Antibacterial properties of *Moringa oleifera*

Saba Shamim* and Usman Raza

Institute of Molecular Biology and Biotechnology (IMBB), The University of Lahore (UOL), Defence road campus,
off Bhobatian chowk, Lahore, Pakistan.
Email: sabashamimgenetics@gmail.com

Received 22 August 2017; Received in revised form 12 November 2018; Accepted 7 December 2018

ABSTRACT

Moringa oleifera, considered a medicinal tree by many civilizations, owes its repute to its medicinal attributes, and in particular, to its antimicrobial properties. Different parts of this plant, including pods, stem bark, leaves, roots, and seeds contain bioactive agents such as quercetin, phenolic acids, alkaloids, flavonoids, etc. The modes of action of these bioactive agents are varied, ranging from the inhibition of enzymes to the disruption of bacterial cell membranes. The various antimicrobial properties of the plant are manifested in extracts of methanol, ethanol, hexane, chloroform, and water. Such extracts, which also display antibacterial activity against biofilms, can serve as therapeutic agents against multidrug resistant pathogens, including both Gram-negative and Gram-positive bacteria.

Keywords: *Moringa oleifera*, antimicrobial properties, Gram-positive bacteria, Gram-negative bacteria, bioactive agent

INTRODUCTION

Plants have been the source of many natural antimicrobial compounds since the history of mankind (Arora and Onsare, 2014). An example of such plants is *Moringa oleifera* Lam. (synonymous to *Moringa pterygosperma* Gaertn), a highly valued medicinal plant that is often considered a "miracle tree". It belongs to the monogeneric plant family Moringaceae and grows to a height of 5-10 meters (Morton, 1991).

It consists of 33 species, among which *M. oleifera* and *Moringa peregrina* (forsk) fiore. are well known species. The synonym of *M. oleifera* is *M. pterygosperma* Gaertn. Other names used for *M. peregrina* include *Moringa aptera* Gaertn., *Moringa arabica* (Lam.) Pers., *Moringa zeylanica* Sieb. and *Balanus myrsipica* Blackm. (Lalas *et al.*, 2012; Arora and Onsare, 2014).

The tree is widely distributed (Nadkarni, 1976; Ramachandran *et al.*, 1980). It is commonly found near sandy beds of rivers and water bodies (Qaiser, 1973), but it adapts to a wide range of environments, ranging from the humid tropics to hot dry lands. Accordingly, it is little affected by drought (Morton, 1991) and thrives in rainfall between 250 mm to 3000 mm. It tolerates both acidic and alkaline soils, adapting to soil pH of 5.0-9.0 (Palada and Changi, 2003; Anwar *et al.*, 2007). While the tree is found in the wild, *Moringa* can be cultivated easily in household gardens.

According to Arora *et al.* (2013), the history of *Moringa* dates back to 150 B. C. It is mentioned in ancient scriptures of the Egyptians, Greek, Romans, and Indians. The tree was used by ancient kings and queens in their royal diet to maintain good physical and mental health. Its leaves were given to ancient Maurians of India to remain fit and healthy in times of war. Having been used as a medicinal tree in more than 80 countries, *Moringa* has been reported in more than 200 local languages in the literature (Mossa, 1985; Booth and Wickens, 1988; Nikkonet *et al.*, 2003; Arora *et al.*, 2013).

The taxonomic classification of *M. oleifera* is given below.

Kingdom: Plantae
Subkingdom: Tracheobionta
Super division: Spermatophyta
Division: Magnoliophyta
Class: Eudicots
Subclass: Rosids
Order: Brassicales
Family: Moringaceae
Genus: *Moringa*
Species: *oleifera*

Taxonomic classification of *M. oleifera* (Arora *et al.*, 2013).

The occurrence of *Moringa* is widespread. It has been reported in Pakistan, India, Asia minor, Africa and Saudi Arabia (Mughal *et al.*, 1999), the Philippines, Cambodia, Central, North and South America, and the Caribbean (Morton, 1991; Anwar *et al.*, 2007).

As a “miracle tree” (Jerri *et al.* 2012), different common names are used for *Moringa* in different countries. In Pakistan, it is called as “Sohanjana” (Qaiser, 1973; Anwar *et al.*, 2005), whereas in the Nile valley, people called it “Shagara al Rauwaq” which means “tree for purifying” (von Maydell, 1986). Other names include the drumstick tree, horse radish tree, kelor tree, and medicinal tree (Anwar and Bhanger, 2003; Anwar *et al.*, 2007).

MORINGA OLEIFERA AS A MEDICINAL TREE

Plants produce primary and secondary metabolites (Croteau *et al.*, 2000; Arora *et al.*, 2013) that have applications for different purposes, e.g. curing diseases, healing injuries, etc. Such secondary metabolites are bioactive compounds that include alkaloids, phenolics, tannins, phytosterols and terpenoids (Balandrin *et al.*, 1985; Arora *et al.*, 2013). The importance of different parts of the *Moringa* plant as a source of these useful compounds cannot be ignored (Walter *et al.*, 2011). In many cultures, they would be considered a part of “natural nutrition”. The flowers, leaves, seeds, pods, stem, and bark of the tree have high nutritional value (D’souza and Kulkarni, 1993; Anwar and Bhanger, 2003; Anwar *et al.*, 2005; Anwar *et al.*, 2007).

Medicinal properties of *M. oleifera*

All parts of *M. oleifera* plants possess medicinal properties. These are discussed briefly below. Figure 1 shows the *M. oleifera* tree and its parts.

Leaves

The leaves of *M. oleifera* are a rich source of calcium, potassium, protein, β -carotene, antioxidants (ascorbic acid, flavonoids, phenolics, carotenoids) (Dillard and German, 2000; Siddhuraju and Becker, 2003). Their inclusion in the diet increases milk production in women, and hence, the tree is often referred to as “mother’s best friend” in the Philippines. Some doctors also recommend *Moringa* leaves to anemic patients (Estrella *et al.*, 2000; Siddhuraju and Becker, 2003). Another medical application of *Moringa* leaves is as a treatment for fevers, piles, bronchitis, sore throat, ear and eyes infections, catarrh. They are also used to control blood sugar levels, reduce swelling of glands, and as a purgative. The leaves are rubbed on the temples for headaches and applied as a poultice to sores (The Wealth of India, 1962; Dahot, 1988; Morton, 1991; Makonnen *et al.*, 1997; Fuglie, 1999; Anwar *et al.*, 2007).

Figure 1: Figure showing *M. oleifera* tree and its different parts; (a) leaves (b) flowers (c) stem bark (d) gum (e) seeds (f) roots (g) tree.

Roots

Known for their medicinal properties (The Wealth of India, 1962; Padmarao *et al.*, 1996; Dahot, 1988; Ruckmani *et al.*, 1998; Anwar *et al.*, 2007), *Moringa* roots are useful for the treatment of numerous ailments, e.g. paralytic afflictions, rheumatism, inflammations, articular pains, lower back or kidney pain and constipation. Besides being useful as a laxative, they are also act as an antilithic agent, helping the body to prevent the formation of stones in the gall bladder and kidney, as well as aiding the body in their removal. *Moringa* roots are also used as a carminative agent, they help to prevent or relieve flatulence. *Moringa* roots are useful also as antifertility, anti-inflammatory, and abortifacient agents (Anwar *et al.*, 2007).

Bark

The bark of the *Moringa* stem is used to cure eye diseases. It is used also for the treatment of delirious patients, as a medication to prevent enlargement of the spleen, formation of tuberculous glands of the neck, and

as an agent that destroys tumors and heals ulcers. The juice from the root bark is put into the ears to relieve earaches and also placed in a tooth cavity as a pain killer. It is reputed to have anti-tubercular activity (Bhatnagar *et al.*, 1961; Siddhuraju and Becker, 2003; Anwar *et al.*, 2007).

Gums

The gums extracted from *Moringa* are used for treatment of dental caries. It is an astringent. If the gum is mixed with sesame oil, it is effective for the relief of headaches, fevers, intestinal complaints, dysentery and asthma. It is sometimes used as an abortifacient, and to treat syphilis and rheumatism (Fuglie, 1999; Anwar *et al.*, 2007).

Flowers

The flowers of *Moringa* are reported to possess high medicinal value as a stimulant, an aphrodisiac, an abortifacient and a cholagogue. It is used to treat inflammation, muscle diseases, hysteria, tumors, enlargement of the spleen, and to lower serum cholesterol, phospholipids, triglycerides, VLDL, LDL cholesterol to achieve a desirable phospholipid profile. It improves the atherogenic index, decreases lipid profile in hypercholesterolaemic rabbits and increases the excretion of fecal cholesterol (Bhattacharya *et al.*, 1982; Dahot, 1998; Mehta *et al.*, 2003; Siddhuraju and Becker, 2003; Anwar *et al.*, 2007).

Seeds

Moringa seed extracts exerts their protective effect by decreasing liver lipid peroxides. They contain antihypertensive compounds. Thiocarbamate and isothiocyanate glycosides have been isolated from the acetate phase of the ethanolic extract of *Moringa* pods (Faizi *et al.*, 1998; Lalas and Tsaknis, 2002; Anwar *et al.*, 2007).

ANTIMICROBIAL SIGNIFICANCE OF *M. OLEIFERA*

The medicinal properties of this plant have been attributed to a wide range of antimicrobial compounds present in its tissues (Kostova and Dinchev, 2005; Vieira *et al.*, 2010). The cell walls of Gram-negative bacteria do not allow passage of many antibiotics, and thus act as a barrier to their action (Tortora *et al.*, 2001). Accordingly, *Moringa* extracts tend to be more effective against Gram-positive than Gram-negative bacteria (Kudi *et al.*, 1999; Ali *et al.*, 2001; Palombo and Semple, 2001; Vieira *et al.*, 2010). The widely reported antimicrobial action of this plant (Siddhuraju and Becker, 2003; Vaghasiya and Chanda, 2007; Mashari *et al.*, 2009; Walter *et al.*, 2011) is mediated through the inhibition of enzyme activity or disruption of cell membranes (Silvestro *et al.*, 2000; Suarez *et al.*, 2003; Anwar *et al.*, 2007). According to Cáceres *et al.* (1991), fresh leaf juice and aqueous seed extracts inhibit *Pseudomonas aeruginosa* and

Staphylococcus aureus growth. Folkard and Sutherland (2005) find that *Moringa* seeds destroy *Salmonella typhi* living in the human intestine. Oil in the seeds contains the antibiotic pterygospermin (Aney *et al.*, 2009) that form a thin film over the walls of the intestines, thus protecting them from penetration by microorganisms (Caceres and Lopez, 1991; Cáceres *et al.*, 1991; Nwosu and Okafor, 1995; Walter *et al.*, 2011). The *Moringa* seeds also contain a gum like compound which is antityphoid in nature (Fuglie, 1999; Harristoy *et al.*, 2005).

