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Research Article

A Review of Antibacterial Properties of Medicinal Plants in the Context of Wound Healing

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2. Keywords

Antimicrobial; Medicinal plants; Bioactive compounds; Complementary medicine; Wound healing

1. Abstract

Wounds of various types including injuries, cuts, burns and chronic ulcers have a severe socioeconomic impact on the cost of healthcare in both developing and developed countries. Bacterial resistance to current therapeutics continue to increase, hence, alternative antimicrobial agents derived from natural sources are being targeted. Traditional herbal medicines have been used for millennia across a multitude of cultures for the effective treatment of wounds and cognate infections. The aim of this review is to identify medicinal plants capable of treating bacterial infection within the context of wound healing. In this article, a considerable number of plants belonging to various genera which have scientifically validated antibacterial properties have been reviewed. Identification of medicinal plants with antibacterial properties was accomplished using the scientific database Scopus. In the majority of studies, antimicrobial effects were evaluated using in vitro methods. Although in some investigations, unique novel methods were implemented to determine potential antibacterial activity. Various parts of the plants which include leaves, fruits, stem bark and roots were used for the evaluation of antibacterial properties. In many instances, the methods performed in each investigation differed greatly, thereby hindering direct comparison between studies. However, it was evident that several plants contain either a single compound or a synergistic group of compounds which confer bactericidal effects. Unfortunately, identification of the bioactive compounds in question hasn't been undertaken, nor elucidation of their mode of action. Nevertheless, it is possible that a number of bioactive compounds could translate across to become an effective treatment against antibiotic-resistant bacteria.

3. Introduction

Wound healing is the restoration of skin integrity after damage or injury. Regardless of type or degree of a wound, it is the depth of injury which determines how the renewal process occurs either by spontaneous regeneration of dermal tissue, or by repair of connective tissue [1]. Wound healing involves several successive stages which is initiated by haemostasis and subsequently advances into more complex biochemical and overlapping physiological processes [2,3]. All four phases of the wound healing process i.e. haemostasis, inflammation, proliferation and remodeling, are controlled by a broad range of growth factors and cytokines [4]. Failure to heal within four weeks post-injury classifies a wound as chronic. Further, chronic wounds are those that have failed to transgress through the normal wound healing process and hence, perpetually cycle within the inflammatory phase [5]. Due to an increase in associated risk factors such as diabetes, smoking, obesity, cardiovascular illness and age, the global prevalence and healthcare burden of chronic wounds is predicted to rise substantially in the immediate future [6-8]. Although wound healing is a fundamental process, an infection can cause significant delays within the repair and regeneration cycle [1]. Moreover, microorganisms such as bacteria and fungi continue to be the most com-

