suggest that the meticulous combining of these plant extracts may serve as a promising alternative to inhibit quorum sensing regulated virulence factors’ production, thereby combating multidrug-resistant wound colonizing bacteria.

6. AUTHORS CONTRIBUTION STATEMENT

The study was designed and executed under the guidance of Dr. Bindhu O.S. Plant extract preparation, pigment and biofilm inhibition assays as well as data analysis were performed by Habibu Tanimu. MIC experiment and bacterial culture maintenance was performed by Nadasha Koonath Vijayan. Conceptualization, supervision, review and editing was done by Dr. Bindhu O.S. Manuscript writing was also initiated under the guidance of Dr. Bindhu O.S. All authors critically reviewed the manuscript, contributed to its revision, and approved the final version submitted.

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8. CONFLICT OF INTEREST

Conflict of interest declared none.

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