Antimicrobial properties of different plant parts

As mentioned earlier, all parts of *M. oleifera* plant exhibit antimicrobial properties (Arora and Onsare, 2014) (Table 1). The following paragraphs outline the antibacterial properties in the different parts of the tree.

Pods

The pod husks are found to have antibacterial properties effective against *S. aureus*, *Staphylococcus epidermidis*, *Salmonella typhimurium*, *E. coli* and *Klebsiella pneumoniae*. The major phytochemicals found in the pods are flavonoids, alkaloids, tannins, triterpenes, diterpenes and cardiac glycosides. Among these, the antimicrobial compounds are flavonoids and diterpenes (Arora and Onsare, 2014). According to Nantanchit (2006), purified extracts of capsules have been found to be effective against both Gram-positive and Gram-negative bacteria. The vegetable peels of *M. oleifera* have been observed to be active against *Enterobacter aerogenes*, *K. pneumoniae*, *S. aureus*, *Staphylococcus subflava*, *Proteus mirabilis*, *Cryptococcus luteolus*, *Clostridium rubrum*, *S. typhimurium* (Chanda *et al.*, 2010).

Roots

In different civilizations including India, Vietnam and Pakistan, *Moringa* roots are held in high esteem owing to their antibacterial properties (Rao *et al.*, 2001). In 1957, Das *et al.* reported that the antibiotic compound pterygospermin from *Moringa* roots were found to exhibit antifungal as well as antibacterial properties. After the 1950s, different researchers all over the world reported various antimicrobial components from the *Moringa* root. For example, Eilert *et al.* (1981) reported 4- α -L-rhamnosyloxybenzyl isothiocyanate as a major antimicrobial constituent. In 2003, Nikkon *et al.* stated that the aglycone of deoxy-niazimicine (N-benzyl, S-ethyl thioformate) isolated from the chloroform fraction of an ethanol extract of the root bark was responsible for antibacterial and antifungal activities observed. The root bark was also reported by Dewangan *et al.* (2010) to show antibacterial activity against *S. aureus*, *E. coli*, *Staphylococcus gallinarum* and *P. aeruginosa*. Raj *et al.* (2011) observed antimicrobial activity against *P. aeruginosa*, *S. aureus*, *E. coli*.

Table 1: Antibacterial mode of action of major chemical classes of phytoconstituents and their subclasses.

Chemical structural classes	Major subclasses	Normal function	Antibacterial mode of action	References
Phenolics	Simple phenols Phenolic acids	Protection against oxidative stress	Inhibition of ATP production. Inhibition of enzymes (urease, proline dehydrogenase). Inhibition of nucleic acid synthesis i.e. DNA or RNA.	Tholl, 2006; Simões <i>et al.</i> , 2009
	Flavones (apigenin, luteolin)	Antioxidants, anti-inflammatory, and anticancer activities	-	Bumke-Vogt <i>et al.</i> , 2014
	Flavonols (quercetin, kaempferol, myricetin, isorhamnetin)	Attraction for pollinating insects to flowers, protection against UV damage (flavonoids, anthocyanins)	Quercetin-increase in permeability of inner bacterial membrane, dissipation of membrane potential, binding of GyrB subunit of <i>E. coli</i> DNA gyrase and inhibition of the enzyme ATPase activity.	Mirzoeva <i>et al.</i> , 1997; Plaper <i>et al.</i> , 2003; Tholl, 2006
Terpenoids	Terpenoids	Plant-environment interaction; also plant fragrance, an essential oil	Alteration of membrane permeability, disruption of cytoplasmic membrane.	Cowan, 1999; Brehm-Stecher and Johnson, 2003; Simões <i>et al.</i> , 2008
Essential oils	Essential oils	Aroma and fragrance	Alteration of ion transport processes. Inhibition of respiration. Disturbance of membrane embedded protein. Interference with membrane expansion. Increase in membrane fluidity and permeability.	Simões <i>et al.</i> , 2008
Alkaloids	Alkaloids	Inhibition of multidrug resistance	Inhibition of efflux pumps, interaction with bacterial cytoplasmic membrane.	Gibbons and Udo, 2000; Simões <i>et al.</i> , 2008
Lectins	Lectins	Pathogen invader. Involvement in plant physiology and functionality	-	Cowan, 1999; Dorman and Deans, 2000; Newman <i>et al.</i> , 2000; Stavri <i>et al.</i> , 2007; Simões <i>et al.</i> , 2009
Polypeptides	Peptides	Signalling agents, working as intracellular chemical messengers	-	Bergey <i>et al.</i> , 1996; Pearce <i>et al.</i> , 2001
Polyacetylenes	Quinones	Pathogen invader. Involvement in plant physiology and functionality	-	Cowan, 1999; Dorman and Deans, 2000; Newman <i>et al.</i> , 2000; Stavri <i>et al.</i> , 2007; Simões <i>et al.</i> , 2009
	Tannins	Structural constitutive function, found in almost every plant part (bark, wood, leaves, fruits, roots). Responsible for astringent taste of wine or unripe fruit. Components of flower color and autumn leaves	-	Bergey <i>et al.</i> , 1996; Pearce <i>et al.</i> , 2001
Miscellaneous	Coumarins Polyketides Polyamines Isothiocyanates Sulfides Thiosulfates Glycosides Phenanthrenes Stilbenes	Pathogen invader. Involvement in plant physiology and functionality	-	Cowan, 1999; Dorman and Deans, 2000; Newman <i>et al.</i> , 2000; Stavri <i>et al.</i> , 2007; Simões <i>et al.</i> , 2009

Flowers

Pterygosperminis also present in the flowers of *M. oleifera*. Thus, the flowers have antimicrobial properties which are effective against many microorganisms, including bacteria and fungi (Rao *et al.*, 2001).

Bark

The stem of *M. oleifera* has been a drug of choice for treating urinary tract infection (UTI) as it is cheap and easily available (Chetia and Gogoi, 2011). It is reported to contain 4-hydroxymellin and octacosanoic acid (Faizi *et al.*, 1994), two alkaloids (namely moringine and moringinie), vanillin, β -sitosterol, β -sitostenone, and phenolics (Kumbhar *et al.*, 2012), procyanidin (Atawodi *et al.*, 2010), and 4-(α -L-rhamnopyranosyloxy)-benzylglucosinolate (Bones and Rossiter, 1996; Maurya and Singh, 2014). It showed prominent effect against *E. coli* (MIC 64 μ g/mL), which is a major causative agent of UTI. Maurya and Singh, (2014) also concurred regarding its activity against *E. coli* (Chetia and Gogoi, 2011). Zaffer *et al.* (2014) found that the bark of *M. oleifera* has broad spectrum antibacterial properties effective against both Gram-positive and Gram-negative bacteria (Maurya and Singh, 2014). *E. coli* involved in UTI is killed by bark extract at MIC 64 μ g/mL (Chetia and Gogoi, 2011; Maurya and Singh, 2014).

Leaves

The *Moringa* leaves contain protein that is reported to contain antimicrobial activity against *E. coli*, *K. aerogenes*, *S. aureus* and *Bacillus subtilis* (Dahot, 1998).

Seeds

Eilert *et al.* (1981) identified 4- α -rhamnosyloxy-benzyl isothiocyanate being an active antimicrobial agent in *M. oleifera* seed powder which helped in reducing Most Probable Number (MPN) and Standard Plate Count (SPC) at a dosage of 100-150 mg/L (Mangale *et al.*, 2012). According to Padla *et al.* (2012), *M. oleifera* contains the antibacterial compound 4-(α -L-rhamnosyloxy) benzyl isothiocyanate. It was effective against *Mycobacterium phlei* and *B. subtilis* at concentrations of 12.5 μ g/mL and 17.5 μ g/mL respectively (Eilert *et al.*, 1981). The antimicrobial peptides in seeds of *Moringa* are discussed further below.

Oil

A study on the chemical composition of oil from leaves via GC and GCMS analysis found that hexacosane (13.9%), pentacosane (13.3%) and heptacosane (11.4%) were the main constituents (Marrufo *et al.*, 2013). UPLC-DAD analysis also detected the presence of the flavonoids quercetin (126 μ g/g) and luteolin (6.2 μ g/g). The bacteria *B. cereus* and *P. aeruginosa* were found to be sensitive to *Moringa* oil, with luteolin showing biological and

pharmacological properties like antimicrobial, antiallergic, anticancer, antiplatelet and antioxidant characteristics.

Antimicrobial peptide from seeds

The crushed kernels of *Moringa* seeds are reported to possess antimicrobial water-soluble peptides (Suarez *et al.*, 2005). These proteins have residues at their terminals, which can bind to any suspended particulate matter, including microorganisms, present in the medium. One such well-known antimicrobial peptide (AMP) is Flo. The positive charge of this cation enables it to interact with the negative charges present on the surface of microorganisms. This confers upon the peptide the role of the first line of defense against many pathogens. The amphiphilic structures of the AMP allow their incorporation into the cellular membrane, leading to transmembrane channel formation and the consequent leakage of cellular components out of the cell. Depolarization of bacterial membrane follows, resulting in uneven distribution of lipids between cell membrane layers, leading eventually to intracellular damage (Zhang *et al.*, 2001; Suarez *et al.*, 2005). Cell death has been hypothesized in the following ways (Suarez *et al.*, 2005).