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mon cause of delayed healing and infection [9]. The commensal microbiome on human skin consists of a wide spectrum of organisms with *Proteobacteria* and *Acetinobacteria* being the most abundant. Polymicrobial communities naturally form biofilms and are subject to the influence of the host's natural immune mechanisms. Wounds create an ideal environment for microorganisms to colonize and develop biofilms which are increasingly resistant to antibiotics [10]. The microbiota of wounds cannot only differ between disparate wound sites within the same host, but also between acute and protracted wounds as chronic ulcers have a greater incidence of *Streptococcal* and *Staphylococcal* colonization within the wound bed [10,11]. Based on current experimental evidence, *Staphylococcus* spp. are more likely to impair the wound healing process, thus contributing to chronicity [10]. A recent study showed that wound-colonizing bacteria such as *Pseudomonas aeruginosa*, are capable of degrading skin proteins and inhibiting fibroblast growth, thereby resulting in an enlargement of the wound and delayed healing [7]. Hollinworth [12] reported that a key factor in delayed chronic wound repair was the failure of the host response to combat multifactorial infections including *Escherichia coli, Staphylococcus,* haemolytic *Streptococcus, Bacillus, Pseudomonas* and *Proteus* species. The understanding and control of microbial infection is of great importance for the enhanced healing and management of wounds [13]. Continued overuse of antibiotics has undoubtedly driven the evolution of resistance. Inappropriate prescribing, extensive agricultural use, a decline in the availability of new antibiotics and the various adaptations by which pathogenic bacteria obviate the effects of antimicrobials has further augmented the threat [14-18]. In recent decades, antibiotic resistant bacteria isolated from burn patients have escalated, as resistance to various drug classes such as penicillins, cephalosporins and sulphonamides have increased by 70% subsequent to hospitalization [19]. Methicillin-resistant *Staphylococcus aureus* (MRSA) is the cause of a wide range of life-threatening complications and morbidity [20,21]. The bacterium has been implicated as a dominant hospital-acquired pathogen, which places a substantial burden on health and economies given its mounting global prevalence [22,23]. Antibiotic resistance has been implicated in approximately 70% of hospital-acquired infections within the USA [24]. Resistance to beta-lactams, macrolides and the dual combination drug trimethoprim + sulfamethoxazole, continues to increase among clinical isolates of *Streptococcus pneumoniae* [25]. Many diseases and disease agents that were once controlled by antibiotics have evolved into new resistant forms which are no longer susceptible to the original antimicrobial therapy [26]. Moreover, epidemics due to drug resistant microorganisms are now a universal problem that pose enormous public health concerns [26,27]. The global emergence of multidrug-resistant bacteria continues to limit the efficacy of current therapeutics, thus resulting in treatment failure and infection recurrence [26,28]. As resistance to first through to fourth generation antibiotics gains momentum, the development of new antimicrobial agents must be a priority if the problem is to be contained [28]. The past record of rapid spread and emergence of resistance to newly introduced antimicrobials has previously suggested that even novel therapies will have a short life expectancy [29]. However, teixobactin, a compound produced by soil-derived bacteria, is the first newly discovered class of antibiotic since the discovery of diarylquinolines in 1987. Whilst this is indeed a major breakthrough and a significant step forward in the fight against bacterial resistance, gram-negative bacteria are impervious to the drug [30]. The plant kingdom is a diverse and largely unexplored reservoir that is rich in a wide variety of secondary metabolites, such as tannins, terpenoids, alkaloids and flavonoids; all of which have reported antimicrobial properties [15,16,26]. Globally, approximately 20,000 plant species are used as ethnomedicines [14] by approximately 80% of the world's population for the treatment of communicable and non-communicable diseases [31]. In India, there are more than 2,500 known medicinal plant species however; this figure does not encapsulate the country's vast array of flora and other potential remedial uses [32]. South African folkloric medicine also incorporates an extensive selection of plants that have purported antibacterial activity, although most have not been scientifically appraised for their alleged medicinal qualities [33]. Thailand's history is also rich with traditional plant usage and as observed in other historic cultures across the world, many herbal formulas are in current use without modern validation [34]. Further, whilst there is a wealth of published data validating the antimicrobial activity of medicinal plants commonly used in folk medicine, to date, none have commercialized target compounds for use as novel antibacterial agents [35]. Scientific exploration has provided major innovations and advancements toward the understanding and evaluation of traditional plant usage and its subsequent integration into conventional medicine [36]. In various folklore traditions, numerous medicinal plants have been used for the treatment of infections that are now resistant to modern day pharmaceutics [37]. However, there is a paucity of data with regards to the safety, quality and efficacy profiles of these plant ex-

tracts to adequately protect the public's health and wellbeing [38]. Based purely on traditional knowledge, plants and preparations have been used to accelerate the wound healing process without any scientific evidence to support efficacy or information regarding active compounds and their mode of action [39,40]. Most drugs used to treat pathogenic, infectious microorganisms are secondary metabolites isolated from natural sources, which also serve as templates or act as lead compounds for the derivation of novel antibiotics [14]. Plants contain a number of organic components including alkaloids, flavones, phenols, quinones, terpenoids, glycosides and tannins, all of which have known antibacterial activity [41]. Biodiversity with regards to plants, algae and animals, provide a variety of natural medicinal compounds for the treatment of various infectious diseases. Hence, plant-derived products are considered alternative solutions to the problem of wound treatment in developing countries. Plants as the source of medicines are potential agents for wound healing and are generally preferred due to their widespread availability and effectiveness as crude preparations [9].

