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Antimicrobial Activity of Plant Secondary Metabolites: A Review

K.L. Compean and R.A. Ynalvez

Texas A and M International University, Laredo, Texas, 78041, USA

Corresponding Author: R.A. Ynalvez, Department of Biology and Chemistry, Texas A and M International University, 5201 University Blvd., Laredo, TX 78041, USA

ABSTRACT

The increasing incidence of microorganisms becoming resistant to antibiotics has continuously become a scientific community concern. Many scientists around the world are performing research on plants to be able to discover possible antimicrobial compounds. To date, many plant secondary compounds are known to have diverse biological activities. These may include antibacterial, antifungal and anticancer activities. In this regard, many scientists want to isolate, purify and identify plant secondary metabolites. The aim of this study is to provide recent insights on the different secondary metabolites class and the experimental evidences of antibacterial activities against many different pathogens.

Key words: Antimicrobial activity, secondary metabolites, phytochemicals, plant extracts, antimicrobial agents, ethnopharmacology

INTRODUCTION

There is increased prevalence of antibiotic resistant bacteria emerging from the extensive use of antibiotics. This renders current antimicrobial agents insufficient to control at least some bacterial infections (Riffel *et al.*, 2002). Plants are used for the treatment of diseases and novel drugs continue to be developed through research from plants. There are more than 20,000 plant species used in traditional medicines and they are prospective reservoirs for new pharmaceuticals. Traditional medicinal plants have received significant attention because their phytochemicals may lead to new drug discoveries (Amor *et al.*, 2009).

For several years, there has been an increased interest in the study of different extracts obtained from traditional medicinal plants as potential sources of new antimicrobial agents. The search for new antimicrobial agents is an important line of research because of the resistance acquired by several pathogenic microorganisms (Hossain *et al.*, 2012; Riffel *et al.*, 2002). From previous research studies, several secondary metabolites have been revealed as potential antibacterial agents; therefore, this study will discuss the different secondary metabolites produced by plants and their potential antibacterial activities.

In many developing countries, plant materials have been known to be used as traditional medicine. There is the lack of healthcare in these countries. Thus plants become readily accessible and economical sources available for the treatment of many infections and diseases. In recent years, medicinal plants have started to increase its appeal to pharmaceutical companies and the scientific research community. This was due to evidences that these plant-derived compounds have a potential for many biological activities which include antimicrobial activity (Savoia, 2012). Scientists' aim is to extract and characterize active phytochemicals found in plants, since they have provided high activity profile drugs (Vaghasiya *et al.*, 2011).

Ethnopharmacology has recently become an area of interest because of the use of these medicinal plants against infectious diseases. In this study, the raw materials from a plant are collected and further analyzed for the bioactive constituents exhibiting the biological activity. Thus in the future, they can be used as pharmaceutical drugs (Savoia, 2012). These natural products are chemical compounds derived from any living organism, including plants. Primary metabolites are necessary compounds produced by the plant for growth and metabolism; they include carbohydrates, proteins and lipids. On the other hand, secondary metabolites are compounds that are products of primary metabolism and are known for plant defense mechanisms (Ramawat, 2007). Drugs derived from natural products are usually secondary metabolites and their derivatives. Phytochemical screening of different plants has revealed numerous bioactive compounds including alkaloids, tannins, flavonoids, glycosides and saponins. These plant secondary metabolites serve as defense mechanisms against many microorganisms, insects and herbivores (Vaghasiya *et al.*, 2011).

SECONDARY METABOLITES

Secondary metabolites are being the subject for many research studies because these compounds exhibit many biological activities. These include antimicrobial, antifungal, anticancer and anti-inflammatory activities. For this study, only the antimicrobial activity of different secondary metabolite compounds from different plants will be discussed. In addition, the evidences of the presence of antimicrobial biological activity reported in recent studies will be presented. Table 1 summarizes these different secondary metabolites and their antibacterial activities.

