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Evaluating antimicrobial activity and total phenolic content of commonly used herbs and spices in Fiji

Zafiar Tasmeen Naaz[1]*, Krishneel Raj[1], Kriti Karvina Singh[1], Shonal Lata[1], Dr. Ashneel Ajay Singh[1,2]

[1]Department of Science, School of Science and Technology, The University of Fiji, Lautoka, Fiji.
[2]School of Agriculture, Geography, Environment, Ocean and Natural Sciences, The University of the South Pacific, Suva, Fiji.

*Address all correspondence to Zafiar Naaz, MSc, USP, S. Pac.
Email naazzafia@gmail.com

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Abstract

Traditionally, crude extracts from various plants were used for treatment of diseases and ailments, while spices have been used for flavour, as preservatives, in rituals and as medicines for treating infectious diseases. The essential oils of 12 medicinal plants and spices were extracted and tested against *Escherichia coli* 0157:H7 (EHEC) to determine the antimicrobial properties. The selected plants and spices are *Eugenia caryophyllata (F)*, *Jasminium (F), Eucalyptus globulus (L), Zingiber officinale (R), Allium sativum (L)*, *Occimum sanctum (L), Azadirachta indica (L)*, *Psidium guajava (L)*, *Citrus limon (L)*, *Carica papaya (L)*, *Morinda citrifolia (L)* and *Azadirachta indica (seed)*. These plants and spices were chosen due to their dependence by local households as a means of traditional medicine. Essential oils extracted from the plant and spices showed growth inhibition of *E. coli* 0157:H7, whereas the highest antimicrobial activity was recorded for clove oil. Jasmine, pawpaw and neem (seed oil) had the lowest growth respectively. All other extracts had moderate activity. Additionally, the aqueous and ethanol extracts of each plant were used to determine the total phenolic content (TPC). From the plants tested, the TPC of aqueous extract varied from 612±3.15 to 2.67±0.11 (mg GAE/100gdw), while TPC of ethanol extract varied from 434±2.87 to 1.02±0.09 (mg GAE/100gdw). The highest TPC was recorded for noni aqueous extract and the lowest was for jasmine ethanol extract. This study reports the inhibitory effects and phenolic content of 12 herbs and spices and thus its potential use for developing safe pharmaceutical agents.

Introduction

The Pacific island countries have high faunal and floral diversity which is a resource base for food and folk medicine. Traditional medicines have been used in Fiji by all ethnic groups including indigenous Fijians and Indians. Indigenous and traditional knowledge of treating diseases and use of medicinal plants have been accumulated through self-taught experiences and observation of village practitioners over many generations[1]. Approximately 44% of the population in Fiji is of Indian origin[2] who also rely on herbal folk medicine along with the Fijian traditional medicines[3]. Indigenous people in Fiji use medicinal plants for treating illness of the body (*mate vayano*) such as cough, cold, headache, stomach ailment, cuts and burns among others. Almost all parts of a plant can been used for the treatment of more than one ailment; however, the leaves and barks are more frequently used compared to fruits and flowers[4].

Every year several bacterial diseases emerge and gain resistance against the synthetic medicine over a short period of time[5]. To this effect, pharmaceutical companies are working with scientists in order to find ways to fight diseases through use of natural products including various herbs[6] due to the ability of these plants to inhibit the growth of wide range of pathogens[7]. Medicinal plants produce essential oils which are odorous and volatile products of plant secondary metabolism that play an important role in folk medicine[8]. These volatile oils have antibacterial, anti-inflammatory, anti-fungal, anti-viral, anti-mutagenic, anti-carcinogenic and antioxidant properties[9]. An antibacterial screen of essential oils is carried out using an agar diffusion technique whereby filter paper discs are soaked with essential oils and placed in an agar plate inoculated with bacterial strain[10].

