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Antimicrobial activity of selected plant extracts against common food borne pathogenic bacteria

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ABSTRACT

Increasing antibiotic resistance of important human pathogens calls for investigation and discovery of new antibiotics. Various medicinal plants and spices available in Fiji have antimicrobial potential against various food-borne pathogens. This research aims to address the assumed antimicrobial activity of twelve selected plant extracts against fifteen food-borne pathogens and to evaluate the pathogens resistances. The Kirby-Bauer Method was used in this study to determine the potency of plant extracts. Total Phenolic Content (TPC) was determined by the Folin-Ciocalteu Spectrophotometric method. The chosen plant species samples used were *Morinda citrifolia* (noni) leaves, *Syzygium aromaticum* (clove) bud, *Psidium guajava* (guava) leaves, *Ocimum basilicum* (basil) leaves, *Carica papaya* (pawpaw) leaves, *Azadirachta indica* (neem) seed oil, *Citrus limon* (lemon) leaves, and *Zingiber officinale* (ginger) root. Extracts from these eight plants were tested against common food-borne bacteria; *Clostridium perfringens, Citrobacter youngae, Enterobacter aerogenes, Enterobacter amnigenus, Enterobacter cloacae, Escherichia coli, Hafnia alveia, Klebsiella oxytoca, Klebsiella pneumoniae, Morganella morganii, Proteus vulgaris, Proteus mirabilis, Photobacterium damselae, Raoultella ornithinolytica* and *Vibrio alginolyticus*. Both resistance and antibacterial responses were observed for the different plant extracts. All plant extracts were successful in inhibiting bacterial growth for different number of species at varying levels of effectiveness with noni being the most effective. The highest inhibition zones (ZOI > 14 mm) were shown by garlic, basil, jasmine and neem. Highest mean ZOI was shown by noni at 11.4 mm followed by garlic at 10.1 mm and clove at 8.4 mm. Minimum inhibitory concentrations were determined for extracts exhibiting antibacterial potential. TPC may attribute to the antibacterial properties of the extracts, however, this needs further investigation. Results indicate presence of possible bioactive compounds in the extracts which can aid in search for new antibiotic drugs from plant sources. Studies that identify the compounds of therapeutically important flora in Fiji is recommended.

1. Introduction

Antimicrobial drugs (antibiotics) are crucial in combating various forms of infectious diseases in all parts of the world. However, researches indicate the emergence of multidrug-resistant strains of pathogenic bacteria which have very little or no effect of antimicrobial agents known for treating infections (Shin et al., 2018).

A recent study has found that the United States has recorded six multidrug-resistant strains, which financially impacted the cost of healthcare. This study featured methicillin-resistant *Staphylococcus aureus*, and carbapenem-resistant Acinetobacter (Nelson et al., 2021). Many food-borne bacterial pathogens are responsible for food poisoning, various illnesses and diseases. The common food-borne bacterial pathogens include; *Escherichia coli, Staphylococcus aureus, Salmonella*, Pathogenic *Vibrio* sp. and *Shigella* sp., to name a few (Ju et al., 2019). One such pathogenic species that may be considered is *Clostridium perfringens*. The United States confirmed 14 outbreaks between 2015 and 2018 and 289 confirmed outbreaks between 1998 and 2010 which found 15,208 illnesses, 83 hospitalizations, and 8 deaths resulting from *C. perfringens* (Grass et al., 2013; Wittry et al., 2022). Another example of a food-borne pathogen that caused havoc is *Klebsiella pneumoniae*. Cases emerged in Asian countries, where the

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pyogenic liver abscess were caused by the mentioned pathogen. This pathogen creates a pocket of fluid that grows into an abscess within the liver (Liu et al., 2013).