ALKALOIDS

Alkaloids are organic heterocyclic nitrogen compounds that are basic-forming water-soluble salts. They contain nitrogen, which is usually derived from an amino acid. Several classes of flavonoids include phenylalkylamines, pyrrolidines, tropane alkaloids, pyrrolizidines and purine alkaloids (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007). These metabolic compounds are grouped into three classes, depending on the precursors and final structure of the molecule. The classes include; (1) True alkaloids, which are basic and contain nitrogen in a heterocyclic ring-includes nicotine, (2) Pseudoalkaloids, which are also basic but they are not derived from amino acids-includes caffeine and (3) Protoalkaloids, which are amino acid derivatives, basic, but the nitrogen is not in a heterocyclic ring-includes phenylethylamine derived alkaloids including mescaline. Furthermore, alkaloids have been shown to have analgesic effects; morphine alkaloids are pain relievers that are used as narcotics (Agbafor *et al.*, 2011).

Tamarindus indica (Fabaceae) aqueous pulp extract was tested for antimicrobial activity against *Escherichia coli*, *Staphylococcus aureus*, *Salmonella typhi* and *Pseudomonas aeruginosa*. Phytochemical screening of the aqueous extract revealed that the main constituents found in higher concentrations were alkaloids (4.32%). The *T. indica* pulp extract was found to have antibacterial effects against all microorganisms tested, except *S. typhi* (Abukakar *et al.*, 2008). Moreover, *Zapoteca portoricensis* (Fabaceae) leaves were collected and extractions were done using four different solvents namely, water, methanol, ethylacetate and diethylether. These plant extracts were tested for antibacterial activity against *E. coli*, *S. aureus*, *Streptococcus pyogenes*, *Klebsiella pneumonia* and *P. aeruginosa*. After performing phytochemical analysis, it was shown that the aqueous plant extract was abundant with alkaloids. Therefore, these constituents may be exhibiting the antibacterial activity of the *Z. portoricensis* leaves, which can potentially be used for

Table 1: Secondary metabolites from different plant families and their reported antibacterial activities

Secondary metabolite and plant families	Antibacterial activity	References
Alkaloids		
Fabaceae	<i>Escherichia coli</i>	Carson and Hammer (2010)
Amaryllidaceae	<i>Staphylococcus aureus</i>	Savoia (2012)
Mimosaceae	<i>Pseudomonas aeruginosa</i>	Ramawat (2007)
Capparaceae	<i>Mycobacterium tuberculosis</i>	Agbafor <i>et al.</i> (2011)
Rubiaceae	<i>Mycobacterium kansasii</i>	Mariita <i>et al.</i> (2011)
Compositae	<i>Salmonella typhi</i>	Munyendo <i>et al.</i> (2011)
Rutaceae	<i>Staphylococcus epidermidis</i> Methicillin-resistant <i>Staphylococcus aureus</i> (MRSA)	Sibi <i>et al.</i> (2012)
Flavonoids		
Fabaceae	<i>Pseudomonas aeruginosa</i>	Agbafor <i>et al.</i> (2011)
Amaryllidaceae	<i>Mycobacterium fortuitum</i>	Munyendo <i>et al.</i> (2011)
Rubiaceae	<i>Staphylococcus aureus</i>	Sibi <i>et al.</i> (2012)
Labiatae	<i>Salmonella typhi</i>	
Rutaceae	<i>Staphylococcus epidermidis</i> Methicillin-resistant <i>Staphylococcus aureus</i> (MRSA)	
Tannins		
Myrtaceae	<i>Staphylococcus aureus</i>	Abdulhamid <i>et al.</i> (2014)
Fabaceae	<i>Streptococcus faecalis</i>	Mariita <i>et al.</i> (2011)
Mimosaceae	<i>Bacillus subtilis</i>	Sibi <i>et al.</i> (2012)
Rubiaceae	<i>Escherichia coli</i>	Oboh (2010)
Labiatae	<i>Salmonella typhi</i> <i>Pseudomonas aeruginosa</i> <i>Staphylococcus epidermidis</i> <i>Shigella dysentria</i> <i>Proteus sp.</i>	
Terpenes		
Myrtaceae	<i>Streptococcus faecalis</i>	Sibi <i>et al.</i> (2012)
Rubiaceae	<i>Pseudomonas aeruginosa</i>	Abdulhamid <i>et al.</i> (2014)
Compositae	<i>Staphylococcus epidermidis</i>	Munyendo <i>et al.</i> (2011)
Labiatae	Methicillin-resistant	Korir <i>et al.</i> (2012)
Rutaceae	<i>Staphylococcus aureus</i> (MRSA)	
Caesalpinaceae		
Amaranthaceae		
Quinones		
Boraginaceae	<i>Staphylococcus aureus</i>	Papageorgiou <i>et al.</i> (2008)
Plumbaginaceae	<i>Staphylococcus epidermidis</i>	Carson and Hammer (2010)
Ebanaceae		Savoia (2012)
Droseraceae		Ramawat (2007)
Resins		
Labiatae	<i>Pseudomonas aeruginosa</i>	Oboh (2010)
Fabaceae	<i>Shigella dysentria</i> <i>Proteus sp.</i> <i>Staphylococcus aureus</i> <i>Mycobacterium fortuitum</i> <i>Salmonella typhi</i>	Mariita <i>et al.</i> (2011)