The mechanism of action of essential oils depends on the chemical composition which reacts with the bacterial cell. As such, gram-negative bacteria are more resistant to the effects of essential oils due to the presence of capsules that limit penetration of essential oil, and lack of chemical modification of the cell membrane compared to gram-positive bacteria[11]. Common multi-drug resistant bacteria that are food-borne or hospital-acquired include *Pseudomonas aeruginosa, Staphylococcus* spp., *Shigella, Salmonella*, and *Escherichia coli* (*E. coli*)[12]. *E. coli* is a gram-negative bacterium present in the gastrointestinal tract of humans and animals. Ingesting food contaminated with *E. coli* can cause a urinary tract infection, diarrhoea, vomiting, septicaemia and coleocystis[13]. Antibiotic resistance of *E. coli* has increased over the years and since *E. coli* is the most common gram-negative pathogen in humans, treating and controlling infectious disease is a challenge. The effective use of essential oils against *E. coli* have been reported[14], which has led to a growing interest in the scientific community in identifying traditional medicine and its essential oils to prevent the development of pathogen and resistance.

The plants tested in this study include *Eugenia caryophyllata* (clove), *Jasminium* (jasmine)*, Eucalyptus globulus* (eucalyptus)*, Zingiber officinale* (ginger)*, Allium sativum* (garlic), *Occimum sanctum* (basil), *Azadirachta indica* (neem, including leaves and seed oil), *Psidium guajava* (guava), *Citrus limon* (lemon), *Carica papaya* (pawpaw) *and Morinda citrifolia* (noni). These plants have essential oil secretory tissue[15] from which these complex volatile compounds can be extracted using the process of steam distillation. These selected herbs and spices have been used in traditional medicine to treat various infections in Fiji and might potentially have antibacterial properties.

The biological properties of herbs and spices are related to the ability of plants to synthesise compounds that have antimicrobial and antioxidant activity. Phenolic compounds are secondary metabolites synthesised by plants that have both antioxidant and antimicrobial properties, and which have the potential to delay oxidative damage caused by free radicals therefore decreasing the rate of heart disease and cancer in humans[16]. With the potential of phenolics to neutralise free radicals, determining the total phenolic content (TPC) in food research has become a common practice[17]. The Folin-Ciocalteu method is one of the commonly used assays for determining the concentration of polyphenols in plant extracts[18]. This reaction involves the oxidation reduction reaction where the phenolic group gets oxidised and the metal ion gets reduced[19]. Natural antioxidants including phenolic compounds are gaining public interest, therefore medicinal herbs and spices are tested in this study to determine the TPC and use as a potential source of natural antioxidants.

Despite the extensive use of medicinal plants and herbs in Fiji, there is a lack of publication on Fijian medicinal plants that systematically reports the parts of the plant used for treatment of specific diseases. As such, this lack of quality studies of herbal medicinal products to determine their efficacy is one of the challenges of drug development[20]. This study was aimed at determining the ability of the 12 herbs and spices to inhibit the growth of *E. coli* 0157:H7 (EHEC) and report the medicinal uses of respective spices and herbs tested. The TPC of the 12 herbs and spices were also determined using the Folin-Ciocalteu method. These chemical and biological properties help develop an important knowledge regarding the tested plant extracts. Overall this study investigates the use of selected herbs and spices in its broad application in the food and pharmaceutical industry.

Materials and method

Medicinal plants and spices used

Herbs and spices tested in this study were selected based on their common usage in Fijian households. Clove oil, ginger, basil leaves, garlic, neem leaves, neem seed oil, guava leaves, lemon leaves, pawpaw leaves, eucalyptus oil, jasmine oil and noni leaves were used as antimicrobial sources. Most plants and spices were collected from selected villages in Lautoka, Ba and Rakiraki (Viti Levu, Fiji). The ethnobotanical information and properties of these spices and plant extracts are shown in Table 1.

Preparation of samples by steam distillation

Essential oils of clove, eucalyptus and jasmine were bought (Ashwin Fine Chemicals and Pharmaceutical, India) along with neem essential oil (Ahmed and Company Limited, India).

The parts of the plant (leaves, stems or roots) and the spices were collected from various villages and settlements in Viti Levu between August and September 2019. Samples were prepared according to the methods described in Tawatsin et al.[21]. For the leaf, stem or root samples, a mixture was prepared by first weighing 600g of the sample followed by blending it with 250ml of distilled water using a kitchen blender.

The mixture was then subjected to steam distillation in a Clevenger apparatus for 2–3 hours at 80˚C. The distillate was collected in a separating funnel forming two layers; the lower layer containing water was slowly drained off until only the upper (essential oil) remained. This step was repeated until at least 1ml of oil was recovered. The volatile oil was collected and stored in a 1ml micro-centrifuge tube and stored at 4˚C.