Barrel Stave Model: By formation of pores by amphipatic helices of the peptide in the lipid bilayer, either in the lipid core region or aqueous environment within the pore (Boheim, 1974; Ehrenstein and Lecar, 1977; He *et al.*, 1995).

Aggregate Channel Model: By formation of pores constituted by peptide and phospholipid heads from bent membrane (Matsuzaki *et al.*, 1996; Oren and Shai, 1998).

Carpet Model: By a more general disorganization of the membrane hydrophobic and hydrophilic layers, leading to their disruption (Pouny *et al.*, 1992; He *et al.*, 1996; Bechinger, 1999; Heller *et al.*, 2000).

The strong antimicrobial activity of the *Moringa* AMP is under investigation in many laboratories. Improvement to the AMP has been achieved either by mutating the primary sequence, for instance, to augment its amphiphilic character (Dathe *et al.*, 1996; Friedrich *et al.*, 2000; Dathe *et al.*, 2001; Tachi *et al.*, 2002; Farnaud *et al.*, 2004), or by multimerizing the active sequence (Azuma *et al.*, 1999; Lee *et al.*, 2002; Tam *et al.*, 2002).

Recommended dosage

The recommended doses of different parts of *M. oleifera* plant are: intact form of seed: 5-10 grams, root bark: 2-5 grams, leaf (aqueous juice): 10-20 ml, powder of seed, root, bark, leaf, fruit and flower: 1-3 grams. (API; Mishra *et al.*, 2011).

PHYTOCHEMISTRY OF *M. OLEIFERA*

In order to understand the exact mechanism of a bioactive compound from *M. oleifera* against microorganisms, it is necessary to have some insights into the phytochemistry of the plant. The phytochemical profile for *M. oleifera* plants includes alkaloids, saponin, glycoside, flavanoids, tannins and terpenoids. Various chemical compounds, including tannins, saponins, flavonoids and steroids, are found in its leaves, seeds and flowers. Among the compounds present in extracts of *Moringa* that are responsible for the plant's antimicrobial activity are tannins (Scalbert, 1991), glycosides (Aboaba and Efuwape, 2001), saponins (Hostettman and Nakanishi, 1979), terpenoids and flavonoids (Leven *et al.*, 1979), and alkaloids (Karou *et al.*, 2005; Gami and Parabia, 2011). The phytochemicals found in seeds have been found to be effective against *K. pneumoniae*, *S. aureus* and *Streptococcus*. The agent present in the flower is effective against *E. coli*, *K. pneumoniae* and *P. mirabilis*. The leaf compounds are effective against *E. coli*, *K. pneumoniae*, *Enterobacter*, *P. aeruginosa* and *S. aureus* (Nepolean *et al.*, 2009). The details of phytochemical constituents in *M. oleifera* are given in Table 2.

Antibacterial mode of action of different phytoconstituents

The antimicrobial modes of action of different constituents from *M. oleifera* are given below (Table 2) while Figure 2 shows a graphical summary of mode of action of different parts of the *M. oleifera* plant.

Essential Oils

In the plant kingdom, many species produce essential oils, for example thymol, terpenoids, carvacol etc. that are responsible for the characteristic flavor and aroma of the plant. Although their exact mechanisms of action are not known, they are considered to be involved in the disruption of bacterial membranes through formation of lipophilic products that could increase membrane permeability and membrane fluidity, alter the ion transport processes, inhibit the electron transport chain, interfere with membrane-embedded proteins, alter membrane size, etc. (Mendoza *et al.*, 1997; Griffin *et al.*, 1999; Simões *et al.*, 2009). Any of the said mechanisms or a combination of them could induce the deaths of Gram-positive and Gram-negative bacteria (Simões *et al.*, 2009).

Alkaloids

Alkaloids are known to inhibit efflux mechanism by intercalating with DNA. Essentially, alkaloids can disrupt bacterial cytoplasmic membrane, resulting in antibacterial action (Jennings and Ridler, 1983; Khan *et al.*, 2006; Simões *et al.*, 2009). Khan *et al.* (2006) reported alkaloids as antimicrobial agent against *S. aureus*.

Phenols and Phenolic Acids

Phenol and phenolic compounds inhibit enzymes like polyphenol oxidase by binding covalently to functional residues of proteins including sulfhydryl and primary amino groups, resulting in disruption of energy production (Mason and Wasserman, 1987; Simões *et al.*, 2009). The inhibition of enzymes like urease or proline dehydrogenase by phenolics has been reported (Simões *et al.*, 2009). The inhibition of proline dehydrogenase results in the disruption of energy production at the plasma membrane of Gram-negative bacteria such as *Helicobacter pylori* (Li *et al.*, 2005; Simões *et al.*, 2009).

Plants are hosts to many antioxidants that include phenolics which act as free radical terminators or metal chelators (Shahidi *et al.*, 1992). In plant seeds, they are commonly present in bound form (Arranz *et al.*, 2009), cross linking with the cell wall through ester or ether linkages involving their hydroxyl and carboxyl groups (Yu *et al.*, 2001). These bound phenolics are released when seeds are subjected to treatments with enzymes, acids or alkalis (Durkee and Thivierge, 1975; Krygier *et al.*, 1982; Dvořáková *et al.*, 2008). According to Negi, (2012), phenolic compounds that display antibacterial potential include quercetin, cinnamic acid, protocatechuic acid, caffeic acid, vanillin, ferulic acid, p-coumaric acid, catechin, epicatechin, and gallic acid (Singh *et al.*, 2013).

Flavonoids

Flavonoids that include various polyphenols are known to inhibit the synthesis of the nucleic acids of Gram-positive and Gram-negative bacteria. Flavonoids contain a B-ring which plays the role of an intercalating agent by creating hydrogen bond in stacks of nucleic acid. In this manner, flavonoids play a significant role in inhibiting the synthesis of DNA or RNA (Mori *et al.*, 1987; Mirzoeva *et al.*, 1997; Cushnie and Lamb, 2005; Simões *et al.*, 2009).

Crude extracts of flavonoids from selected plant species and tissue calli have been tested for their antimicrobial activity against the Gram-positive bacteria *B. subtilis*, *S. aureus*, the Gram-negative bacteria *E. coli*, *K. pneumoniae* and the fungal pathogen *C. albicans*. Flavonoids extracted especially from tissue calli show high antimicrobial activity against microorganisms because of the higher concentrations of flavonoids in such material (Talreja, 2010; Talreja *et al.*, 2012; Onsare and Arora, 2014).

Antibacterial activity in different extracts

The presence of secondary metabolites in plants confers the following advantages to their hosts: they protect against biotic or abiotic stresses, they serve as defense mechanisms by virtue of their repellent properties, and they maintain tissue structural integrity. Secondary metabolites of plants, including phenolic compounds, alkaloids, flavonoids, terpenoids, can be extracted in organic or aqueous solvents (Paiva *et al.*, 2010). The extracts are categorized on the basis of their polarity:

1. Polar solvents: e.g. organic acids.
2. Solvents of intermediate polarity e.g. methanol, ethanol, acetone, dichloromethane.
3. Low polarity solvents e.g. hexane, chloroform.

Many studies have been undertaken to investigate medicinal plants in order to validate their ethnopharmacological claims. The extract of the same plant part in solvents of different polarities may exhibit different biological properties (Tepe *et al.*, 2005; Paiva *et al.*, 2010). Almost all the plant parts of *Moringa* can be used for organic solvent extraction. Organic extracts may have antibacterial property against only Gram-negative bacteria or Gram-positive bacteria, or both. As mentioned earlier, Gram-negative bacteria have an outer membrane containing lipopolysaccharides which makes it impermeable to lipophilic solutes, while the presence of porins act as a selective barrier to hydrophilic solutes with a cut off value of 600 Da. Solutes greater in size than 600 Da cannot pass through porins (Paiva *et al.*, 2010). On the other hand, the presence of an outer peptidoglycan layer on Gram-positive bacteria makes it more susceptible to solutes as it is not considered an effective barrier (Arias *et al.*, 2004; Paiva *et al.*, 2010). The solvents used for extraction can be hexane, acetone, methanol, ethanol, etc. According to previous literature (Jabeen *et al.*, 2008; Khesorn, 2009), ethanolic, methanolic, and

dichloromethane extracts show the highest antimicrobial activities against various Gram-negative and Gram-positive bacteria.

Acetone extract

The acetone extract of *Moringa* contains various phytochemicals, including phenolics, flavonoids, tannins, glycosides (Korithu *et al.*, 2011), alkaloids, carbohydrates, proteins, amino acids, saponins and triterpenoids (Gami and Parabia, 2011). These agents have been shown to be effective against *S. typhii*, *S. aureus*, *E. coli* and *B. subtilis* (Korithu *et al.*, 2011). Masika *et al.* (2012) reported the antimicrobial effect of leaf acetone extract at 5 mg/ml against both Gram-negative and Gram-positive bacteria, including *E. coli*, *Enterobacter cloacae*, *P. vulgaris*, *S. aureus* and *Micrococcus kristinae*. *M. oleifera* acetone extract was bactericidal on *E. coli* and *M. kristinae*, while it was bacteriostatic on *S. aureus*, *E. cloacae* and *Proteus vulgaris*. Although, the minimal bactericidal concentration (MBC) value for the *M. oleifera* acetone extract against *M. kristinae* was higher (1.0 mg/mL) than its minimal inhibitory concentration (MIC) value of 0.5 mg/mL, it is interesting to note that the MIC and MBC values (5 mg/mL) against the inhibited bacteria were the same (Masika *et al.*, 2012).

Figure 2: Overall summary of mode of action of different parts of *M. oleifera* plant.

Table 2: Antibacterial property of phytoconstituents present in *M. oleifera* plant parts.