skin infection treatment, since the aqueous extract exhibited a large zone of inhibition against *P. aeruginosa*. The discovery of these secondary metabolites being active in inhibiting a

gram-negative bacterium is astounding since secondary metabolites are usually known to more active against gram-positive bacterium and mostly inactive against gram-negative bacterium (Agbafor *et al.*, 2011).

In another experimental study, methanol extracts were prepared from eight different plant species, which included: *Thylachium africanum* (Capparaceae), *Boscia angustifolia* (Capparaceae), *Cissus quadrangularis* (Vitaceae), *Grewia simi* (Tiliaceae), *Acacia etbaica* (Mimosaceae), *Scadoxus multiflorus* (Amaryllidaceae), *Commiphora africana* (Burseraceae) and *Acacia nilotica* (Mimosaceae). These extracts were tested against *Mycobacterium tuberculosis*, *Mycobacterium kansasii*, *Mycobacterium smegmatis*, *Mycobacterium fortuitum*, *S. typhi*, *K. pneumoniae*, *P. aeruginosa*, *E. coli* and *S. aureus* to determine their potential antibacterial activity. Mariita *et al.* (2011) used different chemical tests to identify the phytochemicals present in the plant extracts. It was revealed that there were a few promising antibacterial activities, including: (1) *S. multiflorus* methanol extract was found to be active against *M. tuberculosis*, (2) *B. angustifolia* presented inhibition against *M. kansasii* and *M. tuberculosis* compared to dimethyl sulphoxide (negative control), (3) *A. nilotica* displayed a strong antimicrobial activity against *S. aureus* and *P. aeruginosa* and (4) *B. angustifolia* and *S. multiflorus* presented strong antimicrobial activity against *S. aureus* and *S. typhi* (Mariita *et al.*, 2011).

Furthermore, from the phytochemical analysis it was revealed that from the methanol extracts that had a potential for antimicrobial activity, alkaloids were present in high concentrations for the plant species *S. multiflorus* and *A. nilotica*, while *B. angustifolia* was found to have a trace of alkaloids. The presence of these alkaloids with additional phytochemicals possibly contribute to the antibacterial activity that has been discussed (Mariita *et al.*, 2011). In a similar study, plant materials-whole leaves, roots and stem of *Morinda citrifolia* (Rubiaceae) were used to prepare ethanol extracts. These extracts were tested against several bacterial isolates, which included: *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Serratia marcescens*, *Streptococcus pyogenes*, *Escherichia coli*, *Pseudomonas aeruginosa* and *Klebsiella pneumoniae*. After performing a qualitative phytochemical analysis, the extracts presented different phytochemicals depending on the plant material. All plant materials had alkaloids present, but they differed in quantity; the leaf extract has the highest concentration of alkaloids present, followed by the stem and then the root. Root extracts exhibited significant antibacterial activity with larger zone of inhibitions, then the leaf and root extracts; all extracts were found to be susceptible only to *P. aeruginosa* and *S. epidermidis*. Therefore, these alkaloids along with other phytoconstituents likely attribute to the antimicrobial activity (Sibi *et al.*, 2012).