Inoculating bacteria with streaking method

E. coli 0157:H7 was inoculated on a petri dish by the streak method with a sterilised cotton swab. The petri dishes were wrapped with parafilm and incubated at 37˚C for 24 hours to ensure even growth of bacteria.

Antimicrobial activity and determination of zone of inhibition

The antibacterial activities for each of the 12 spices were examined against *E. coli* 0157:H7 using the agar disk-diffusion method. The same method was used by Irshad et al.[22] and Tayel and El-Tras[23] to determine the

Table 1. Ethnobotanical data and properties of spices and plant extracts utilised

Family	Scientific name	Common name	Plant part used	Bioactive compounds	Medicinal properties	Reference
Myrtaceae	***Eugenia caryophyllata***	Clove, Laung (H)	Flower bud	• **Eugenol** • Isoeugenol • Acetyleugenol, sesquiterpene, pinene, vanillin, gallic acid, flavonoids, phenolic acids	• Aids in dengue fever • Treats toothaches and gum diseases • Is a cough remedy • Helps with earache • Helps with arthritis pain	Cortés-Rojas et al. (2014)[94] Yashin et al. (2017)[95]
Oleaceae	***Jasminium***	Jasmine, Chamelee (H)	Flower	• Propanamide • Acetyldehyde • 2-phenylthiolane • (Aminomethyl) cyclopropane • Cyclohexene, 3-etheny • N-methylallylamine • Phthalic acid, bis (7-methylocytyl) ester • 1H-Terazol-5-amine • 10-methylnonadecane • 1,2-benzenedicarboxylic acid, diisooctyl ester	• Helps to lower labour pain • Has an antiseptic effect • Decreases symptoms of menopause • Helps with hepatitis • Helps with dysemenorrhea • Helps with stomatitis • Helps with duodentitis	Al-Snafi (2018)[47] Joseph & Fernandes (2013)[96] Rassem et al. (2018)[97]
Myrtaceae	***Eucalyptus globulus***	Eucalyptus	Leaves	• **1,8-cineole** • Cryptone, α-pinene, *p*-cymene, α-terpineol, *trans*-pinocarveol, phellandral, cuminal, globulol, limonene, aromadendrene, spathulenol, terpiene-4-ol	• Helps treat colds • Reduces joint and muscle pain • Is a dental anti-microbial agent • Heals wound and fungal infection	Bhavaniramya et al. (2019)[37] Fawad et al. (2012)[98] Takahashi et al. (2004)[99]
Zingiberaceae	***Zingiber officinale***	Ginger, Adarak (H)	Root	• **Gingerol** • Turmeric, paradol, geraniol, geranial, borneol, linalool, camphene, zingerol, zingiberon	• Decreases muscle pains • Treats coughs and colds	Yashin et al. (2017)[95] Singletary (2010)[100]
Amaryllidaceae	***Allium sativum***	Garlic, Lehsan (H)	Cloves	• **Allicin**, dially sulfide, diallyl disulfate, diallyl trisulfate, allyl isothiocyanate, *S*-allyl cysteine	• Helps treat arthritis • Protects the skin against poisonous substances	Yashin et al. (2017)[95] Rivlin (2001)[101]
Lamiaceae	***Ocimum sanctum***	Basil, Tulsi (H)	Leaves	• **Camphor** • Eucalyptol, eugenol, α-bisabolene, β-bisabolene, β-caryophyllene	• Helps in cough relief • Treats cardiovascular diseases • Helps diabetic patients • Treats skin infections	Yamani et al. (2016)[38] Miller & Miller (2003)[102]