4. Method

The resources for this review (obtained from the Scopus database) were the scientific publications relating to antibacterial or antimicrobial effects of plant extracts in the context of wound healing. Further, only those research articles written in English, published after 1999, had a Scopus CiteScore ≥ 0.5 and a SCImago Journal Rank H-index ≥ 30 were selected for review. We are also aware of the fact that Scopus database is updated routinely and therefore source articles selected for this review were those available at the time this article was being prepared. Scopus is the largest abstract and citation database of peer reviewed literature that includes scientific journals, books and conference proceedings. CiteScore, a simple way of measuring the citation impact is calculated on the average number of citations received in a calendar year by all items published in that journal in the preceding three years. Derived from the Scopus database which is almost twice the size of the next leading abstract and citation data provider, CiteScore metrics offer a more robust and accurate indication of impact [42]. In contrast, H-index combines the number of publications plus the impact of citations. It performs better than other single number criteria commonly used to evaluate the scientific output of a researcher [43]. Due to the many advantages the H-index has over other bibliometric measures as an evaluator of research output coupled with the simplistic calculations used to achieve a value, the H-index has been well received in the scientific community [44]. All publications which fitted the selection criteria were carefully reviewed and analysed, including plant species, microorganisms tested and methods used to determine potential antimicrobial effects. The International Plant Name Index (www.ipni.org) database was used to validate scientific names of the plants. This helped to identify misspellings and the use of synonyms for different species.

4. Results and Discussion

A total of 28 articles resulted from the search performed using the Scopus database and ranged from 2004 – 2016 **(Figure 1)** covering 12 countries **(Figure 2)**.

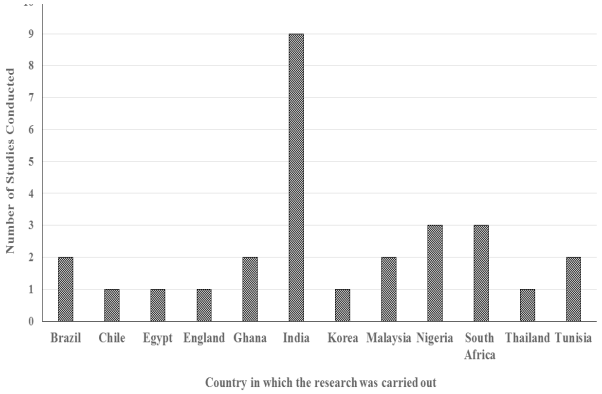

Figure 1: A total of 28 articles resulted from the search performed using the Scopus database and ranged from 2004 – 2016.

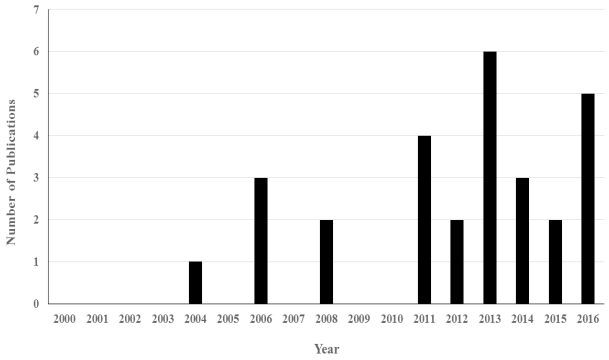

Figure 2: A total of 28 articles resulted from the search performed using the Scopus database and ranged from 2004 – 2016 covering 12 countries.

Overall, there were 116 species belonging to 67 plant families **(Table 1)**.

Table 1: Medicinal plants with antimicrobial properties

Plant species	Family	Country of origin	References
Ageratum conyzoides	*Asteraceae*	Nigeria	Chah *et al.* [46]
Ocimum gratissimum	*Lamiaceae*		
Anthocleista djalonensis	*Loganiaceae*		
Napoleonaea imperialis	*Lecythidaceae*		
Psidium guajava	*Myrtaceae*		
Bergia ammannioides	*Elatinaceae*	Egypt	Ezzat *et al.* [47]
Bridelia ferruginea	*Euphorbiaceae*	Nigeria	Adetutu *et al.* [48]
Ficus asperifolia	*Moraceae*	Ghana	Annan *et al.* [49]
Gossypium arboreum	*Malvaceae*		