Plant parts	Constituents	Antimicrobial property	Microorganisms against which it is active	References
Whole plant	Rhamnose	-	-	Fahey <i>et al.</i> , 2001; Bennet <i>et al.</i> , 2003
	Glucosinolates	-	-	
	Isothiocyanates	Yes	Both Gram + & -	
Stem bark	Alkaloid	Yes	Both Gram + & -	Kerharo, 1969; Faizi <i>et al.</i> , 1994a
	Moringine	-	-	
	Moringin	-	-	
	Vanillin	-	-	
	β -sitosterol	-	-	
	β -sitostenone	-	-	
	4-hydroxymellin	-	-	
Whole gum exudate	Ocatcosanoic acid	-	-	Bhattacharya <i>et al.</i> , 1982
	L-arabinose	-	-	
	L-galactose	-	-	
	L-glucuronic acid	-	-	
	L-rhamnose	-	-	
	L-mannose	-	-	
Degraded gum exudate	L-xylose	-	-	Bhattacharya <i>et al.</i> , 1982
	L-galactose	-	-	
Flowers	L-glucuronic acid	-	-	Faizi <i>et al.</i> , 1994a; Siddhuraju and Becker, 2003
	L-mannose	-	-	
	Nine amino acids	-	-	
	Sucrose	-	-	
	D-glucose	-	-	
	Traces of alkaloids	-	-	
	Wax	Yes	Both Gram + & -	
	Quercetin	-	-	
	Kaempferate	Yes	Both Gram + & -	
	Flavonoid pigments	-	-	
Pods	Alkaloids	Yes	Both Gram + & -	Faizi <i>et al.</i> , 1998
	Kaempferol	-	-	
	Rhamnetin	-	-	
	Isoquercitrin	-	-	
	Kaempferitrin	-	-	
	Thiocarbamate	-	-	
	Isothiocyanate glycoside	-	-	
Fruit	Cytokinin	-	-	Nagar <i>et al.</i> , 1982
Leaves	Ascorbic acid	-	-	Anwar <i>et al.</i> , 2005; Makkar and Becker, 1996
	Flavonoid	-	-	
	Phenolics	Yes	Both Gram + & -	
	Carotenoids	-	-	
Roots	Pterygospermin	Yes	Both Gram + & -	Das <i>et al.</i> , 1957; Eilert <i>et al.</i> , 1981; Rao <i>et al.</i> , 2001; Dewangan <i>et al.</i> , 2010
	4- α - L-rhamnosyloxybenzyl isothiocyanate	Yes	Both Gram + & -	
	Aglycone of deoxy-niazimicine (N-benzyl, S-ethyl thioformate)	Yes	Both Gram + & -	
Seed	O-ethyl-4-(α -L-rhamnosyloxy) benzyl carbamate	-	-	Guevara <i>et al.</i> , 1999; Anwar <i>et al.</i> , 2007
	4(α -L-rhamnosyloxy)-benzyl isothiocyanate	Yes	Both Gram + & -	
	Niazimicin	-	-	
	3-o-(6'-O-oleyl- β -D-glucopyranosyl)- β -sitosterol	-	-	
	β -sitosterol-3-o- β -D-glucopyranoside	-	-	
	Niazirin	-	-	
	β -sitosterol	-	-	
Oil (seed)	Glycerol-1-(9-octadecanoate)	-	-	Tsaknis <i>et al.</i> , 1999; Lalas and Tsaknis, 2002; Anwar and Bhanger, 2003; Anwar <i>et al.</i> , 2005
	Campesterol,	-	-	
	Stigmasterol,	-	-	
	β -sitosterol,	-	-	
	Δ^5 -avenasterol,	-	-	
	Clerosterol,	-	-	
	24-methylene cholesterol,	-	-	
	Δ^7 -campestanol,	-	-	
	Stigmastanol,	-	-	
	28-isoavenasterol	-	-	

Ethanollic Extract

Bukar *et al.* (2010) reported that *M. oleifera* leaf ethanolic extract had the broadest spectrum of activity on the test bacteria, a finding that was in agreement with Doughari *et al.* (2007). The ethanolic extract of *M. oelifera* was reported to be effective against *B. subtilis* and *S. aureus*, *E. coli* and *K. pneumoniae* (Talreja, 2010). Peixoto *et al.* (2011) found it effective against *S. aureus*, *V. parahaemolyticus*, *E. feacalis* and *A. caviae*. Doughari *et al.* (2007) reported an ethanolic extract of the plant at 100 mg/ml demonstrated the highest activity, while the aqueous extract showed the least activity. Renitta *et al.* (2009) reported highest antimicrobial activity from the ethanolic extract of leaves, seeds and flowers of *M. oleifera* against microorganisms like *E. coli*, *K. pneumoniae*, *Enterobacter* spp., *P. mirabilis*, *P. aeruginosa*, *S. typhi* A, *S. aureus*, *Streptococcus* spp. and *C. albicans* (Kalpana *et al.*, 2013). One study showed that whereas the seed aqueous extract was not effective against Gram-negative bacteria (*E. coli*, *Shigella flexneri* and *S. typhi*), the seed ethanolic extract showed zones of inhibition against the same (Cáceres *et al.*, 1991; Jamil *et al.*, 2007; Lar *et al.*, 2011; Mishra *et al.*, 2011; Saadabi and Abu, 2011; Farooq *et al.*, 2012). Ethanol based extracts were also effective against *S. aureus* and *Vibrio cholera* (Vieira *et al.*, 2010) and against *E. coli*, *S. flexneri*, and *S. typhi* (Lar *et al.*, 2011).

Ethyl acetate extract

In one study, an ethyl acetate extract of *Moringa* leaf recorded the highest antimicrobial activity against four microorganisms namely, *S. epidermidis*, *S. aureus*, *P. aeruginosa* and *Bacillus cereus*, respectively (Abdallah, 2016).

Butanol extract

In the same study, a butanol *Moringa* leaf extract was active only against *S. epidermidis* and *S. aureus* (Abdallah, 2016).

Aqueous extract

Abalaka *et al.* (2012) found that the MIC of an aqueous leaf extract on *E. coli* and *S. typhi* were 1.667 mg/ ml and 0.417 mg/ ml respectively, but no MIC was reported for the extract on *P. aeruginosa*. Mehta and Agrawal, (2008) also reported antimicrobial activity of an aqueous extract of seeds against *E. coli*, *S. aureus* and *P. aeruginosa*. The water-based extract was similarly found to be effective against *S. aureus* and *V. cholera* (Vieira *et al.*, 2010). According to Abdallah, (2016) an aqueous leaf extract was active only against *S. epidermidis*. Unlike leaves, the aqueous extracts of seeds did not show any activity (Cáceres *et al.*, 1991; Jamil *et al.*, 2007; Jabeen *et al.*, 2008; Lar *et al.*, 2011; Mishra *et al.*, 2011; Saadabi and Abu, 2011; Farooq *et al.*, 2012). Another *Moringa* species, *M. peregrina*, showed activity in its aqueous seed

extracts and seed oil against *E. coli*, *C. albicans*, *S. aureus*, *S. epidermidis*, *P. aeruginosa* (Spiliotis *et al.*, 1997; Lalas *et al.*, 2012).

Hexane extract

Antibacterial activity of *M. oleifera* seeds in a hexane extract was reported against *S. typhi*, *V. cholera* and *E. coli* (Walter *et al.*, 2011).

Chloroform extract

Nikken *et al.* (2003) isolated the aglycon of deoxy-niazimicine (N-benzyl,S-ethyl thioformate) from *M. oleifera* crude chloroform extract. It exhibited antimicrobial activity against *S. aureus*, *Shigella dysenteriae*, *Shigella boydii*, *S. typhi* and *P. aeruginosa*. The antibacterial effect of the chloroform extract was also reported against *S. aureus* (Abdallah, 2016). The MICs of the chloroform leaf extract on *E. coli*, *S. typhi* and *P. aeruginosa* were 1.667 mg/mL, 0.417 mg/mL and 0.417 mg/mL, respectively (Abalaka *et al.*, 2012).

Methanol extract

A methanol extract of *Moringa* leaves was found effective against a broad range of microorganisms, including *K. pneumoniae*, *P. aeruginosa*, *Enterobacter. aerogens*, *Salmonella typhi*, *Salmonella paratyphi* A, *S. aureus*, *Micrococcus luteus* and *B. Subtilis* (Gami and Parabia, 2011). The methanolic extract of dried leaf of *M. oleifera* was found to possess potent phytochemicals with high inhibitory activities on bacteria of UTI origin (Okiki *et al.*, 2015).

Phytochemicals and biofilms

When bacterial cells start to grow on a solid surface, the colony may take the form of film that is known as a biofilm (Simões *et al.*, 2009). The plant-microbe interaction can be exploited for the production of phytochemicals that can interfere with biofilm formation (Costerton *et al.*, 1987; Ramey *et al.*, 2004; Jain *et al.*, 2007; Simões *et al.*, 2009). Biofilm formation involves the attachment of bacterial cells by extracellular appendages and hydrophobicity of cell surface. If this step is disturbed, then biofilm formation cannot take place. This initial attachment can be disturbed by flavonoids obtained from *M. oleifera* seed coat (Cushnie and Lamb, 2005). This step is concentration and exposure time dependent (Simões *et al.*, 2008).

Antibacterial mode of action

The presence of the lipopolysaccharide membrane in Gram-negative bacteria makes it impermeable to exogenous molecules (Nikaido and Vaara, 1985; Gami and Parabia, 2011). The significance of the cell membrane is already known. It is involved in various processes like uptake and transport of solute molecules, cell signaling, metabolism regulation, energy transducing

processes, and maintenance of osmotic pressure (Sikkema *et al.*, 1995). In Gram-positive bacteria, the cell membrane has low lipid content and is high in lipoteichoic acids. When an antibacterial agent enters the cell, imbalance of ions (K^+ and H^+) occurs, resulting in disturbance of metabolism which leads to protein and enzyme denaturation and, eventually, cell death. According to Singh *et al.* (2013), phenolic compounds disturb the enzymatic machinery of the cell, thereby inducing an antimicrobial effect. In Gram-negative bacteria, the presence of the outer lipopolysaccharide membrane makes entry of exogenous compounds difficult. If antibiotic compounds gain entry, cell membrane disruption takes place due to interference in ATP generation from dextrose (Gill and Holley, 2004). Cushnie and Lamb, (2005) reported that phenolic compounds like quercetin and luteolin which are found in *Moringa* extracts interfere with the bacterial DNA gyrase activity.