Combating these different pathogens might warrant some seeking a synthetic option. Various plants and spices available in Fiji have previously shown antimicrobial potential against various food-borne pathogens and may be more suitable for investigation. Hence, ethnobotany/ethnopharmacology helps identify and use indigenous knowledge related to natural products and its benefit to human health (Cowan, 1999; Cambie & Ash, 1994; Chand et al., 2018; Miyamoto et al., 2021; Naaz et al., 2021). Noni (*Morinda citrifolia*) extracts have reported to exhibit significant antibacterial properties against various human pathogens with its effectiveness attributed to flavonoids, phenolic contents and polysaccharides (Yee, 2019; Dubreuil, 2020; Mayekar et al., 2021; Naaz et al., 2021; Royani et al., 2022; Wang et al., 2022). Clove (*Syzygium aromaticum*) extracts have been reported as an antibacterial agent against gram-negative bacteria with phenolic extracts being effective against human pathogens (Saeed & Tariq, 2008; El-Maati et al., 2016; De Silva et al., 2018). Guava (*Psidium guajava*) and neem (*Azadirachta indica*) extracts have shown to exhibit antibacterial activity against various gram-positive and gram-negative food-borne pathogens and spoilage bacterial species (Mahfuzul Hoque et al., 2007; Farjana et al., 2014; Mohammed & Omar, 2015; Fu et al., 2016; Farhana et al., 2017). Antibacterial activity of guava was attributed to it phenolic components (Fu et al., 2016; Farhana et al., 2017). Basil (*Ocimum basilicum*) and pawpaw (*Carica papaya*) leaf extracts have been reported to show antibacterial activity against different food-borne pathogens which could be attributed to their phenolic contents to some extent (Anibijuwon & Udeze, 2009; Moghaddam et al., 2011; Bulfon et al., 2014; Bisht et al., 2016; Khattab et al., 2016). Similarly, lemon (*Citrus limon*) leaves and ginger (*Zingiber officinale*) extracts have been demonstrated to exhibit antibacterial properties against human pathogenic bacteria with the extracts containing phenolic compounds that may have contributed to their antibacterial potentials (Karuppiah & Rajaram, 2012; Azadpour et al., 2016; Ewansiha et al., 2016; Asker et al., 2020).

Antimicrobial traits are found naturally in many plants with diverse secondary metabolites such as phenolic compounds, alkaloids and flavonoids (Djeussi et al., 2013). When looking at lemon, for example, it is a common ingredient one would find in the kitchen. A study conducted on the inhibitory effects of citrus lemon oil against *Streptococcus sobrinus* found evidence of some level of inhibition ability on the pathogen (Liu et al., 2020a).

Like other Pacific Island countries, Fiji is vulnerable to increased frequency of cyclone with secondary impacts on food and health safety. Therefore, the increase incidence of food-borne disease and the development of antimicrobial resistance necessitates further studies on the identification, evaluation and control of outbreaks. People in Fiji has relied on traditional plants to treat cuts, wounds and minor ailments (Cambie & Ash, 1994; Chand et al., 2018; Miyamoto et al., 2021). These extensive use of plants, including noni, clove, ginger, basil, guava, neem and pawpaw as medicines, are attributed to their intrinsic antimicrobial properties (Naaz et al., 2021). This research seeks to address the assumed antimicrobial activity of selected plant extracts against selected food-borne pathogens and to evaluate the resistances of the pathogens to these extracts.

2. Materials and method

2.1. Selected plant samples

A total of eight plant species (Table 1) were used in this research experiment including clove (bud), ginger (root), garlic (root), basil (leaves), guava (leaves), lemon (leaves), pawpaw (leaves), noni (leaves), and neem (seed oil). The plants were collected from Nadi area in Fiji between July-August, 2021. The selection of the plants was based on ethnobotanical significance.

2.2. Extraction and testing of total phenolic content (TPC)

Fresh plant samples were collected, washed with distilled water, and air-dried for one week. The air-dried plant samples were grounded into a fine powder, and 20 g of the respective plant powders were soaked in two different solvents for extraction. The first solvent was distilled water, and the other was a 70% ethanol. The resulting concoctions were concentrated at 40 degrees Celsius via a rotary evaporator. The ethanolic and aqueous extracts were stored at 4 degrees Celsius to prevent spoilage.

The Folin-Ciocalteu method was used to quantify the Total Phenolic Content (TPC). Gallic acid concentrations 10, 20, 30, 40, and 50 μg/mL were used as a standard in conjunction with 1 mL of the Folin-Ciocalteu reagent. After this, 10 mL of 7 % sodium carbonate were added and the resulting mixture was incubated at room temperature for 90 min. The absorbance of the aqueous and ethanolic extract samples were measured via UV spectroscopy at 750 nanometers via a reagent blank. Triplicates were carried out for each plant extract sample while the averages were expressed via gallic acid equivalent (GAE) in mg per 100 g of the dried sample weight.