Aloe arborescens	*Asphodelaceae*	South Africa	Ghuman *et al.* [38]
Aloe aristata	*Asphodelaceae*		
Aloe ferox	*Asphodelaceae*		
Bulbine frutescens	*Asphodelaceae*		
Bulbine natalensis	*Asphodelaceae*		
Haworthia limifolia	*Asphodelaceae*		
Eucomis autumnalis	*Asparagaceae*		
Merwilla plumbea	*Asparagaceae*		
Hypericum aethiopicum	*Hypericaceae*		
Tetradenia riparia	*Lamiaceae*		
Zantedeschia aethiopica	*Araceae*		
Arctium minus	*Asteraceae*	England	Watkins *et al.* [54]
Agrimonia eupatoria	*Rosaceae*		
Potentilla reptans	*Rosaceae*		
Pseudopanax laetevirens	*Araliaceae*	Chile	Molgaard *et al.* [40]
Acrisione denticulata	*Asteraceae*		
Baccharis elaeoides	*Asteraceae*		
Baccharis magellanica	*Asteraceae*		
Baccharis sphaerocephala	*Asteraceae*		
Laurelia sempervirens	*Atherospermataceae*		
Laureliopsis philippiana	*Atherospermataceae*		
Berberis buxifolia	*Berberidaceae*		
Blechnum chilense	*Blechnaceae*		
Buddleja globosa	*Buddlejaceae*		
Lobelia tupa	*Campanulaceae*		
Coriaria ruscifolia	*Coriariaceae*		
Weinmannia trichosperma	*Cunoniaceae*		
Durvillaea antarctica	*Durvillaeaceae*		
Aristotelia chilensis	*Elaeocarpaceae*		
Crinodendron hookerianum	*Elaeocarpaceae*		
Mitraria coccinea	*Gesneriaceae*		
Gleichenia quadripartita	*Gleicheniaceae*		
Ribes magellanicum	*Grossulariaceae*		
Gunnera chilensis	*Gunneraceae*		
Persea lingue	*Lauraceae*		
Desfontainia spinosa	*Loganiaceae*		
Tristerix tetrandrus	*Loranthaceae*		
Corynabutilon vitifolium	*Malvaceae*		
Amomyrtus meli	*Myrtaceae*		
Ugni molinae	*Myrtaceae*		
Fuchsia magellanica	*Onagraceae*		
Chusquea quila	*Poaceae*		
Podocarpus nubigenus	*Podocarpaceae*		
Polypodium feuillei	*Polypodiaceae*		
Embothrium coccineum	*Proteaceae*		
Gevuina avellana	*Proteaceae*		
Lomatia hirsuta	*Proteaceae*		
Acaena argentea	*Rosaceae*		
Francoa appendiculata	*Saxifragaceae*		
Cestrum parqui	*Solanaceae*		
Latua pubiflora	*Solanaceae*		
Rhaphithamnus spinosus	*Verbenaceae*		
Cissus striata	*Vitaceae*		
Drimys winteri	*Winteraceae*		
Plagiochasma appendiculatum	*Aytoniaceae*	India	Singh *et al.* [45]
Opuntia ficus-indica	*Cactaceae*	Tunisia	Ammar *et al.* [50]
Struthanthus vulgaris	*Loranthaceae*	Brazil	Vittorazzi *et al.* [51]
Lannea welwitschii	*Anacardiaceae*	Ghana	Agyare *et al.* [63]
Justicia flava	*Acanthaceae*		
Wedelia biflora	*Compositae*	India	Biswas *et al.* [39]
Bowdichia virgilioides	*Fabaceae*	Brazil	Agra *et al.* [52]
Holoptelea integrifolia	*Urticaceae*	India	Reddy *et al.* [70]
Acacia arabica	*Fabaceae*	India	Bhatnagar *et al.* [64]
Moringa oleifera	*Moringaceae*		
Capparis tomentosa	*Capparaceae*	South Africa	Steenkamp *et al.* [33]
Dicoma anomala	*Asteraceae*		
Gunnera perpensa	*Haloragaceae*		
Helichrysum foetidum	*Asteraceae*		
Leonotis leonurus	*Lamiaceae*		
Pterocarpus angolensis	*Fabaceae*		
Terminalia sericea	*Combretaceae*		
Urtica urens	*Urticaceae*		
Xysmalobium undulatum	*Asclepiadaceae*		
Tecomella undulata	*Bignoniaceae*	India	Suganya *et al.* [74]
Cinnamomum porrectum	*Lauraceae*	Malaysia	Buru *et al.* [14]
Cinnamomum iners	*Lauraceae*		
Cinnamomum altissimum	*Lauraceae*		
Cinnamomum impressicostatum	*Lauraceae*		
Pyrostegia venusta	*Bignoniaceae*	India	Roy *et al.* [57]
Tragia involucrata	*Euphorbiaceae*	India	Samy *et al.* [16]
Maranta arundinacea	*Marantaceae*	Thailand	Chusri *et al.* [60]
Oroxylum indicum	*Bignoniaceae*		
Commelina benghalensis	*Commelinaceae*		
Curcuma longa	*Zingiberaceae*		
Areca catechu	*Arecaceae*		
Oryza sativa	*Gramineae*		
Garcinia mangostana	*Guttiferae*		
Ceiba pentandra	*Bombacaceae*		
Aloe barbadensis	*Asphodelaceae*		
Coccinia grandis	*Cucurbitaceae*		
Senna siamea	*Caesalpiniaceae*		
Chromolaena odorata	*Asteraceae*		
Tinospora crispa	*Menispermaceae*		
Pupalia lappacea	*Amaranthaceae*	Nigeria	Udegbunam *et al.* [53]
Carissa spinarum	*Apocynaceae*	India	Sanwal and Chaudhary [62])
Blechnum orientale	*Blechnaceae*	Malaysia	Lai *et al.* [65]
Camellia sinensis	*Theaceae*	R. of Korea	Park *et al.* [61]
Areca catechu	*Arecaceae*	India	Nithyakalyani *et al.* [32]
Pongamia pinnata	*Fabaceae*		
Ficus benghalensis	*Moraceae*		
Vinca rosea	*Apocynaceae*		
Cleome viscosa	*Cleomaceae*		
Ixora coccinea	*Rubiaceae*		
Tridax procumbens	*Asteraceae*		
Aleo vera	*Asphodelaceae*		
Morinda pubescens	*Rubiaceae*		
Achyranthes aspera	*Amaranthaceae*	South Africa	Ndhlala *et al.* [36]
Globularia alypum	*Globulariaceae*	Tunisia	Ghlissi *et al.* [56]