Family	Scientific name	Common name	Plant part used	Bioactive compounds	Medicinal properties	Reference
Maliaceae	***Azadirachta indica***	Indian lilac, Neem (H)	Leaves	• **Azadirachtin** • Nimbolinn, nimbin, nimbidin, nimbidol, sodium nimbinate, gedunin, salannin, quercetin Desacetylnimbin • Azadiradimo • Salanin	• Treats asthma • Helps in tooth aches • Reduces glucose level in body • Helps with leprosy • Helps with eye problem • Helps with intestinal worms • Helps with anorexia • Helps with biliousness • Helps with skin ulcers	Biswas et al. (2002)[103] Alzohairy (2016)[104]
Myrtaceae	***Psidium guajava***	Guava, Quwawa (F), Amrood (H)	Leaves	• α-pinene, β-pinene, limonene, menthol, terpenyl acetate, β-caryophyllene, isopropyl alcohol, longicyclene	• Helps with malaria • Treats wounds, coughs and dental diseases • Helps in reducing bad cholesterol	Rattanachaikunsopon & Phumkhachorn (2010)[105] Joseph & Priya (2011)[106]
Rutaceae	***Citrus limon***	Lemon	Leaves	• **Limonene** • Geranial, neral, caryophyllene, linalool, β-pinene, citronellal	• Treats migraine headaches • Offers asthma relief	Vankar & Shukla (2012)[107] Hojjati & Barzegar (2017)[108]
Caricaceae	***Carica papaya***	Pawpaw, Papita (H)	Leaves	• Chymopapain • Papain • Caffeic acid • Alkaloids • Saponins • Carpain, Psuedo-carpain • Choline • Carposide	• Treats fever • Aids in diabetes • Reduces inflammation • Helps with asthma • Used as a wound dressing • Helps with jaundice • Helps with gonorrhoea • Helps with vermifuge	Owoyele et al. (2008)[109] Vij & Prashar (2015)[110]
Rubiaceae	***Morinda citrifolia***	Noni, Kura (F), Achi (H)	Leaves	• Octanoic acid • Chlorogenic acid • Cyclopropyl, hexanoic acid, *n*-decanoic acid, allantoin, sorbitol, mannitol, glycerin, gamma-tocopherol • Gentisic acid	• Aids in diabetes • Reduces high blood pressure • Reduces aches, pains	Wang et al. (2002)[111] Silva et al. (2017)[112] Rivera et al. (2012)[113]
Maliaceae	***Azadirachta indica***	Neem	Seed	• Nimbidin • Nimbolide • Limonoids • Azadirachtin, nimbidiol, 3-tigloylazadirachtol, salannol, salannin, nimbinin, nimbin, nimbidin, 3-tigloylazadirachtol	• Improves health and boosts immunity • Helps with antifertility • Is effective against malarial parasites	Biswas et al. (2002)[103] Swapna Sonale et al. (2018)[114]

Bold constituents with demonstrated antimicrobial activities effectiveness of plants and spices on *E. coli* 0157:H7 bacteria. For each spice, 1µL of crude extract was impregnated on the filter paper disc (~6mm in diameter). The volume added was chosen because it represented the approximate volumetric capacity of each disc. The discs were then placed on the petri dish that had previously been surface inoculated with *E. coli* 0157:H7. The plates were incubated at 37˚C for 24 hours and observed for inhibitory bacterial growth. Three replicates for each extract was assayed on different plates. After incubation, the diameter of the clear zones surrounding the disc was measured in millimetres. Measurements were taken from the edge of each disc. The extract was considered active if one or more replicates produced a zone of inhibition >1mm beyond the edge of the disc similar to the study by Akhtar[24].

TPC testing

For this, fresh samples were washed, air dried for at least 1 week and grounded to powder. For each sample, 20g of powdered leaves were soaked in two different extraction solvents – (a) distilled water and (b) 70% ethanol at 27˚C for 72 hours for maceration. The filtrates were then added to a rotatory evaporator for concentrating at 40˚C. These liquid extracts were stored at –4˚C.

TPC was quantified using the Folin-Ciocalteu method described by Singleton and Rossi[25] with some modifications. Gallic acid was used as a standard with the following concentration – 10, 20, 30, 40 and 50µg/ml. 1ml aliquot of extract or standard solution of gallic acid was added to volumetric flask containing 9ml water and mixed thoroughly with 1ml of Folin-Ciocalteu's reagent. After this, 10ml of 7% sodium carbonate was added to the mixture and incubated for 90 minutes at room temperature. The absorbance of the reaction mixture was recorded at 750nm determined by reagent blank using distilled water. The total phenolic concentration was determined in triplicate for each sample using the calibration curve (R^2=0.9989) and the average was expressed as gallic acid equivalent in milligrams per 100g of dried weight (mg GAE/100gdw).