2.3. Antimicrobial susceptibility test

2.3.1. Bacterial samples and growth of common food-borne pathogenic bacteria

The organisms *E. coli*, *Enterobacter aerogenes, Enterobacter cloacae, Proteus vulgaris, Proteus mirabilis, Citrobacter youngae, Klebsiella oxytoca, K. pneumoniae* and *Raoultella ornithinolytica* were obtained as clinical isolates from the Microbiology Lab, Colonial War Memorial Hospital (CWM), Suva, Fiji. Other bacterial cultures was purchased including *Clostridium perfringens* (ATCC 13124), *Enterobacter amnigenous* (NZ isolate ERL00/748), *Hafnia alvei* (CDC 5190–70), *Morganella morganii* (ATCC 25830), *Photobacterium damselae* (ATCC 33539) and *Vibrio alginolyticus* (NCTC 10675). These species were selected since they are recognized as important food-borne pathogens with development of resistance to various clinical drugs at different levels (Hernández-Robles et al., 2016; Annavajhala et al., 2019; Davin-Regli et al., 2019; Karam et al., 2019; Kozieł et al., 2019; Wang et al., 2019; Bandy, 2020; Hajjar et al., 2020; Liu et al., 2020b; Ramos-Vivas, 2020; Sun et al., 2020; Algammal et al., 2021; Mehdizadeh Gohari et al., 2021; Petchimuthu et al., 2022; Yang et al., 2022). The streak-plate technique was used to isolate pure cultures of fifteen bacterial species that are known to cause food spoilage or lead to food-borne infection. Using a sterilized cotton swab, the inoculum was streaked onto a petri dish set with agar. After inoculating the bacteria, the petri dish was wrapped with parafilm to prevent contamination and ensure uniform bacterial growth. The bacterial cultures were then incubated at 37 ˚C for 24 h.

2.3.2. Growth inhibition assay using Kirby-Bauer method

The resistance of the bacteria was tested against the eight plant extract samples using the Kirby-Bauer Method. The plant ethanolic extract samples were the main ingredient in the agar-disk diffusions. Each plant extract sample was imbued on 6 mm paper discs and placed on the Petri dishes already inoculated with bacterial culture. Triplets of the petri dishes were incubated for 24 h at 37 ˚C. After this incubation period, inhibition zones around the plant extract sample discs were measured. Each measurement was recorded in millimeters from the disc's edge and antimicrobial activity was determined when zones of inhibition $>$ 1 mm were observed. The procedure was repeated for aqueous extracts.

2.3.3. Minimum inhibitory concentration of ethanolic plant extracts

The Minimum Inhibitory Concentration (MIC) of the plant extracts that inhibit the growth of bacteria after incubation was used to determine susceptibility of bacteria to the plant extract. The method described by Rodríguez-Tudela et al. (2003) was used as follows: the broth

Table 1
Ethnobotanical data of plant extracts used during the experiment.

Plant species	Family	Local name	Common name	Plant part used
Morinda citrifolia	Rubiaceae	Kura	Noni	Leaves
Syzygium aromaticum	Myrtaceae	Lavanga	Clove	Bud
Psidium guajava	Myrtaceae	Quwawa	Guava	Leaves
Ocimum basilicum	Lamiaceae	Pudina	Basil	Leaves
Carica papaya	Cariceae	Weleti	Pawpaw	Leaves
Azadirachta indica	Meliaceae	Neem	Neem	Seed Oil
Citrus limon	Rutaceae	Moli	Lemon	Leaves
Zingiber officinale	Zingiberaceae	Ginger	Ginger	Root

micro-dilution method was used whereby the ethanolic extracts of the plants were dissolved in 10 % DMSO to give an extract concentration of 100 mg/mL and stored at 4 °C prior to use. Serial dilution of the mixture was carried out directly in a 96-well sterile micro-titer plate containing 100 µL sterilized Mueller Hinton broth into wells 2–12 of the plate creating a concentration sequence. The well 1 was used as a growth control containing distilled water instead of plant extracts. The inoculated plates were sealed with a sterile lid and incubated for 24 h at 37 °C. After incubation, the control well was observed to ensure the bacteria had grown. The MIC of wells containing ethanolic plant extract was determined by turbidity assessment via optical density readings at 600 nm using a UV-Spectrophotometer.