Asparagaceae, *Asteraceae* and *Lamiaceae* were the most common plant families that were the subject of various investigations **(Figure 3)**.

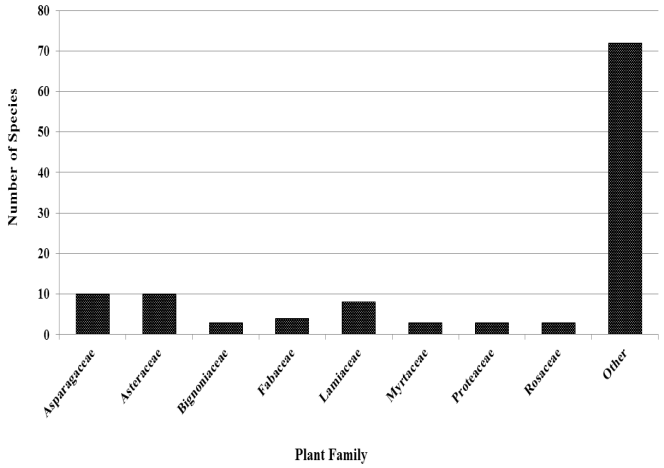

Figure 3: *Asparagaceae*, *Asteraceae* and *Lamiaceae* were the most common plant families that were the subject of various investigations.

151 bacteria and 16 fungi were used to determine the effectiveness of various plants extracts **(Figure 4)**.

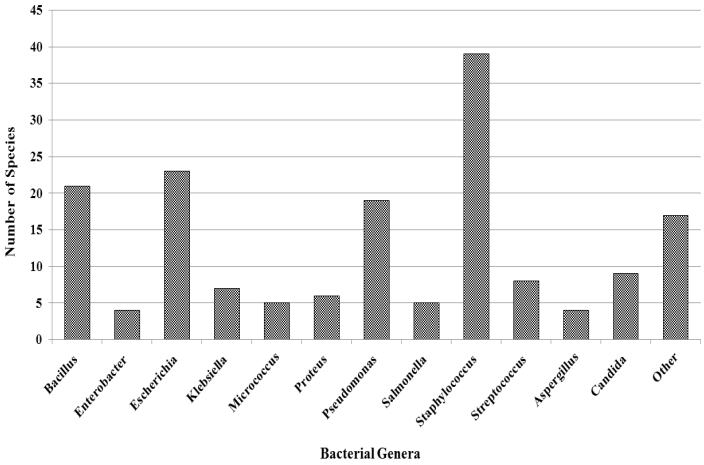

Figure 4: 151 bacteria and 16 fungi were used to determine the effectiveness of various plant extracts.