Additionally, *Aspilia mossambicensis* (Compositae), *Ocimum gratissimum* (Labiatae) and *Toddalia asiatica* (Rutaceae) were examined for antimicrobial activity against methicillin-resistant *S. aureus* and *P. aeruginosa*. Munyendo *et al.* (2011) prepared several extracts with different solvents (n-hexane, ethyl acetate and methanol) and different plant parts (leaves, stem bark and root). From this study, the methanol plant extracts had promising results including: (1) More bactericidal activity against the gram positive bacteria (MRSA) than gram-negative bacteria (*P. aeruginosa*), (2) Striking finding of the plant extract having higher antimicrobial activity levels than Gentamycin, the antibiotic positive control and (3) Highest antibacterial activity was seen in the stem bark of *T. asiatica*. After a phytochemical screening of different metabolites, it was evident that all the different plants and respective parts possessed different phytochemicals. The leaf and root extract of *A. mossambicensis*, leaf and root extract of *O. gratissimum* and all plant materials from the extract of *T. asiatica* displayed an abundance of alkaloids, in addition to other phytochemicals (Munyendo *et al.*, 2011).

FLAVONOIDS

Flavonoids are phenolic structures found abundantly in photosynthesizing cells. They are usually found in many common edible plant parts such as: Fruits, vegetables, nuts and seeds. Flavonoid compounds have a structural feature of the 2-phenyl-benzopyrane or flavine nucleus, which consists of two benzene rings linked through a heterocyclic pyrane ring. To date, there have been 14 classes of flavonoids identified; they differ based on the chemical nature and position of substituents on the different rings (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007).

Many flavonoids have been known to have antioxidant, anti-inflammatory and antitumor activity. In one experimental study, these secondary metabolites were also thought to contribute to antibacterial activity. The phytochemicals flavonoids were found in the aqueous plant extract of *Zapoteca portoricensis* leaves. From this research, it was demonstrated that these secondary metabolites could be partaking in the anti-*Pseudomonas aeruginosa* activity (Agbafor *et al.*, 2011).

In addition, in a similar study, the methanol extract of *S. multiflorus* exhibited anti-*M. fortuitum*, *S. aureus* and *S. typhi* activities, after phytochemical analysis, it was found that this methanol extract was present in high concentrations of flavonoids. Therefore, these flavonoids, with the presence of other phytochemical could contribute to the different antibacterial activities (Mariita *et al.*, 2011). Likewise, plant materials (leaf, root, whole leaves) of *Morinda citifolia* (Rubiaceae) were examined for antibacterial activity. The ethanol root extract exhibited antimicrobial activity to *P. aeruginosa* and *S. epidermidis*. After phytochemical analysis, it was shown that both the leaf and root ethanol extracts had a high concentration of flavonoids present, consequently revealing this biological activity (Sibi *et al.*, 2012).

Moreover, *Aspilia mossambicensis* (Compositae), *Ocimum gratissimum* (Labiatae) and *Toddalia asiatica* (Rutaceae) were examined for antimicrobial activity against methicillin-resistant *S. aureus* and *P. aeruginosa*. It was found that the ethanol extract had the highest antibacterial activity against MRSA; flavonoids were revealed to be found in abundant numbers in all plant materials (leaves, stem bark and root) tested for the *O. gratissimum* extracts, while only a trace amount of flavonoids were found in all *T. asiatica* plant extracts. The flavonoids, along with other secondary metabolites could contribute to this biological activity (Munyendo *et al.*, 2011).

TANNINS

Tannins are polymeric phenolic substances found in nearly all plant parts. In previous studies, tannins have been known to display different biological activities including antifungal and antibacterial (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007). For instance, the antibacterial activity of ethanol and aqueous stem bark extracts from *Psidium guajava* (Myrtaceae) was evaluated against *Staphylococcus aureus*, *Streptococcus faecalis*, *Bacillus subtilis*, *Escherichia coli* and *Salmonella* sp. (Abdulhamid *et al.*, 2014). Tannins were present in high concentrations for both the ethanol and aqueous extracts. Ethanol and aqueous extract of the bark of *Psidium guajava* exhibited antimicrobial activities against all microorganisms tested; however, the ethanol extract displayed larger zones of inhibitions than the aqueous extract for the most susceptible microorganism being *S. faecalis* and the least susceptible to *Salmonella* sp. (Abdulhamid *et al.*, 2014).