CONCLUSIONS

A serious threat of multi-drug resistance has arisen this century. In such a scenario, natural remedies are increasingly under investigation to validate their reputed pharmaceutical properties in the quest for new drugs. *M. oleifera*, despite being regarded by many as a miracle tree, has not been well researched or validated for its many potential medicinal applications. Reports on its antimicrobial properties, for example, are few and dispersed in different publications. This review is, therefore, an effort to collect all the antimicrobial information related to the plant's parts, extracts and phytochemistry of *M. oleifera*. In summary, it can be said that all parts of the *Moringa* plant that are extracted in any solvent exhibit antimicrobial properties against Gram-positive and Gram-negative bacteria. The *Moringa* plant offers natural and safe protection against a broad spectrum of pathogens.

CONFLICT OF INTEREST: The authors declare no conflict of interest.

REFERENCES

- Abalaka, M. E., Daniyan, S. Y., Oyeleke, S. B. and Adeyemo, S. O. (2012). The antibacterial evaluation of *Moringa oleifera* leaf extracts on selected bacterial pathogens. *Journal of Microbiology Research* **2**(2), 1-4.
- Abdallah, E. M. (2016). Antibacterial properties of leaf extracts of *Moringa oleifera* Lam. growing in Sudan. *Journal of Advances in Medical and Pharmaceutical Sciences* **5**(1), 1-5.
- Aboaba, O. O. and Efuwape, B. M. (2001). Antibacterial properties of some Nigerian spices. *Biology Research Communications* **13**, 183-188.
- Ali, N. A. A., Jülich, W. D., Kusnick, C. and Lindequist, U. (2001). Screening of Yemeni medicinal plants for antibacterial and cytotoxic activities. *Journal of Ethnopharmacology* **74**, 173-179.
- Anwar, F. and Bhanger, M. I. (2003). Analytical characterization of *Moringa oleifera* seed oil grown in temperate regions of Pakistan. *Journal of Agricultural and Food Chemistry* **51**, 6558-6563.
- Anwar F., Ashraf, M., and Bhanger, M. I. (2005). Interprovenance variation in the composition of *Moringa oleifera* oilseeds from Pakistan. *Journal of American Oil Chemists' Society* **82**, 45-51.
- Anwar F., Latif, S., Ashraf, M. and Gilani, A. H. (2007). *Moringa oleifera*: a food plant with multiple medicinal uses. *Pytotherapy Research* **21**, 17-25.
- Aney J., Rashmi, T., Maushumi, K. and Kiran, B. (2009). Pharmacological and pharmaceutical potential of *Moringa oleifera*: A review. *Journal of Pharmacy Research* **2**(9), 1424-1426.
- API – The Ayurvedic Pharmacopoeia of India, Part I. Government of India. Ministry of Health and Family Welfare, Department of Ayush, **2**, 163-165.
- Arias M. E., Gomez, J. D., Cudmani, N. M., Vattuone, M. A. and Isla, M. I. (2004). Antibacterial activity of ethanolic and aqueous extracts of *Acacia aroma* Gill. ex Hook et Arn. *Life Sciences*, **75**, 191-202.
- Arora, D. S., Onsare, J. G. and Kaur, H. (2013). Bioprospecting of *Moringa* (Moringaceae): microbiological perspective. *Journal of Pharmacognosy and Phytochemistry* **1**(6), 193-215.
- Arora, D. S. and Onsare, J. G. (2014). *In vitro* antimicrobial evaluation and phytoconstituents of *Moringa oleifera* pod husks. *Industrial Crops and Products* **52**, 125-135.
- Arranz S., Saura-Calixto, F., Shaha, S. and Kronn, P. A. (2009). High contents of nonextractable polyphenols in fruits suggest that polyphenol contents of plant foods have been underestimated. *Journal of Agricultural and Food Chemistry* **57**, 7298-7303.
- Atawodi S. E., Atawodi, J. C., Idakwo, G. A., Pfundstein, B., Huabner, R., Wurtele, G., Bartsch, H. and Owen, R. W. (2010). Evaluation of the polyphenol content and antioxidant properties of methanol extracts of the leaves, stem, and root barks of *Moringa oleifera* Lam. *Journal of Medicinal Food* **13**(3), 710-716.
- Azuma, M., Kojima, T., Yokoyama, I., Tajiri, H., Yoshikawa, K., Saga, S. and Del-Caprio, C. A. (1999). Antibacterial activity of multiple antigen peptides homologous to a loop region in human lactoferrin. *Journal of Peptide Research* **54**, 237-241.
- Balandrin, M. F., Klocke, J. A., Wurtele, E. S. and Bollinge, W. H. (1985). Natural plant chemicals: sources of industrial and medicinal materials. *Science* **228**, 1154-1160.
- Bechinger, B. (1999). The structure, dynamics and orientation of antimicrobial peptides in membranes by multidimensional solid-state NMR spectroscopy. *Biochimica et Biophysica Acta* **1462**, 157-183.
- Bennet, R. N., Mellon, F. A., Foidl, N., Pratt, J. H., Dupont, M. S., Perkins, L. and Kroon, P. A. (2003). Profiling glucosinolates and phenolics in vegetative and reproductive tissues of the multi-purpose trees *Moringa oleifera* (horseradish tree) and *Moringa*

- stenopetala* L. *Journal of Agricultural and Food Chemistry* **51**, 3546-3553.
- Bergey, D. R., Howe, G. A. and Ryan, C. A. (1996).** Polypeptide signaling for plant defensive genes exhibits analogies to defense signaling in animals. *Proceedings of the National Academy of Sciences of the United States of America* **93**(22), 12053-12058.
- Bhatnagar, S. S., Santapau, H., Desai, J. D. H., Yellore, S. and Rao, T. N. S. (1961).** Biological activity of Indian medicinal plants. I. Antibacterial, antitubercular and antifungal action. *The Indian Journal of Medical Research*, **49**, 799-805.
- Bhattacharya, S. B., Das, A. K. and Banerji, N. (1982).** Chemical investigations on the gum exudates from Sonja (*Moringa oleifera*). *Carbohydrate Research* **102**, 253-262.
- Boheim, G. (1974).** Statistical analysis of alamethicin channels in black lipid membranes. *Journal of Membrane Biology* **19**, 277-303.
- Bones, A. M. and Rossiter, J. T. (1996).** The pyrosinase-glucosinolate system, its organisation and biochemistry. *Physiologia Plantarum* **97**(1), 194-208.
- Booth, F. E. M. and Wickens, G. E. (1988).** Non-timber uses of selected arid zone trees and shrubs in Africa (1988). FAO Conservation Guide 19, Rome, Food and Agriculture Organization, 1988, 176. *The Plant List* (2010). (Published on the internet; version 1; <http://www.theplantlist.org/>-accessed 1st January, 2017).
- Brehm-Stecher, B. F. and Johnson, E. A. (2003).** Sensitization of *Staphylococcus aureus* and *Escherichia coli* to antibiotics by the sesquiterpenoids Nerolidon, Farnesol, Bisabolol, and Apitone. *Antimicrobial Agents and Chemotherapy* **47**(10), 3357-3360.
- Bukar A., Uba, A. and Oyeyi, T. I. (2010).** Antimicrobial profile of *Moringa oleifera* Lam. extracts against some food borne microorganisms. *Bayero Journal of Pure and Applied Sciences* **3**(1), 43-48.
- Bumke-Vogt, C., Osterhoff, M. A., Borchert, A., Guzman-Perez, V., Sarem Z., Birkenfeld, A. L., Bähr, V. and Pfeiffer, A. F. H. (2014).** The flavones apigenin and luteolin induce FOXO1 translocation but inhibit gluconeogenic gene expression in human cells. *PLoS ONE* **9**(8), 1-16.
- Caceres, A. and Lopez, S. (1991).** Pharmacological properties of *Moringa oleifera*. 3: Effects of seed extract in the treatment of experimental pyoderma. *Fitoterapia* **62**, 449-450.
- Cáceres, A., Cabrera, O., Morales, O., Mollinedo, P. and Méndia, P. (1991).** Pharmacological properties of *Moringa oleifera*. 1: Preliminary screening for antimicrobial activity. *Journal of Ethnopharmacology* **33**, 213-216.
- Chanda, S., Baravalia, Y., Kaneria, M. and Rakholiya, K. (2010).** Fruits and vegetable peels – strong natural source of antimicrobics; current research, technology and education topics. In: Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology. Méndez-Vilas, A. (ed.). Formatex. pp. 444-450.
- Chetia, B. and Gogoi, S. (2011).** Antibacterial activity of the methanolic extract of stem bark of *Spondias pinnata*, *Moringa oleifera* and *Alstonia scholaris*. *Asian Journal of Traditional Medicine* **6**(4), 163-167.
- Costerton, J. W., Cheng, K. J., Geesey, G. G., Ladd, T. I., Nickel, J. C., Dasgupta, M. and Marrie, T. J. (1987).** Bacterial biofilms in nature and disease. *Annual Review of Microbiology* **41**, 435-464.
- Cowan, M. M. (1999).** Plant products as antimicrobial agents. *Clinical Microbiology Reviews* **12**(4), 564-582.
- Croteau, R., Kutchan, T. M. and Lewis, N. G. (2000).** Natural products (secondary metabolites). In: *Biochemistry and Molecular Biology of Plants* (Buchanan, B., Gruissem, W., Jones, R., (eds.)). Rockville, MD, American Society of Plant Physiology. pp. 1250-1318.
- Cushnie, T. P. T. and Lamb, A. J. (2005).** Antimicrobial activity of flavonoids. *International Journal of Antimicrobial Agents* **5**, 343-356.
- Dahot, M. U. (1998).** Antimicrobial activity of small protein of *Moringa oleifera* leaves. *Journal of Islamic Academy of Sciences* **11**(1), 27-32.
- Das, B. R., Kurup, P. A., Rao, P. L. and Narasimha-Rao, P. L. (1957).** Antibiotic principle from *Moringa pterygosperma*. VII. Antibacterial activity and chemical structure of compounds related to pterygospermin. *Indian Journal of Medicinal Research* **45**, 191-196.
- Dathe, M., Schumann, M., Wieprecht, T., Winkler, A., Beyermann, M., Krause, E., Matsuzaki, K., Murase, O. and Bienert, M. (1996).** Peptide helicity and membrane surface charge modulate the balance of electrostatic and hydrophobic interactions with lipid bilayers and biological membranes. *Biochemistry* **35**, 12612-12622.
- Dathe M., Nikolenko, H., Meyer, J., Beyermann, M. and Bienert, M. (2001).** Optimization of the antimicrobial activity of magainin peptides by modification of charge. *FEBS Letters* **501**, 146-150.
- Dewangan, G., Koley, K. M., Vadlamudi, V. P., Mishra, A., Poddar, A. and Hirpurkar, S. D. (2010).** Antibacterial activity of *Moringa oleifera* (drumstick) root bark. *Journal of Chemical and Pharmaceutical Research* **2**(6), 424-428.
- Dillard, C. J. and German, J. B. (2000).** Phytochemicals: nutraceuticals and human health. A review. *Journal of the Science of Food and Agriculture* **80**, 1744-1756.
- Dorman, H. J. D. and Deans, S. G. (2000).** Antimicrobial agents from plants: antibacterial activity of plant volatile oils. *Journal of Applied Microbiology* **88**(2), 308-316.
- Doughari, J. H., Pukuma, M. S. and De, N. (2007).** Antibacterial effects of *Balanites aegyptiaca* L. Drel. and *Moringa oleifera* Lam. on *Salmonella typhi*. *African Journal of Biotechnology* **6**(19), 2212-2215.
- Durkee, A. B. and Thivierge, A. P. (1975).** Bound phenolic acids in *Brassica* and *Sinapis* oilseeds. *Journal of Food Science* **40**, 820-822.