MIC is the lowest concentration of antibiotics at which there is no visible growth of bacteria; therefore, growth of one or two colonies was disregarded. The lowest concentration of each extract displaying no visible growth was recorded as the Minimum Inhibitory Concentration. The lowest MIC tested was at 1.25 mg/L.

2.4. Statistical data analysis

IBM SPSS Statistic v 20.0 (Statistical Package for the Social Science) was used to analyze the TPC of the eight medicinal plants using an alpha level of 0.05 to determine the statistical significance. A paired sample T-Test was conducted to determine if there is a significant difference between the TPC values using the aqueous and ethanolic solvents.

3. Results

In this study two properties of the medicinal plants were tested including the total phenolic content and the antimicrobial properties using the Kirby-Bauer Method. The antimicrobial effectiveness of selected plants was further described in terms of the Minimum Inhibitory Concentration.

Firstly, the phenol concentration in the eight plants was determined using the spectrophotometric method. Gallic acid acts as an antioxidant, uses the free radicals, and reduces them for quantification. The highest concentration of total phenol was measured in Noni aqueous (614 ± 3.14 mg GAE/g) and ethanolic extract (432 ± 2.78 mg GAE/g), while the lowest TPC was observed in aqueous ginger extract (8.06 ± 1.04 mg GAE/g) and ethanolic extract (2.39 ± 0.5 mg GAE/g) Fig. 1. While aqueous extract of noni, clove and guava yielded a higher TPC value compared to ethanolic extracts, basil and pawpaw TPC values were vice versa for the extracts. These values of TPC are similar to the phenolic content tested by Naaz et al. (2021). There is a significant difference in the TPC values of the plants extracted using aqueous or ethanolic solvents ($t = 1.311$, $p = 0.0231$).

The antimicrobial activity and MIC values exhibited by ethanolic extracts against the tested bacterial species are shown in Table 2 and Table 3, respectively. The extracts showed different degrees of antimicrobial activity. MIC varied with bacterial species for each plant extract. Lowest tested MIC were noted at 1.25 mg/mL for noni against *R. ornithinolytica*, clove against *E. cloacae* and *V. alginolyticus*, guava

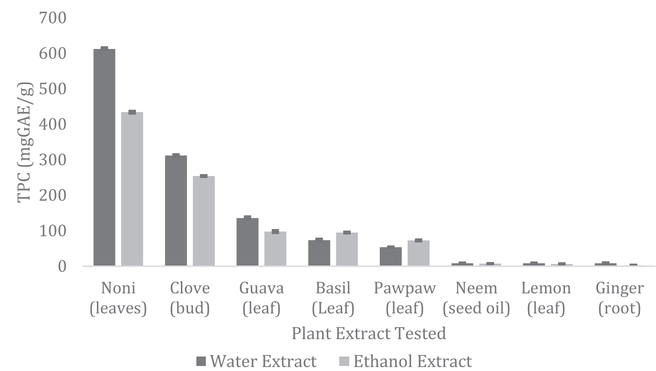

Fig. 1. Total Phenolic Content (TPC) (msGAE/g) of Ethanolic and Aqueous extracts of different plant components.

against *C. perfringens*, basil against *H. alvei*, lemon against *C. perfringens*, and ginger against *E. cloacae* and *E.coli*.