In another study, the methanol extract of *S. multiflorus* exhibited anti-*Mycobacterium fortuitum*, *S. aureus* and *S. typhi* activities, after phytochemical analysis, it was found that this methanol extract was present in high concentrations of tannins. In addition, the methanol extract of *A. nilotica*, which exhibited anti-*Staphylococcus aureus* and

Pseudomonas aeruginosa activities, presented a high concentration of tannins as well. Therefore, these tannins, with the presence of other phytochemicals, could potentially exhibit these antibacterial activities (Mariita *et al.*, 2011).

Moreover, plant materials (whole leaves, roots and stem) of *Morinda citifolia* (Rubiaceae) were tested for antimicrobial activity. The ethanol leaf extract exhibited antimicrobial activity to *P. aeruginosa* and *S. epidermidis*. After phytochemical analysis, it was shown that both the leaf and root ethanol extracts had a high concentration of tannins present, consequently revealing antimicrobial activity (Sibi *et al.*, 2012). In addition, in a similar study, Oboh (2010) collected *Ocimum gratissimum* L. (Labiatae) leaves because they are widely distributed in Nigeria and is commonly used as an herbal medicine for the treatment of many respiratory infections, headaches and skin diseases. He prepared an ethanol extract and tested it against several microorganisms including: *Proteus species*, *Pseudomonas aeruginosa*, *Shigella dysentria*, *Escherichia coli*, *Klebsilla species* and *Staphylococcus aureus*. It was found that the *O. gratissimum* extract exhibited antimicrobial activity against *P. aeruginosa*, *S. dysentria*, *Proteus sp.* and *S. aureus*. After phytochemical screening, it was revealed that the leaves possess several secondary metabolites, including tannins; therefore, these secondary metabolites can contribute to their antimicrobial activities (Oboh, 2010).

TERPENES

Terpenes form the largest group of natural compounds found, with currently over 30,000 known structures. The number of isoprene units they possess can identify them; therefore, 1 isoprene unit is called hemiterpene, 2 isoprene units are called monoterpenes and so forth. Mostly, essential oils are made up of monoterpenes or sesquiterpenes (3 isoprene units) (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007). Monoterpenes are formed when two five-carbon isoprene units are joined, having a molecular structure of $C_{10}H_{16}$. The structures of monoterpenes can be cyclic, linear, regular or irregular. Some derivatives of monoterpenes include alcohols, esters, phenols, ketones and aldehydes (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007). The biosynthesis of terpenes occurs via., two different biological pathways: (1) Mevalonic-acid pathway, which mostly produces sesquiterpenes, sterols and ubiquinones, (2) Methyl-erythritol phosphate pathway, which the majority of the compounds synthesized are hemiterpenes, monoterpenes and diterpenes (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007).

One example of terpene derivatives is terpenoids. Terpenoids were extracted from the bark of *Psidium guajava* and it was discovered that these compounds were found in high concentrations for the ethanol extract, but was not detected in the aqueous extract. These compounds, along with other phytochemicals found in the bark, exhibited anti-*Streptococcus faecalis* activity (Abdulhamid *et al.*, 2014). In addition, after phytochemical analysis, plant materials of *Morinda citifolia* (Rubiaceae) displayed a high concentration of terpenoids present in the leaf ethanol extract. This extract was found to have anti-*P. aeruginosa* and *S. epidermidis* activities (Sibi *et al.*, 2012). Similarly, *Aspilia mossambicensis* (Compositae), *Ocimum gratissimum* (Labiatae) and *Toddalia asiatica* (Rutaceae) were examined for antibacterial activity against methicillin-resistant *S. aureus* (MRSA) and *P. aeruginosa*. From this study, it was discovered that the ethanol extract had the highest antibacterial activity against MRSA. Terpenoids were revealed to be found in abundant numbers in all plant materials (leaves, stem bark and root) tested for

the *O. gratissimum* extracts, while only a trace amount of terpenoids were found in all *A. mossambicensis* and *T. asiatica* plant extracts. These secondary metabolites, along with other phytochemicals could be involved in this antibacterial activity (Munyendo *et al.*, 2011).