- Dvořáková, M., Guido, L. F., Dostalek, P., Skulilová, Z., Moneira, M. M. and Barros, A. A. (2008).** Antioxidant properties of free, soluble ester and insoluble compounds in different barley varieties and corresponding malts. *Journal of the Institute of Brewing* **114**, 27-33.
- D'souza, J. and Kulkarni, A. R. (1993).** Comparative studies on nutritive values of tender foliage of seedlings and mature plants of *Moringa oleifera* Lam. *Journal of Economic and Taxonomic Botany* **17**, 479-485.
- Ehrenstein, G. and Lecar, H. Q. (1977).** Electrically gated ionic channels in lipid bilayers. *Quarterly Reviews of Biophysics* **10**(1), 1-34.
- Eilert, U., Wolters, B. and Nadrtdt, A. (1981).** The antibiotic principle of seeds of *Moringa oleifera* and *Moringa stenopetala*. *Planta Medica* **42**, 55-61.
- Estrella, M. C. P., Mantaring, J. B. V. and David, G. Z. (2000).** A double-blind randomized control trial on the use of malunggay (*Moringa oleifera*) for augmentation of the volume of breastmilk among non-nursing mothers of preterm infants. *Philippines Journal of Pediatrics* **49**, 3-6.
- Fahey, J. W., Zalcman, A. T. and Talalay, P. (2001).** The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry* **56**(1), 5-51.
- Faizi, S., Siddiqui, B. S., Saleem, R., Siddiqui, S., Aftab, K. and Gilani, A. H. (1994).** Isolation and structure elucidation of new nitrile and mustard oil glycosides from *Moringa oleifera* and their effect on blood pressure. *Journal of Natural Products* **57**(9), 1256-1261.
- Faizi, S., Siddiqui, B. S., Saleem, R., Aftab, K., Shaheen, F. and Gilani, A. H. (1998).** Hypotensive constituents from the pods of *Moringa oleifera*. *Planta Medica* **64**, 225-228.
- Friedrich, C. L., Moyles, D., Beveridge, T. J. and Hancock, R. E. (2000).** Antibacterial action of structurally diverse cationic peptides on Gram-positive bacteria. *Antimicrobial Agents and Chemotherapy* **44**, 2086-2092.
- Farooq, F., Rai, M., Tiwari, V., Khan, A. A. and Farooq, S. (2012).** Medicinal properties of *Moringa oleifera*: an overview of promising healer. *Journal of Medicinal Plants Research* **6**(27), 4368-4374.
- Farnaud, S., Spiller, C., Moriarty, L. C., Patel, A., Gant, V., Odell, E. W. and Evans, R. W. (2004).** Interactions of lactoferricin-derived peptides with LPS and antimicrobial activity. *FEMS Microbiology Letters* **233**, 193-199.
- Folkard, G. and Sutherland, J. (2005).** *Moringa oleifera* – a multi-purpose tree. *Journal of Tropical Medicine and Hygiene* **90**, 101-109.
- Fuglie, L. J. (1999).** The miracle tree: *Moringa oleifera*: Natural nutrition for the tropics. Church World Service, Dakar. pp 68.
- Gami, B. and Parabia, F. (2011).** Screening of methanol and acetone extract for antimicrobial activity of some medicinal plant species of Indian folklore. *International Journal of Research in Pharmaceutical Sciences* **2**(1), 69-75.
- Gibbons, S. and Udo, E. E. (2000).** The effect of reserpine, a modulator of multidrug efflux pumps, on the *in vitro* activity of tetracycline against clinical isolates of methicillin resistant *Staphylococcus aureus* (MRSA) possessing the *tet(K)* determinant. *Phytotherapy Research* **14**(2), 139-140.
- Gill, A. O. and Holley, R. A. (2004).** Mechanisms of bactericidal action of cinnamaldehyde against *Listeria monocytogenes* and of eugenol against *L. monocytogenes* and *Lactobacillus sakei*. *Applied and Environmental Microbiology* **70**, 5750-5755.
- Griffin, S. G., Wyllie, S. G., Markham, J. L. and Leach, D. N. (1999).** The role of structure and molecular properties of terpenoids in determining their antimicrobial activity. *Flavour and Fragrance Journal* **14**(5), 322-332.
- Guevara, A. P., Vargar, C., Sakurai, H., Fujiwara, Y., Hashimoto, K., Maoka, T., Kozuka, M., Ito, Y., Tokuda, H. and Nishino, H. (1999).** An antitumor promoter from *Moringa oleifera* Lam. *Mutation Research* **440**(2), 181-188.
- Harristoy, X., Fahey, J., Scholtus, I. and Lozniewski, A. (2005).** Evaluation of antimicrobial effects of several isothiocyanates on *Helicobacter pylori*. *Planta Medica* **71**, 326-330.
- He, K., Ludtke, S. J., Heller, W. T. and Huang, H. W. (1996).** Mechanism of alamethicin insertion into lipid bilayers. *Biophysical Journal* **71**, 2669-2679.
- He, K., Ludtke, S. J., Huang, H. W. and Worcester, D. L. (1995).** Antimicrobial peptide pores in membranes detected by neutron in-plane scattering. *Biochemistry* **34**, 15614-15618.
- Heller, W. T., Waring, A. J., Lehrer, R. I., Harroun, T. A., Weiss, T. M., Yang, L. and Huang, H. W. (2000).** Membrane thinning effect of the beta-sheet antimicrobial protegrin. *Biochemistry* **39**, 139-145.
- Hostettman, K. and Nakanishi, K. (1979).** Moronic acid, a simple triterpenoid keto acid with antimicrobial activity isolated from *Ozoroa mucronata*. *Journal of Medicinal Plant Research* **31**, 358-366.
- Jabeen, R., Shahid, M., Jamil, A. and Ashraf, M. (2008).** Microscopic evaluation of the antimicrobial activity of seed extracts of *Moringa oleifera*. *Pakistan Journal of Botany* **40**(4), 1349-1358.
- Jain, A., Gupta, Y., Agrawal, R., Khare, P. and Jain, S. K. (2007).** Biofilms – A microbial life perspective: A critical review. *Critical Reviews in Therapeutic Drug Carrier Systems* **24**, 393-443.
- Jamil, A., Shahid, M., Khan, M. and Ashraf, M. (2007).** Screening of some medicinal plants for isolation of antifungal proteins and peptides. *Pakistan Journal of Botany* **39**(1), 211-221.
- Jennings, B. R. and Ridler, P. J. (1983).** Interaction of chromosomal stains with DNA. *Biophysics of Structure and Mechanism* **10**, 71-79.
- Jerri, H. A., Adolfsen, K. J., McCullough, L. R., Velegol, D. and Velegol, S. B. (2012).** Antimicrobial