4. Discussion

The growing resistances of important food-borne pathogens to medication calls for alternative sources of antimicrobial materials. Plants have been traditionally used to treat various ailments and infections in the Pacific Island Countries as well as other parts of the world. Plant extracts form a pool of potential sources of antimicrobial compounds that needs to be explored further. Plants contain diverse secondary metabolites or phytochemicals, including phenolic compounds, terpenoids, and alkaloids, which contribute to their antimicrobial properties (Radulovic et al., 2013). Secondary plant metabolites such as phenols serve as plant defense against microorganisms, insects and herbivores (Cowan, 1999). These compounds exert pharmacological and toxicological effects on humans (Velu et al., 2018). Medicinal plants are a natural source of antioxidants and antimicrobial compounds, which make them feasible for use as food preservatives and drugs (Mahboubi et al., 2013, pp. 7621). All extracts in this study showed growth inhibition of more than one food-borne pathogen with varying levels of effectiveness. Resistance of pathogens against extracts was also observed at different levels.

The results from the agar bioassay for antimicrobial activity is similar to the results obtained via MIC technique. For the antimicrobial and inhibitory effects, noni was shown to have the highest effectiveness for all pathogens tested. Noni extracts have shown antibacterial properties against different pathogens including *E. coli, Pseudomonas aeruginosa, L. monocytogenes, Staphylococcus aureus, Bacillus subtilis* and *Salmonella typhimurium* (Yee, 2019; Dubreuil, 2020; Mayekar et al., 2021; Naaz et al., 2021; Royani et al., 2022; Wang et al., 2022). The broad-spectrum effectiveness of noni can be attributed to flavonoids, phenolic contents and polysaccharides as demonstrated in previous studies (Yee, 2019; Dubreuil, 2020; Mayekar et al., 2021; Royani et al., 2022; Wang et al., 2022). Our results show noni having highest TPC content out of all extracts studied similar to an earlier report (Bramorski et al., 2010).

Table 2
Zone of Inhibition (ZOI) for the tested bacteria against the Ethanolic extracts. ZOI excludes disc diameter. Values are in millimeter (mm).

Bacterial Species	Zones of inhibition (ZOI) (mm)							
	Noni	Clove	Guava	Basil	Pawpaw	Neem seed	Lemon	Ginger
Clostridium perfringens	12.3 ± 1.36	11.5 ± 0.57	9.8 ± 0.76	14.4 ± 1.27	-	7.4 ± 0.84	7.5 ± 0.52	5.4 ± 0.36
Citrobacte youngae	13.2 ± 0.72	-	-	9.4 ± 0.86	-	5.4 ± 1.12	-	7.4 ± 0.67
Enterobacter aerogenes	10.4 ± 1.38	12.2 ± 0.46	12.3 ± 1.15	8.4 ± 0.93	11.2 ± 0.28	12.4 ± 0.51	-	-
Enterobacter amnigenus	9.7 ± 0.44	13.3 ± 0.32	-	4.5 ± 0.96	-	-	9 ± 0.49	-
Enterobacter cloacae	12.7 ± 1.45	12.2 ± 1.14	7.1 ± 0.29	-	12.4 ± 1.17	7.2 ± 0.62	8.4 ± 1.47	12.0 ± 1.45
Escherichia coli	9.0 ± 1.15	11.7 ± 1.76	9.0 ± 0.12	10.0 ± 0.06	7.0 ± 1.12	7.0 ± 0.32	9.0 ± 2.01	9.0 ± 1.15
Hafnia alvei	9.6 ± 0.28	9.0 ± 0.44	-	0.92 ± 0.69	-	-	-	-
Klebsiella oxytoca	11.2 ± 0.24	-	12.2 ± 0.64	10.1 ± 0.38	4.2 ± 0.31	-	-	-
Klebsiella pneumoniae	12.1 ± 0.95	7.0 ± 0.89	13.2 ± 0.56	11.4 ± 1.38	10.2 ± 0.89	11.4 ± 0.39	-	-
Morganella morganii	9.8 ± 0.67	-	-	-	-	-	7 ± 0.63	-
Proteus vulgaris	13.4 ± 1.44	7.0 ± 1.18	-	8.2 ± 0.28	7.4 ± 0.84	14.3 ± 0.29	-	12.3 ± 1.38
Proteus mirabilis	11.2 ± 0.31	11.2 ± 0.27	5.6 ± 0.73	7.6 ± 0.45	6.8 ± 0.47	12.2 ± 1.26	9.3 ± 1.22	10.4 ± 1.11
Photobacterium damselae	11.8 ± 0.82	8.2 ± 1.30	-	4.7 ± 0.38	-	-	9.7 ± 0.61	7.8 ± 0.90
Raoultella ornithinolytica	12.80.79	11.6 ± 0.41	-	-	4.2 ± 0.63	13.2 ± 0.96	6.1 ± 0.94	-
Vibrio alginolyticus	11.4 ± 0.25	10.2 ± 1.17	4.1 ± 0.61	-	-	8.2 ± 0.89	-	7.2 ± 0.38