Statistical analysis

IBM SPSS Statistic v 20.0 (Statistical Package for the Social Science) was used to analyse the 12 essential oils extracted from the spices and plants. An alpha level of 0.05 was used to determine the statistical significance. For the zone of inhibition, a single sample t-test was carried out using the mean of the three trials to find if there was a statistically significant difference between the zones of inhibition of different spices using SPSS.

For TPC, a two-sample paired t-test was carried out to test if there is a difference in the phenolic content of aqueous extract and ethanol extract. The mean of the three replicate values was used.

Results

In this research, the essential oil of 12 medicinal plants and spices was extracted. These extracts were tested against *E. coli* 0157:H7 to observe the zone of inhibitions. The 12 extracts exhibited growth inhibition properties against *E. coli* 0157:H7 at varying degrees as shown in Table 2.

Out of the 12 extracts that were tested, clove showed the largest zone of inhibition (15.2±1.76mm) followed by lemon (13.4±0.64) against *E. coli* 0157:H7, while neem (seed oil), pawpaw (leaves) and jasmine (flower) had the lowest zone of inhibitions. All other extracts had moderate levels of activity. Overall, all the extracts had the ability to inhibit growth of *E. coli* 0157:H7 to some extent.

Table 3 shows the TPC of the 12 herbs and spices tested in two different solvents, namely water and ethanol. The TPC calculated from the calibration curve (R^2=0.9989) was highest in noni aqueous and ethanol extract, 612±3.15mg GAE/100g, 434±2.87mg GAE/100g, respectively. The lowest TPC was recorded for jasmine aqueous and ethanol extract, 2.67±0.11 GAE/100g and

Table 2. Growth inhibition screening test of 12 plant extracts ± SD against E. coli 0157:H7

Plant species	Common name	Inhibition zones (mm)
Eugenia caryophyllata (F)	Clove	15.2±1.76
Jasminium (F)	Jasmine	6.1±0.58
Eucalyptus globulus (L)	Eucalyptus	11.3±1.67
Zingiber officinale (R)	Ginger	9.4±1.15
Allium sativum (L)	Garlic	10.4±0.58
Ocimum sanctum (L)	Basil	10.6±0.24
Azadirachta indica (L)	Neem	10.2±0.88
Psidium guajava (L)	Guava	9.3±0.54
Citrus limon (L)	Lemon	13.4±0.64
Carica papaya (L)	Pawpaw	7.3±0.57
Morinda citrifolia (L)	Noni	11.2±1.15
Azadirachta indica (Seed)	Neem	6.8±0.38

There was a highly significant difference between the means of zone of inhibition of the 12 spices tested (p<0.001).

1.02±0.09 GAE/100g, respectively. This study reports that the TPC values of aqueous extract and ethanol extract prepared from the herbs and spices as quantified using the Folin-Ciocalteu method did not differ significantly (p>0.05).

Discussion

In this study the antimicrobial properties of 12 extracts from plants and spices were tested against *E. coli* 0157:H7 bacteria. All of the extracts tested in this study showed statistically significant antibacterial properties. According to the disc diffusion results, clove essential oil had the highest antimicrobial activity (11.7±1.8mm) against *E. coli* 0157:H7. Clove has also been shown to have antimicrobial properties against various food-borne pathogens including: *Staphylococcus aureus*, *Staphylococcus epidermis*, *Bacillus cereus, Bacillus subtilis, Bacillus sp.*[26–29] and strains of *Helicobacter pylori*[30].

Spices such as clove, thyme, cinnamon and cumin have been used to treat infectious diseases due to their proven antimicrobial activity against pathogenic bacteria and fungi[31,32]. Therefore, these plants and spices have the potential to reduce the growth of *E. coli* colonies, hence these can be used to treat illnesses caused by *E. coli*.

The clove essential oil of leaf extracts contain 78.8–94.4% eugenol[33,34]. Apart from clove, eugenol is also found in cinnamon, ginger, oregano, thyme, tulsi and pepper, basil, and nutmeg[35,36]. Other constituents of clove essential oil are β-caryophyllene (17.4%), α-humulene (2.1%) and eugenyl acetate (1.2%) which have bacterial growth inhibitory properties[33]. The mode of action of these bioactive compounds include disruption of cell wall structures resulting in an increased permeability, followed by leakage of ions causing cell death[28,37].