- sand via adsorption of cationic *Moringa oleifera* protein. *Langmuir* **28**, 2262-2268.
- Kalpana, S., Moorthi, S. and Kumara, S. (2013).** Antimicrobial activity of different extracts of leaf of *Moringa oleifera* (Lam) against Gram-positive and Gram-negative bacteria. *International Journal of Current Microbiology and Applied Sciences* **2(12)**, 514-518.
- Karou, D., Savadogo, A., Canini, A., Yameogo, S., Montesano, C., Simpore, J., Colizzi, V. and Traore, A. S. (2005).** Antibacterial activity of alkaloids from *Sida acuta*. *African Journal of Biotechnology* **4(12)**, 1452-1457.
- Kerharo, P. J. (1969).** Un remede populaire Sengalais: Le "Nebreday" (*Moringa oleifera* Lann.) employes therapeutiques en milieu Africain chimie et pharmacologie. *Plantes Med Phytother* **3**, 14-219.
- Khan, I. A., Mirza, Z. M., Kumar, A., Verma, V. and Qazi, G. N. (2006).** Piperine, a phytochemical potentiator of ciprofloxacin against *Staphylococcus aureus*. *Antimicrobial Agents and Chemotherapy* **50**, 810-812.
- Khesorn, N. (2009).** Antibacterial activity of the capsules of *Moringa oleifera* Lam. (Moringaceae). *Journal of Ethnopharmacology* **36**, 233-237.
- Korithu, D. P., Manivarnan, N. K., Gopinath, A. and Abraham, R. (2011).** Antimicrobial evaluation, reducing power assay and phytochemical screening of *Moringa oleifera* leaf extracts: effect of solvent polarity. *International Journal of Pharmaceutical Sciences and Research* **2(11)**, 2991-2995.
- Kostova, I. and Dinchev, D. (2005).** Saponins in *Tribulus terrestris* – chemistry and bioactivity. *Phytochemistry Reviews* **4**, 111-137.
- Krygier, K., Sosulki, F. and Hogge, L. (1982).** Free, esterifies and insoluble bound phenolic acids. 2. Composition of phenolic acids in rapeseed seed flour and hulls. *Journal of Agricultural and Food Chemistry* **30**, 334-336.
- Kudi, A. C., Umoh, J. U., Eduvie, L. O. and Gefu, J. (1999).** Screening of some Nigerian medicinal plants for antibacterial activity. *Journal of Ethnopharmacology* **67**, 225-228.
- Kumbhar, M. R., Guleha, V. and Sivakumar, T. (2012).** Estimation of total phenolic content, cytotoxicity and *in vitro* antioxidant activity of stem bark of *Moringa oleifera*. *Asian Pacific Journal of Tropical Diseases* **2(2)**, 144-150.
- Lalas, S. and Tsaknis, J. (2002).** Extraction and identification of natural antioxidants from the seeds of *Moringa oleifera* tree variety of Malawi. *Journal of the American Oil Chemists' Society* **79**, 677-683.
- Lalas, S., Gortzi, O., Athanasiadis, V., Tsaknis, J. and Chinou, I. (2012).** Determination of antimicrobial activity and resistance to oxidation of *Moringa peregrina* seed oil. *Molecules* **17**, 2330-2334.
- Lar, P. M., Ojile, E. E., Dashe, E. and Oluoma, J. N. (2011).** Antibacterial activity of *Moringa oleifera* seed extracts on some Gram-negative bacterial isolates. *African Journal of Natural Sciences* **14**, 57-62.
- Lee, J. H., Kim, M. S., Cho, J. H. and Kim, S. C. (2002).** Enhanced expression of tandem multimers of the antimicrobial peptide buforin II in *Escherichia coli* by the DEAD-box protein and *trx*B mutant. *Applied Microbiology and Biotechnology* **58**, 790-796.
- Leven, M., Vanden, D. A. B., Mertens, F., Vlietinck, A. and Lammens, E. (1979).** Screening of higher plants for biological activities. I. antimicrobial activity. *Planta Medica* **36(4)**, 311-321.
- Li, Y. T., Kwon, Y. I., Labbe, R. G. and Shetty, K. (2005).** Inhibition of *Helicobacter pylori* and associated urease by oregano and cranberry phytochemical synergies. *Applied and Environmental Microbiology* **71**, 8558-8564.
- Makkar, H. P. S. and Becker, K. (1996).** Nutritional value and antinutritional components of whole and ethanol extracted *Moringa oleifera* leaves. *Animal Feed Science and Technology* **63**, 211-228.
- Makonnen, E., Hunde, A. and Damecha, G. (1997).** Hypoglycaemic effect of *Moringa stenopetala* aqueous extract in rabbits. *Phytotherapy Research* **11**, 147-148.
- Mangale, S. M., Chonde, S. G. and Raut, P. D. (2012).** Use of *Moringa oleifera* (Drumstick) seed as natural absorbent and an antimicrobial agent for groundwater treatment. *Research Journal of Recent Sciences* **1(3)**, 31-40.
- Marrujo, T., Nazzaro, F., Mancini, E., Fratianni, F., Coppola, R., Martino, L. D., Agostinho, A. B. and Feo, V. D. (2013).** Chemical composition and biological activity of the essential oil from leaves of *Moringa oleifera* Lam. cultivated in Mozambique. *Molecules* **18**, 10989-11000.
- Mashiar, M., Mominul, I., Sharma, A., Soriful, I., Atikur, R., Mizanur, R. and Alam, M. (2009).** Antibacterial activity of leaf juice extracts of *Moringa oleifera* Lam. against some human pathogenic bacteria. *Chiang Mai University Journal of Natural Sciences* **8**, 219-227.
- Masika, M. B., Julius, P. and Voster, M. (2012).** Antimicrobial activities of *Moringa oleifera* Lam leaf extracts. *African Journal of Biotechnology* **11(11)**, 2797-2802.
- Mason, T. L. and Wasserman, B. P. (1987).** Inactivation of red beet beta-glucan synthase by native and oxidized phenolic compounds. *Phytochemistry* **26**, 2197-2202.
- Matsuzaki, K., Murase, O., Fujii, N. and Miyajima, K. (1996).** An antimicrobial peptide, magainin 2, induced rapid flip-flop of phospholipids coupled with pore formation and peptide translocation. *Biochemistry* **35**, 11361-11368.
- Maurya, S. K. and Singh, A. K. (2014).** Clinical efficacy of *Moringa oleifera* Lam. stems bark in urinary tract infection. *International Scholarly Research Notices* **2014**, 1-7.
- Mehta, L. K., Balaraman, R., Amin, A. H., Bafna, P. A. and Gulati, O. D. (2003).** Effect of fruits of *Moringa oleifera* on the lipid profile of normal and hypercholesterolaemic rabbits. *Journal of Ethnopharmacology* **86**, 191-195.

- Mehta A. and B. Agrawal. (2008).** Investigation into the mechanisms of action of *Moringa oleifera* for its anti-asthmatic activity. *Oriental Pharmacy and Experimental Medicine* **8(1)**, 24-31.
- Mendoza, L., Wilkens, M. and Urzua, A. (1997).** Antimicrobial study of the resinous exudates and of diterpenoids and flavonoids isolated from some Chilean *Pseudognaphalium* (Asteraceae). *Journal of Ethnopharmacology* **58**, 85-88.
- Mirzoeva, O. K., Grishanin, R. N. and Calder, C. (1997).** Antimicrobial action of propolis and some of its components: the effects on growth, membrane potential and motility of bacteria. *Microbiological Research* **152**, 239-246.
- Mishra, G., Singh, P., Verma, R., Kumar, S., Srivastav, S., Jha, K. K. and Khosa, R. L. (2011).** Traditional uses, phytochemistry and pharmacological properties of *Moringa oleifera* plant: A overview. *Der Pharmacia Lettre* **3(2)**, 141-164.
- Mori, A., Nishino, C., Enokib, N. and Tawatta, S. (1987).** Antibacterial activity and mode of action of plant flavonoids against *Proteus vulgaris* and *Staphylococcus aureus*. *Phytochemistry* **26**, 2231-2234.
- Morton, J. F. (1991).** The horseradish tree, *Moringa pterigoserma* (Moringaceae). A boon to arid lands. *Economic Botany* **45**, 318-333.
- Mossa, J. S. (1985).** A study on the crude antidiabetic drugs used in Arabian folk medicine. *International Journal of Crude Drug Research* **23**, 137-145.
- Mughal, M. H., Ali, G., Srivastava, P. S. and Iqbal, M. (1999).** Improvement of drumstick (*Moringa pterygosperra* Gaertn.) – A unique source of food and medicine through tissue culture. *Hamdard Medicus* **42**, 37-42.
- Nadkarni, A. K. (1976).** *Indian Materia Medica*. Popular Prakashan: Bombay. pp. 810-816.
- Nagar, P. K., Iyer, R. I. and Sircar, P. K. (1982).** Cytokinins in developing fruits of *Moringa pterigosperra* Gaertn. *Physiologia Plantarum* **55**, 45-50.
- Nantanchit, K. (2006).** Antibacterial activity of the capsules of *Moringa oleifera* Lamk. (Moringaceae). *Chiang Mai University Journal of Natural Sciences* **5(3)**, 365-368.
- Negi, P. S. (2012).** Plant extracts for the control of bacterial growth: Efficacy, stability and safety issues for food application. *International Journal of Food Microbiology* **156**, 7-17.
- Newman, D. J., Cragg, G. M. and Snader, K. M. (2000).** The influence of natural products upon drug discovery. *Natural Product Reports* **17**, 215-234.
- Nepolean, P., Anitha, J. and Renitta, R. E. (2009).** Isolation, analysis and identification of phytochemicals of antimicrobial activity of *Moringa oleifera* Lam. *Current Biotica* **3(1)**, 33-39.
- Nikaido, H. and Vaara, M. (1985).** Molecular basis of bacterial outer membrane permeability. *Microbiological Reviews* **49(1)**, 1-32.
- Nikkon, F., Saud, Z. A., Rehman, M. H. and Haque, M. E. (2003).** *In vitro* antimicrobial activity of the compound isolated from chloroform extract of *Moringa oleifera* Lam. *Pakistan Journal of Biological Sciences* **22**, 1888-1890.
- Nwosu, M. and Okafor, J. (1995).** Preliminary studies on antifungal activities of some medicinal plants against *Basidiobolus* and some other pathogenic fungi. *Mycoses* **38**, 191-195.
- Okiki, A. P., Balogun, B. D., Osibote, I. A., Asoso, S. and Olufunke, A. (2015).** Antibacterial activity of methanolic extract of *Moringa oleifera* Lam. leaf on ESBL producing bacterial isolates from urine of patients with urinary tract infections. *Journal of Biology, Agriculture and Healthcare* **5(20)**, 124-132.
- Onsare, J. G. and Arora, D. S. (2014).** Antibiofilm potential of flavonoids extracted from *Moringa oleifera* seed coat against *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Candida albicans*. *Journal of Applied Microbiology* **118**, 313-325.
- Oren, Z. and Shai, Y. (1998).** Mode of action of linear amphipathic alpha-helical antimicrobial peptides. *Biopolymers* **47**, 451-463.
- Padla, E. P., Solis, L. T., Levida, R. M., Shen, C. C. and Raqasa, C. Y. (2012).** Antimicrobial isothiocyanates from the seeds of *Moringa oleifera* Lam. *Zeitschrift fur Naturforschung C* **67(11-12)**, 557-558.
- Padmarao, P., Acharya, B. M. and Dennis, T. J. (1996).** Pharmacognostic study on stem bark of *Moringa oleifera* Lam. *Bulletin of Medico-Ethno-Botanical Research* **17**, 141-151.
- Paiva, P. M. G., Gomes, F. S., Napoleao, T. H., Sa, R. A., Correia, M. T. S. and Coelho, L. C. B. B. (2010).** Antimicrobial activity of secondary metabolites and lectins from plants. Current research, technology and education topics in applied microbiology and microbial biotechnology (Méndez-Vilas, A. Ed.). Formatex. pp. 396-406.
- Palada, M. C. and Changi, L. C. (2003).** Suggested cultural practices for *Moringa*. International Cooperators' Guide AVRDC. AVRDC pub # 03-545 (www.avrdc.org).
- Palombo, E. A. and Semple, S. J. (2001).** Antibacterial activity of traditional Australian medicinal plants. *Journal of Ethnopharmacology* **77**, 151-157.
- Peixoto, J. R. O., Silva, G. C., Costa, R. A., Fontenelle, J. L. D. S., Vieira, G. H. F., Filho, A. A. F. and Vieira, R. H. S. D. S. (2011).** *In vitro* antibacterial effect of aqueous and ethanolic *Moringa* leaf extracts. *Asian Pacific Journal of Tropical Medicine* **4(3)**, 201-204.
- Pearce, G., Moura, D. S., Stratmann, J. and Ryan, C. A. (2001).** Production of multiple plant hormones from a single polypeptide precursor. *Nature* **411(6839)**, 817-820.
- Plaper, A., Golob, M., Hafner, I., Oblak, M., Solmajer, T. and Jerala, R. (2003).** Characterization of quercetin binding site on DNA gyrase. *Biochemical and Biophysical Research Communications* **306(2)**, 530-536.