M. Morganii and *H. alvei* were the most resistant to the eight medicinal plants tested. *M. morganii* had a moderate response to only noni and lemon extracts while *H. alvei* had moderate inhibition response to noni and clove extracts. Previous report on *M. morganii* and *H. alvei* growth against noni leaf extract have not been documented. Effectiveness of lemon essential oil from the peels in combination with other antibacterial measures has previous been shown to be bactericidal against *M. morganii* (Kung et al., 2020). Antibacterial studies on lemon leaf extract against *H. alvei* has not been reported previously. *M. morganii* occasionally causes bloodstream infections which is difficult to treat due to the high resistance of the bacteria to various clinical drugs leading to failures in treatments of hospitalized cases which turn into serious issues (Magiorakos et al., 2012; Liu et al., 2016; Laupland et al., 2022; Luo et al., 2022). Similarly, *H. alvei* has also been classified as a multidrug-resistant bacterium needing alternative sources of antibacterial to effectively treat infections (Stanic et al., 2015; Alshabrmi et al., 2022). The present work shows some potential antibiotic sources for these bacteria subject to further clinical investigation of bioactive compounds.

Naaz et al. (2021) used similar range of plant extracts against *E. coli* 0157:H7 and results are comparable with the present work. Antibacterial effectiveness of extracts were assumed to be due to TPC content which are similar to values found in the present work. Some variance in ZOI and TPC level were noted which might be due to the source of plant material and local habitat conditions. Clove extract has previously shown to inhibit growth of *E.coli* and *V. alginolyticus* similar to this work but ineffective against *K. pneumoniae* which is in contrast the results (Oulkheir et al., 2017). The study used clove oil while we used extract from clove bud.

Antibacterial research on a single plant species can give different results depending on certain factors. The bioactivity of plants can be affected by the part of the plant used for extraction since different plant parts may have different constituents of bioactive compounds; geographic location affected by different sets climatic conditions, weather, soil type and stress conditions. All fifteen bacterial species in this study are important food-borne pathogens for humans and animals with different levels of drug resistances as shown in previous works (Hernández-Robles et al., 2016; Annavajhala et al., 2019; Davin-Regli et al., 2019; Karam et al., 2019; Kozieł et al., 2019; Wang et al., 2019; Bandy, 2020; Hajjar et al., 2020; Liu et al., 2020b; Ramos-Vivas, 2020; Sun et al., 2020; Algammal et al., 2021; Mehdizadeh Gohari et al., 2021; Petchimuthu et al., 2022; Yang et al., 2022). All pathogens were inhibited by one or more of the eight plant extracts showing potential for bioactive drug development via further investigations.

Determination of MIC showed that all plants exhibit antimicrobial properties against the tested bacteria. These antimicrobial properties of the tested plants are attributed to the bioactive secondary metabolites. The phenolic composition also attributes to the antimicrobial properties of plants (Royani et al., 2022). According to the MIC values, ginger is the most effective in restricting growth of *E.coli* bacteria. A study by

Table 3
Minimum Inhibitory Concentration (MIC) (mg/mL) of ethanolic plant extracts tested.