Staphylococcus aureus, P. aeruginosa, Escherichia coli and *Bacillus subtilis* were the most commonly used bacteria while *Candida albicans* was the most common choice for the determination of antifungal activity. It is evident that investigation of antimicrobial properties derived from medicinal plants has been based on folkloric accounts. Moreover, almost all of the studies included in this review began by identifying use of medicinal plants in traditional practice. Although there was no significant reporting of the traditional practices in question, the knowledge has been passed from one generation to the next. The potential of these traditional methods have been very well identified over a long period of time all around the globe (Figure 2). Interestingly, the majority of the research work has been undertaken in Asia (46%) and Africa (39%) where indigenous medicinal practices are most prevalent [14,36,38,45].

6. Traditional Use of the Plants

Nigerian folk medicine was traditionally used to treat ulcers, abscesses, wounds and sores [46]. Ezzat and colleagues [47] reported that the *Bergia* species are medicinally important in Indian traditional medicine for healing wounds and sores as is the use of *Bridellia ferruginea* in Nigeria [48]. Numerous plants have previously been identified as useful herbal remedies for the treatment of burns, rashes, boils, sores and cracked skin [38]. Annan and Houghton [49] selected two medicinal plants, *Ficus asperifolia* and *Gossypium arboretum,* based on a survey conducted with traditional healers in the local community and on further reports that neither plant had previously been assessed for potential antibacterial activity. In contrast, the antimicrobial effects of *Plagiochasma appendiculatum,* a plant traditionally used by the Gaddi tribe in Kangra valley, India, has been well established [45]. Due to the attractive biological and pharmacological properties of various parts of *Opuntia ficus,* it has been used for a wide range of medicinal purposes thus, the plant has the potential to be used for the production of promising bioactive compounds and value added products [50]. *Struthanthus vulgaris* is extensively used in Brazilian folk medicine as a treatment for cutaneous ulcers [51]. The bark of *Bowdichia virgilioides* is also a traditional medicine in Brazil for the treatment of wounds, however, there are no published reports concerning the potential bactericidal activity of this plant [52]. There are approximately 13 documented *Cinnamomum* species currently in use by Malaysian communities [14]. Moreover, the leaves and bark from the different plants are routinely used to treat wound infections. The "Malaiali" tribes in Western Ghats of India use different parts of *Tragia involucrata* to treat both superficial skin infections and wounds [16], whilst in Nigeria, the *Pupalia lappacea* plant is a common remedy for healing wounds [53]. Despite a rich history of traditional plant usage throughout Britain, much of the native flora listed in Anglo-Saxon medicinal literature are yet to be fully evaluated for potential pharmacological and medicinal applications [54].

7. Geographical Effect on Biochemical Constituents of Plants

One of the factors affecting the efficacy of medicinal plant extracts is the environment in which the plant grows. Environmental factors, to a great extent, qualitatively and quantitatively model the chemical profiles of a plant and consequently the resulting biological activity of the extracts [55]. Most herbal medicines and their derivative products are often prepared from different plant parts as they contain various phytochemical constituents. The chemical features of these constituents differ considerably amongst species and also as a result of the differences in climate conditions [56]. For example, extracts of *Achyranthes aspera* from two separate geographical locations were shown to have significant differences with regards to biochemical composition, therefore resulting in disparate antibacterial effects [36]. In contrast, another study revealed the presence of different classes

of flavonoids and phenols contained within the leaves of the same plant, regardless of being grown in a different geographical location [57].

8. Bacteria, Most Studied, Most Susceptible and Most Resistant

Bacteriological studies have shown that post-operative wound infection is a global problem and that the bacterial types present vary within geographical locations [32]. In the majority of investigations, the microorganism used for the antibacterial screening was sourced from American Type Culture Collection (ATCC), National Collection of Type Cultures (NCTC) or Microbial Type Culture Collection (MTCC). Chah and colleagues used multi-drug resistant microbial isolates sampled directly from a wound site from hospital patients in Nigeria [46]. Similarly, Nithyakalyani and colleagues collected clinical specimens from patients and found that the clinical isolates were more resistant than the ATCC strains [32]. Vittorazzi and colleagues showed that *S. aureus* was found to be more susceptible to ethanol extracts of leaves and branches from the *S. vulgaris* plant and hence, exhibited significant antimicrobial activity against gram-positive bacteria [51]. MRSA bacteria are difficult to inhibit because they are also multi-resistant and up to now, there are no satisfactory antimicrobial drugs that can totally clear a superbug infection [58]. The surface membrane of gram-negative bacteria has high lipid content due to the presence of lipopolysaccharides and phospholipids, thereby making them less susceptible to most antibacterial compounds [59]. The bactericidal effect of compounds on microorganisms depends upon body temperature of the host and length of bacterial incubation post-infection [16].