In addition, Korir *et al.* (2012) examined the antimicrobial activity of two plant species: *Senna didymobotrya* (Caesalpinaceae) and *Cyanthula polycephala* (Amaranthaceae). For each plant species, three solvents were used for extraction; they include hexane, dichloromethane and methanol. These plant extracts were tested against five different microorganisms, which included *S. aureus*, MRSA, *E. coli*, *P. aeruginosa* and *K. pneumonia*. In this experimental study, zone of inhibitions' diameters were used to measure antimicrobial activity (Korir *et al.*, 2012). Methanol and dichloromethane extracts had the highest activity compared to the water and hexane extracts. Using thin layer chromatography as their phytochemical analysis method, Korir *et al.* (2012) revealed that the both plant extracts had a presence of phenol compounds. A striking discovery found in this study was that the methanol extract of *C. polycephala* was found to be most active against MRSA, a bacterium that has become resistant to antibiotics. The zone of inhibition of this extract was 16.0 mm compared to the positive control Gentamicin, which had a zone of inhibition of 9.0 mm. Furthermore, the methanol extract exhibited anti-bacterial activity against *S. aureus* and *P. aeruginosa* with zone of inhibitions of 14 and 10 mm, respectively (Korir *et al.*, 2012).

QUINONES

Quinones are compounds that contain aromatic rings with two ketone substitutions. In the past years, researchers have been able to identify at least 400 naturally occurring quinones, which are found in all plant organs. The class naphthoquinones are one of the largest groups of plant secondary metabolites with a wide range of biological activities. They can be found in about 20 plant families including Plumbaginaceae, Ebanaceae and Boraginaceae; examples of natural naphthoquinones compounds are plumbagin, shikonin, alkannin and their derivatives (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007). The naphthoquinone plumbagin is an active constituent in the plant families Plumbaginaceae, Droseraceae and Ebenaceae. Depending on the quinone, plants synthesize these metabolites via., several pathways including: (1) Ortho-succinyl benzoic acid pathway for lawsone and juglone, (2) Para-hydroxybenzoic acid-mevalonic acid pathway for shikonin and (3) Acetic acid-mevalonic acid pathway for plumbagin (Ramawat, 2007).

Papageorgiou *et al.* (2008) performed an antimicrobial study on naphthoquinones, specifically the enantiomers alkannins and shikonins. Alkannins and shikonins can be found in at least a hundred and fifty species that belong mainly to the Boraginaceae-including the genera *Lithospermum*. Animal and clinical studies have demonstrated the effectiveness of alkannins and shikonin esters; therefore, it has resulted in the approval of the pharmaceutical ointment known as Histoplastin Red. Clinical studies have revealed that these esters formulated in Histoplastin Red, displayed wound healing properties with both anti-inflammatory activities and antimicrobial activities against ulcer development (Papageorgiou *et al.*, 2008).

Furthermore, Histoplastin Red was tested for anti-*S. aureus* and *S. epidermis* activity. It was found that the enantiomer alkannin inhibited both *Staphylococci* growth. In addition, β -dimethylacryl, an ester of alkannin, also effectively inhibited all *Staphylococci* growth (Papageorgiou *et al.*, 2008). Looking at the clinical evidence, it has been determined that there is a broad antimicrobial spectrum for naphthoquinones derivatives, alkannins and shikonins enantiomers (Papageorgiou *et al.*, 2008).

RESINS

Resins are non-volatile plant products, which can be classified as either a surface or internal resin. They are insoluble in water but are soluble in organic solvents. Resins are usually found in plants as mixtures of compounds, commonly including flavonoids, terpenoids and fatty substances. One class found under the resin group is essential oils; they are volatile oils, soluble in organic solvents and are produced in plant oil glands (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007).