Bacterial Species	Minimum inhibitory concentration (mg/mL)							
	Noni	Clove	Guava	Basil	Pawpaw	Neem seed	Lemon	Ginger
Clostridium perfringens	5.0	2.5	1.25	5.0	-	5.0	1.25	6.25
Citrobacte youngae	7.5	-	-	2.5	-	3.75	-	2.5
Enterobacter aerogenes	5.0	5.00	6.25	7.5	7.5	2.5	-	-
Enterobacter amnigenus	8.75	10.0	-	5.0	-	-	7.5	-
Enterobacter cloacae	10.0	1.25	7.5	-	6.25	2.5	6.25	1.25
Escherichia coli	3.75	5.0	5.0	2.5	5.0	3.75	5.00	1.25
Hafnia alvei	7.5	3.25	-	1.25	-	-	-	-
Klebsiella oxytoca	6.25	-	6.25	3.75	6.25	-	-	-
Klebsiella pneumoniae	3.75	5.0	7.5	6.25	6.25	7.5	-	-
Morganella morganii	3.75	-	-	-	-	-	5.0	-
Proteus vulgaris	6.25	5.0	-	5.0	7.5	7.5	-	5.0
Proteus mirabilis	3.75	2.5	7.5	6.25	7.5	7.5	6.25	7.5
Photobacterium damselae	7.5	7.5	-	3.75	-	-	7.5	3.75
Raoultella ornithinolytica	1.25	5.0	-	-	8.75	6.25	2.5	-
Vibrio alginolyticus	7.5	1.25	2.5	-	-	3.75	-	7.5

Those plant extracts that had < 1 mm zone of inhibition was not tested for MIC. Note: "-" indicates samples not tested for MIC.

Gull et al. (2012), reported similar low MIC values of ginger extract on *E. coli*. Basil, neem, and noni extracts were also effective at restricting growth of *E.coli* at low concentrations. *P. mirabilis* is a gram-negative bacteria known to be the causative agent for urinary tract infection (Schaffer & Pearson, 2015) found in soil and water. *P. mirabilis* showed sensitivity against all eight plant extracts tested. Clove extracts are the most effective in inhibiting the growth of *P. mirabilis*. Similarly, a study by De Silva et al. (2018) also reported clove extracts as an antibacterial agent against gram-negative bacteria, including *Proteus* species.

TPC refers to the yield of the phenolic content of the plant extract samples in accordance with the extraction solvent used. There are similarities and differences in the TPC values of medicinal plants tested in this study compared to the literature, which may be attributed to the different constituents of bioactive compounds based on geographical variation, or the extraction method (Bramorski et al., 2010; Del Serrone et al., 2015; El-Maati et al., 2016; Sakkas & Papadopoulou, 2017; Aryal et al., 2019; Ferreira et al., 2021; Naaz et al., 2021). Some studies report the relationship between TPC and antibacterial properties of different plant extracts (Medina et al., 2006; Mekinić et al., 2014; Pandey et al., 2018; Tian et al., 2018; Sartini et al., 2019; Değirmenci & Erkurt, 2020; Rocchetti et al., 2020). Noni extract had the highest TPC in this study as well as the highest antibacterial property. The extracts used in this study need further research as limited literature is available on TPC and antibacterial correlation.

The results yielded that Noni was the most effective and acted as a wide spectra antimicrobial agent showing antibacterial potential against all fifteen bacterial species. All eight plant extracts were successful in inhibiting bacterial growth for different species at varying levels of effectiveness. The results indicate possible bioactive compounds in the extracts which can aid in searching for new antibiotic drugs from plant sources. TPC may attribute to the antibacterial properties of the extracts, however, this needs further investigation. Despite the extensive use of medicinal plants in Fiji as well as the Pacific Island countries, the knowledge and the properties of this important flora is not well documented. Studies that identify the compounds of therapeutically important flora in Fiji are recommended.

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CRediT authorship contribution statement

Ashneel Ajay Singh – Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing. **Zafiar Tasmeen Naaz** – Validation; Visualization; Roles/Writing - original draft; Writing - review & editing. **Edward Rakaseta** - Data curation; Formal analysis; Software; Supervision; Validation; Visualization; Roles/Writing - original draft. **Marcha Perera** - Data curation; Formal analysis; Software; Supervision; Validation; Visualization; Roles/Writing - original draft. **Vrinda Singh** - Data curation; Formal analysis; Software; Supervision; Validation; Visualization; Roles/Writing - original draft. **Wilson Cheung** - Data curation; Formal analysis; Software; Supervision; Validation; Visualization; Roles/Writing - original draft. **Francis Mani** - Data curation; Formal analysis; Investigation; Methodology; Validation; Writing - review & editing. **Swastika Nath** - Validation; Roles/Writing - original draft; Writing - review & editing.

Statements and Declarations

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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