9. Antibacterial Screening Method

Methods used for evaluating antibacterial effects are broad and diverse (Table 2). Conventional applications such as well diffusion and disc diffusion assays, to novel and innovative applications such as the time-kill assay [60], have been utilized in numerous investigations [32,40,60,61]. Nithyakalyani and colleagues attempted a new method designed to assess the antibacterial activity of herbal finished surface modified polypropylene non-woven fabric against postoperative wound causing pathogens and found it to be an effective method of wound dressing [32]. Park and colleagues used antibacterial microneedles loaded with green tea extracts, a specialized method to deliver antibacterial compounds [61]. Microneedle arrays are, as the name suggests, needle like structures, each with a micron diameter and made of various materials including silicon, glass, metal and polymers. The premise of the method is to disrupt the skin's outer layers, hence enabling trans-dermal drug delivery. Moreover, such a system loaded with green tea extract can be an attractive approach for topical treatment of skin infections by the minimally invasive delivery of antimicrobial molecules.

10. Inconsistency of Investigations and Drawbacks

Some of the results published are confusing since many did not include a suitable positive antibiotic control for comparison purposes. Further, the standard deviation or standard error calculations which are essential to gauge the integrity of the novel treatments were also omitted [46]. In the studies conducted by Watkins [54] and Sanwal [62], there were large standard deviations in the percentage inhibition of *S. aureus* by plant extracts, hence, suggesting a lack of methodological consistency. It is important to have positive and negative controls to identify and compare the effectiveness of the plant extracts and to ensure assay validity. However, in some of the published studies, the authors did not include the proper controls, thereby making it difficult to ascertain the true antibacterial effects of the plant extracts in question [32, 40]. Agra and colleagues observed that the antibacterial effect of *Bowdichia virgilioides* bark extract on *S. aureus* was more effective than against *P. aeruginosa* [52]. The authors attributed the finding on the fact that gram-positive bacteria have a single multi-layered peptidoglycan cell wall unlike gram-negative bacteria, which contain a cytoplasmic membrane, a thin peptidoglycan layer and an outer membrane composed of phospholipids and lipopolysaccharides. Whilst the increased efficacy of the bark extract against the gram-positive bacterium may indeed be due to the differences in cell wall structures, such a claim cannot be definitively made when only one bacterial species from each class of microorganisms were investigated. In a study by Roy and colleagues, the authors observed a moderate to effective antimicrobial effect of the *Pyrostegia venusta* flower extract against pathogenic bacteria [57]. However, a comparison and thus, the effectiveness of the positive control were not indicated, nor was the n value to show number of repeats performed.

11. Preparation of Plant Material

In the majority of studies, extraction of relevant compounds was performed using plant leaves, however, bark, roots, seeds and flowers have also been targeted as potential sources of novel bioactive compounds. Interestingly, selection of plant parts for the purpose of extracting compounds was based on traditional usage [48,49]. Air drying of plant material was traditionally the most popular method for preparing the various components [54,63], however, this has now been superseded by a more scientific approach. Grinding of the dried plant is routinely accomplished by the use of either a mortar and pestle or an electric grinder. Depending upon the type and amount of plant material, combined with the specific grinding method utilized, the overall

yield from the extraction process can vary greatly.

12. Effectiveness of Extraction Method and Solvents

Aqueous extraction methods as well as organic solvents such as methanol, ethanol and ethyl acetate were favored in most of the studies. It is difficult to definitively conclude which solvent or extraction method is more efficient, since plants and target compounds differ between investigations **(Table 2)**.