Antimicrobial activity of basil leaves, locally known as tulsi, and Eucalyptus oil were also effective against *E. coli* 0157:H7. Presence of eugenol (23.7%) in the essential oil of tulsi leaves corresponds to the high cytotoxicity along with presence of camphor (24.2%) and eucalyptol (13.47%)[38]. Essential oil from the leaf of Eucalyptus has antimicrobial, antifungal and antioxidant properties with an effective inhibitory action against *S. aureus, Staphylococcus pyogenes, Staphylococcus pneumoniae* and *Haemophilus influenzae*[39].

Table 3. The TPC of different plant extracts shown in mgGAE per 100g of dry sample. The results are expressed as means of three replicates ± SD

Plant	Common name	Extract	TPC mgGAE/gdw
Eugenia caryophyllata (F)	Clove	Aqueous	312±1.86
		Ethanol	254±1.42
Jasminium (F)	Jasmine	Aqueous	2.67±0.11
		Ethanol	1.02±0.09
Eucalyptus globulus (L)	Eucalyptus	Aqueous	422.15±2.12
		Ethanol	362.48±0.89
Zingiber officinale (R)	Ginger	Aqueous	8.05±1.06
		Ethanol	2.43±0.5
Allium sativum (L)	Garlic	Aqueous	39.95±1.06
		Ethanol	34.6±0.87
Ocimum sanctum (L)	Basil	Aqueous	73.36±2.18
		Ethanol	94.58±1.35
Azadirachta indica (L)	Neem	Aqueous	24.83±1.04
		Ethanol	42.39±1.35
Psidium guajava (L)	Guava	Aqueous	135.57±2.89
		Ethanol	97.36±3.12
Citrus limon (L)	Lemon	Aqueous	8.25±0.57
		Ethanol	5.87±0.85
Carica papaya (L)	Pawpaw	Aqueous	53.37±0.48
		Ethanol	72.62±1.76
Morinda citrifolia (L)	Noni	Aqueous	612±3.15
		Ethanol	434±2.87
Azadirachta indica (Seed)	Neem	Aqueous	8.26±0.47
		Ethanol	7.21±0.36

There is statistically no significant difference in the TPC of aqueous extract and ethanol extract, p>0.05.

Antimicrobial properties of neem, garlic, guava, lemon, and ginger against *E. coli* 0157:H7 were comparatively low; however, it was sufficient to cause a <1mm inhibitory zone. Guava is rich in ascorbic acid and it also has antimicrobial activity against common diarrhoea-causing bacteria such as *Staphylococcus, Shigella, Bacillus, E. coli, Salmonella, Clostridium* and *Pseudomonas*[40]. A study by Cavallito and Bailey[41] also reported antimicrobial properties of garlic against *E. coli* and *S. aureus*. Neem essential oil has been shown to be effective against *S. aureus, Salmonella typhi, E. coli* and *Pseudomonas aeruginosa*[42]. Lemon has been reported to have inhibitory activity against *E. coli, S. aureus* and *B. subtilis*[43]. Ginger has antimicrobial properties against *E. coli, S. typhi and B. subtilis*[44]. Jasmine (flower) and neem (seed oil) had the lowest inhibitory activity against *E. coli* 0157:H7. A study by Al-Khazraji[45] reported that the extract from all parts of the jasmine plant has lower antimicrobial activity compared to ampicillin and gentamicin, having a potent effect on gram-positive bacteria. However, it has been used to treat urinary tract infection which is commonly caused by *E. coli*.

Jasmine flower and leaves have also traditionally been used for treating toothache, and ulceration in the mouth, throat and gums[46]. Pharmacological studies have determined that the plant has antimicrobial, antioxidant, insecticidal, antifertility and dermatological properties[47]. Jasmine oil has been reported to have an inhibitory effect against various bacteria including *E. coli, S. aureus, S. epidermis, B. cereus, B. subtilis, Enterobacter aerogenes, S. typhi, Salmonela typhimurium, Shigella spp.* and fungus[48].