- Pouny, Y., Rapaport, D., Mor, A., Nicolas, P. and Shai, Y. (1992).** Interaction of antimicrobial dermaseptin and its fluorescently labeled analogues with phospholipid membranes. *Biochemistry* **31**, 12416-12423.
- Qaiser, M. (1973).** Moringaceae. In: *Flora of West Pakistan*. Nasir, E. and Ali, S. I. (eds). Ed. 38. University of Karachi press: Karachi. pp. 1-4.
- Raj, A. J., Gopalakrishnan, V. K., Yadav, S. A. and Dorairaj, S. (2011).** Antimicrobial activity of *Moringa oleifera* (Lam.) root extract. *Journal of Pharmacy Research* **4**(5), 1426 - 1427.
- Ramachandran, C., Peter, K. V. and Gopalakrishnan, P. K. (1980).** Drumstick (*Moringa oleifera*): A multipurpose Indian vegetable. *Economic Botany* **34**, 276-283.
- Ramey, B. E., Koutsoudis, M., von Bodman, S. B. and Fuqua, C. (2004).** Biofilm formation in plant-microbe associations. *Current Opinion in Microbiology* **7**, 602-609.
- Rao, V. A., Devi, P. U. and Kamath, R. (2001).** *In vivo* radioprotective effect of *Moringa oleifera* leaves. *Indian Journal of Experimental Biology* **39**, 858-863.
- Renitta, R. E., Anitha, J. and Napolean, P. (2009).** Isolation, analysis and identification of phytochemicals of antimicrobial activity of *Moringa oleifera* Lam. *Current Biotica* **3**(1), 33-37.
- Ruckmani, K., Kavimani, S., Anandan, R. and Jaykar, B. (1998).** Effect of *Moringa oleifera* Lam. on paracetamol-induced hepatotoxicity. *Indian Journal of Pharmaceutical Sciences* **60**(1), 33-35.
- Saadabi, A. M. and Abu, I. E. Z. (2011).** An *in vitro* antimicrobial activity of *Moringa oleifera* L. seed extracts against different groups of microorganism. *Australian Journal of Basic and Applied Sciences* **5**(5), 129-134.
- Scalbert, A. (1991).** Antimicrobial properties of tannins. *Phytochemistry* **30**(12), 3875-3883.
- Shahidi, F., Janitha, P. K. and Wanasundara, P. D. (1992).** Phenolic antioxidants. *Critical Reviews in Food Science and Nutrition* **32**, 67-103.
- Siddhuraju P. and K. Becker. (2003).** Antioxidant properties of various solvent extracts of total phenolic constituents from three different agro-climatic origins of drumstick tree (*Moringa oleifera* Lam.). *Journal of Agricultural and Food Chemistry* **15**, 2144 - 2155.
- Sikkema J., de Bont, J. A. M. and Poolman, B. (1995).** Mechanisms of membrane toxicity of hydrocarbons. *Microbiological Reviews* **59**, 201-222.
- Silvestro, L., Weiser, J. N. and Axelsen, P. H. (2000).** Antibacterial and anti-membrane activities of cecropin A in *Escherichia coli*. *Antimicrobial Agents and Chemotherapy* **44**, 602-607.
- Simões, M., Cleto, S., Rocha, S., Coimbra, M. A. and Vieira, M. J. (2008).** Enhancement of *Escherichia coli* and *Staphylococcus aureus* antibiotic susceptibility using sesquiterpenoids. *Medicinal Chemistry* **4**, 616-623.
- Simões, M., Bennett, R. N. and Rosa, E. A. S. (2009).** Understanding antimicrobial activities of phytochemicals against multidrug resistant bacteria and biofilms. *Natural Product Reports* **26**, 746-757.
- Singh, R. S. G., Negi, P. S. and Radha, C. (2013).** Phenolic composition, antioxidant and antimicrobial activities of free and bound phenolic extracts of *Moringa oleifera* seed flour. *Journal of Functional Foods* **5**, 1883-1891.
- Spiliotis, V., Lalas, S., Gergis, V. and Dourtoglou, V. (1997).** Comparison of antimicrobial activity of seeds of different *Moringa oleifera* varieties. *Pharmacy and Pharmacology Letters* **7**, 39-40.
- Stavri, M., Piddock, L. J. and Gibbons, S. (2007).** Bacterial efflux pump inhibitors from natural sources. *The Journal of Antimicrobial Chemotherapy* **59**(6), 1247-1260.
- Suarez, M., Entenza, J. M., Doerries, C., Meyer, E., Bourguin, L., Sutherland, J., Marison, I., Moreillon, P. and Mermod, N. (2003).** Expression of a plant-derived peptide harboring water-cleaning and antimicrobial activities. *Biotechnology and Bioengineering* **81**, 13-20.
- Suarez, M., Haenni, M., Canarelli, S., Fisch, F., Chodanowski, P., Servis, C., Michielin, O., Freitag, R., Moreillon, P. and Mermod, N. (2005).** Structure-function characterization and optimization of a plant-derived antibacterial peptide. *Antimicrobial Agents and Chemotherapy* **49**(9), 3847-3857.
- Tachi, T., Epand, R. F., Epand, R. M. and Matsuzaki, K. (2002).** Position dependent hydrophobicity of the antimicrobial magainin peptide affects the mode of peptide-lipid interactions and selective toxicity. *Biochemistry* **41**, 10723-10731.
- Talreja, T. (2010).** Screening of crude extract of flavonoids of *Moringa oleifera* against bacteria and fungal pathogen. *Journal of Phytology* **2**(11), 31-35.
- Talreja, T., Yadav, L., Sharma, K. and Goswami, A. (2012).** Flavonoids from some medicinal plants *in vivo* and *in vitro*. *The Bioscan* **7**(1), 157-159.
- Tam, J. P., Yi-An, L. and Jin-Long, Y. (2002).** Antimicrobial dendrimeric peptides. *European Journal of Biochemistry* **269**, 923-932.
- Tepe, B., Daferera, D., Sokmen, A., Sokmen, M. and Polissiou, M. (2005).** Antimicrobial and antioxidant activities of the essential oil and various extracts of *Salvia tomentosa* Miller (Lamiaceae). *Food Chemistry* **90**, 333-340.
- The Wealth of India. 1962.** A Dictionary of Indian raw materials and industrial products. Raw materials. Vol. VI: L-M; Council of Scientific and Industrial Research: New Dehli. pp. 425-429.
- Tholl, D. (2006).** Terpene synthases and the regulation, diversity and biological roles of terpene metabolism. *Current Opinion in Plant Biology* **9**(3), 297-304.
- Tortora, G. F., Funke, B. R. and Case, C. L. (2001).** Microbiology: an introduction. 7th ed. San Francisco: Benjamin Cummings.
- Tsaknis, J., Lalas, S., Gergis, V., Dourtoglou, V. and Spiliotis, V. (1999).** Characterization of *Moringa oleifera* variety Mbololo seed oil of Kenya. *Journal of Agricultural and Food Chemistry* **47**, 4495-4499.

- Vaghasiya, Y. and Chanda, V. (2007).** Screening of methanol and acetone extracts of fourteen Indian medicinal plants for antimicrobial activity. *Turkish Journal of Biology* **31**, 243-248.
- Vieira, G. H. F., Mourão, J. A., Ângelo, Â. M., Costa, R. A., and Vieira, R. H. S. D. F. (2010).** Antibacterial effect (*in vitro*) of *Moringa oleifera* and *Annona muricata* against Gram-positive and Gram-negative bacteria. *Revista do Instituto Medicina Tropical de São Paulo* **52(3)**, 129-132.
- von Maydell, H. J. (1986).** Trees and shrubs of Sahel, their characterization and uses. Deutsche Gesellschaft für Technische Zusammenarbeit, Germany: *Eschborn* **334-337**.
- Walter, A., Samuel, W., Peter, A. and Joseph, O. (2011).** Antibacterial activity of *Moringa oleifera* and *Moringa stenopetala* methanol and n-hexane seed extracts on bacteria implicated in water borne diseases. *African Journal of Microbiology Research* **5(2)**, 153-157.
- Yu, J., Vasanthan, T. and Tamelli, F. (2001).** Analysis of phenolic acids in barley by high-performance liquid chromatography. *Journal of Agricultural and Food Chemistry* **49**, 4352-4360.
- Zaffer, M., Ahmad, S., Sharma, R., Mahajan, S., Gupta, A. and Agnihotri, R. K. (2014).** Antibacterial activity of bark extracts of *Moringa oleifera* Lam. against some selected bacteria. *Pakistan Journal of Pharmaceutical Sciences* **27(6)**, 1857-1862.
- Zhang, L., Rozek, A. and Hancock, R. E. W. (2001).** Interactions of cationic antimicrobial peptides with model membranes. *The Journal of Biological Chemistry* **276**, 35714-35722.