Taxol, a present anticancer drug is composed of phytochemicals known as diterpenes. This drug was first isolated from the bark of *Taxus brevifolia*. Two sesquiterpene precursors coupled make a triterpene, which contains 30 carbons. Several of these compounds occur in plants as glycosides, or saponins. These saponins are molecules that are made up of carbohydrates linked to steroids or triterpenes (Carson and Hammer, 2010; Savoia, 2012; Ramawat, 2007). Oboh (2010) examined the antimicrobial activity of an ethanol extract made from *Ocimum gratissimum* (Labiatae) leaves. It was revealed that the ethanol extract exhibited antibacterial activity against *Pseudomonas aeruginosa*, *Shigella dysentria*, *Proteus* sp. and *Staphylococcus aureus*. From the phytochemical analysis, it was displayed that the leaves from *O. gratissimum* has several phytochemicals, including cardiac glycosides (Oboh, 2010).

The aqueous pulp extract of *Tamarindus indica* was subjected to phytochemical analysis and it was revealed that some phytochemicals found in this pulp extract included resins, specifically saponins (2.2%) and glycosides (1.59%). The pulp extract exhibited the highest sensitivity to *S. aureus*, while not having any sensitivity to *S. typhi* (Abukakar *et al.*, 2008). Likewise, after phytochemical analysis, it was found that the methanol extract of *S. multiflorus* was present in high concentrations of saponins. The methanol extract exhibited anti-*M. fortuitum*, *S. aureus* and *S. typhi* activities. As a result, these secondary metabolites, with the presence of other phytochemicals could potentially exhibit these biological activities (Mariita *et al.*, 2011). In a related experimental study, Oboh (2010) examined the antimicrobial activity of an ethanol extract made from *Ocimum gratissimum* (Labiatae) leaves. It was revealed that the ethanol extract exhibited antibacterial activity against *P. aeruginosa*, *S. dysentria*, *Proteus* sp. and *S. aureus*. From the phytochemical analysis, it was displayed that the leaves from *O. gratissimum* has several phytoconstituents, including saponins (Oboh, 2010).

CONCLUSION

From this study, it is evident that plant cells produce a variety of compounds, mainly secondary metabolites for defense mechanisms against bacteria. As shown, these phytochemicals can possess antibacterial activities. It is clear that many different phytoconstituents have different mechanisms of inhibiting the bacteria, since they differ within the same plant species, different parts of the plants, such as leaves or bark, have been shown to possess different quantities of these metabolites. In addition, the different plant families that have been tested demonstrate that different families have a unique combination of secondary metabolites; therefore, exhibiting different antibacterial activities. Several secondary metabolites exhibited highly potent biological activities that have been attributed to antimicrobial activities; in some cases, the plant extracts that possessed these phytochemicals had higher zone of inhibitions than an antibiotic, demonstrating promising antibacterial activities for these compounds. The emerging research on identifying, purifying and testing antimicrobial activities of different secondary metabolites is underway and further investigations are encouraged to further our knowledge about these compounds. Secondary

metabolites can help to treat infectious diseases that have increased resistance to current antibiotics. They could provide alternative medical treatment for many, especially in developing countries where people may not have access to healthcare.

FUTURE PERSPECTIVES

Over the years, many scientists have performed research on different plant families to be able to identify antimicrobial activities and secondary metabolites. Therefore, in the future, there should be experimental studies to test the biological activities of different plant families. These antibacterial properties are important for future pharmacological uses. Future research is to be able to identify and learn about the mechanisms these secondary metabolites undergo. In addition, future researchers should isolate all compounds from plants, to be able to determine exactly which compound is contributing to the antibacterial activity. In many studies that have been published, a plant extract will have antibacterial potential, so they test it for different secondary metabolites; then several secondary metabolites will be abundant, so it is not certain which components are exhibiting this activity or if it is a synergy among different compounds. Lastly, the future of ethnopharmacology seems very fascinating, there is hope to eliminate these antibiotic-resistant microorganisms by eliminating them with phytochemicals.

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