The pawpaw plant, including fruits, seeds, leaves, latex and roots, has been used as traditional medicines. The two important compounds include chymopapain and papain which helps in digestion[49]. The leaves have antimalarial and antiplasmodial activity and are also reported to treat dengue fever by potentially increasing the number of thrombocytes and leucocytes[50]. The leaf extract has shown to be effective for suppressing growth of *S. aureus, Streptococcus faecalis, E. coli* and *Proteus mirabilis*[51].

Noni (in Hawaiian and Tahitian Islands), also known as *kura* (its Fijian name)[52], is an important plant widely used by Polynesians[53]. The roots, stems, leaves and fruits have been used as traditional medicine for diseases and illness including headaches, arthritis, burns, diabetes and hypertension[54]. Traditionally, leaves have been used for treating malaria, tuberculosis, diabetes, vitamin deficiency, hernia, hypertension, burns, fever and headaches[55].

Our results for the antimicrobial properties concur with studies that have a similar zone of inhibition for clove[56] jasmine[57], eucalyptus[58], ginger[59], basil[60], neem leaves[61], citrus[62] and neem seed oil[63]. However, there are lack of studies that report the zone of inhibition using essential oils from garlic, guava, papaya and noni leaves. Instead, inhibitory effects of methanol and ethanol extracts have been tested by Ngum et al.[64], Dhiman et al.[65], Benmeziane et al.[66] and Natheer et al.[67], respectively.

As reported by Bahri-Sahloul et al.[68], there is a correlation between phenolic composition and antimicrobial activity. For instance, phenolic compounds including quercetin, rutin, epicatechin and procyanidin B2 are antimicrobial[68]. However, the antimicrobial effects are related to the class of polyphenols and the effect varies between gram-negative and gram-positive bacteria. For future studies, essential oils can be examined for phenolic content and their specific antimicrobial properties.

Besides antioxidant properties, many phenolic compounds also exhibit antimicrobial, anti-inflammatory and pro-coagulating activities[69], therefore evaluation of antimicrobial and phenolic contents have commonly been carried out for medicinal plants[70,71]. The phenolic content is known to contribute to the quality and nutritional value of food products and plant defence mechanism[72]. The TPC of the 12 herbs and spices varied in this study. Noni had the highest TPC, followed by eucalyptus and clove, while jasmine had the lowest TPC. Phenolic compounds are major functional micronutrient in noni plants. A study by Torey et al.[73] reported the TPC of noni leaves to be 180.56±1.27μg/ml in methanol extract. A higher TPC was observed mostly for aqueous extract compared to ethanol extract. The TPC results obtained in this study concurred to other studies carried out previously for clove[74], ginger[75,76], basil[77,78], guava[79], lemon[80], pawpaw[81], eucalyptus[82,83], jasmine[84,85], noni[86], neem leaves[87], neem seed oil[88] and garlic[89].

The composition and quality of essential oils are determined by analytical methods including gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS), high performance liquid chromatography (HPLC) and nuclear magnetic resonance (NMR) spectroscopy[90–92]. Essential oils tested in this study meet the quality standard since the TPC values are similar to most of the studies that simultaneously tested the extracts in GC[74,75,77] and HPLC[76,78–81,85,87].

Conclusion

Herbs and spices play a vital role in our lives. Most ancestors in Fiji and the Pacific were dependent on herbal medicines to treat diseases due to availability of fewer medical facilities. Essential oil extracts from tested plant and spices had an effect on the growth of gram-negative *E. coli* 0157:H7, thus can be used as antimicrobial agent to disinfect wounds. The extracts can be used for treatment of various illnesses, mainly caused by bacteria, as indicated by the traditional uses. This study also provides evidence that the herbs and spices are sources of natural antioxidants. Although the plants reported in this study have been used by local people over many generations, it is still mandatory to consult with medical experts to avoid adverse skin reactions and oral toxicity. Many essential oils are inherently toxic even at low concentrations. As reported by Tisserand and Young[93], eucalyptus and garlic oil should not be consumed in any dosage, while clove, basil, ginger and lemon oil can be used both externally and internally with appropriate dilutions. For future studies, the mechanism of action for plant-based medicine can be studied to better understand how these bioactive compounds affect the physiological functions and inhibition.

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Conflict of interest

The authors declare no conflicts of interest.

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