Table 2: Summary of the effectiveness of the medicinal plants with antimicro**bial** properties

Reference	Solvent Used for Extraction	Method of Analysis	Bacterial Species (Code)	Effectiveness
Chah *et al*. [46]	Methanol	Well Diffusion Assay	*Staphylococcus aureus*	Crude extracts of *Napoleona imperialis, Psidium guajava* and *Anthocleista djalonensis* has confirmed antibacterial potential.
			Escherichia coli	
			Pseudomonas aeruginosa	
			Proteus spp.	
			Shigella spp.	
Ezzat *et al*. [47]	Extracted with ethanol 95% and successively fractionated with hexane, chloroform, ethyl acetate and butanol saturated with water	Disc Diffusion Assay	*Escherichia coli (ATCC 10536)*	*Bergia ammannioides* ethanol extract and it's hexane and ethyl acetate fractions have demonstrated significant antibacterial activity against *S. aureus*
			Proteus vulgaris (NCTC 4175)	
			Pseudomonas aeruginosa (CNCM A21)	
			Staphylococcus aureus (ATCC 4175)	
			Bacillus subtilis (NCTC 6633)	
			Sarcina lutea	
			Mycobacterium phlei	
			Salmonella typhi	
Adetutu *et al*. [48]	Extracted separately with ethanol and distilled water	96-well microtitre plate Iodonitrotertrazolium (INT) Assay	*Staphylococcus aureus*	The extracts were able to inhibit *Staphylococcus aureus* and *Bacillus subtilis* more effectively. However, ethanol extracts were more effective than aqueous extracts.
			Bacillus subtilis	
			Escherichia coli	
			Pseudomonas aeruginosa	
Annan *et al*. [49]	Distilled Water	96-well microtitre plate Iodonitrotertrazolium (INT) Assay	*Staphylococcus aureus(NCTC 4173)*	Aqueous extracts of *Ficus asperifolia* bark and *Gossypium arboreum* leaves showed moderate level of antibacterial properties on the 8 bacterial strains tested.
			Bacillus subtilis(NCTC 10073)	
			Micrococcus flavus (NCTC 7743)	
			Escherichia coli (NCTC 9002)	
			Pseudomonas aeruginosa(NCTC 10662)	
			Staphylococcus aureus (SA1199B)	
			Staphylococcus aureus (RN4220)	
			Staphylococcus aureus (XU214)	
Ghuman *et al*. [38]	Extracted separately with hexane, chloroform, dichloromethane, acetone and methanol	Disc Diffusion Assay followed by 96-.well microtitre plate Iodonitrotertrazolium (INT) Assay	*Bacillus subtilus*	Chloroform extracts of *Aloe ferox* leaves has shown broad range of activity since it has effectively inhibited all the bacterial strains tested. Dichloromethane extracts of *Aloe arborescens* leaves has also shown broad range of activity since it has effectively inhibited all the bacterial strains except *Micrococcus* spp. Extracts of *Bulbine frutescens, Eucomis autumnalis, Tetradenia riparia, Hypericum aethiopicum* and *Bulbine natalensis* have showed broad activity against most of the Gram positive and Gram negative bacterial species tested.
			Micrococcus spp.	
			Staphylococcus aureus	
			Staphylococcus epidermidis	
			Streptococcus pneumonia	
			Streptococcus pyogenes	
			Enterobacter aerogenes	
			Klebsiella pneumonia	
			Pseudomonas aeruginosa	
			Shigella sonnei	
			Proteus mirabilis	
			Proteus vulgaris	
			Actinomycetes brasielensis	

Watkins *et al*. [54]	Extracted separately with boiling water red wine, 25% and 75% Ethanol	96-well microtitre plate assay with measuring optical density at 600nm	*Staphylococcus aureus (NCTC 7447)* *Bacillus subtilis (NCTC 3610)* *Escherichia coli (UEL 57)* *Pseudomonas aeruginosa (NCIB 8295)*	Ethanolic root extracts of the plants were more effective than the leaf extracts in inhibiting *Staphylococcus aureus*.
Molgaard *et al*. [40]	Extracted separately with dichloromethane : methanol (1:1), 96% ethanol : methanol (1:1) and boiling water	Thin-layer chromatography agar overlay technique	*Escherichia coli (ATCC 11229)* *Pseudomonas aeruginosa (ATCC 9027)* *Staphylococcus aureus (ATCC 6538)* *Bacillus subtilis (ATCC 6633)* *Streptococcus pneumoniae* *Candida albicans (IMI 349010)* *Penicillium expansum (IMI 285521)*	*Acaena argentea, Aristotelia chilensis, Blechnum chilense, Coriaria ruscifolia, Crinodendron hookerianum, Drimys winterii, Fuchsia magellanica, Gevuina avellana, Laurelia sempervirens* and *Laureliopsis philippiana* have shown broad activity against Gram positive and Gram negative bacterial species tested.
Singh *et al*. [45]	Extracted separately with petroleum ether, acetone, chloroform, ethanol and water	Disc Diffusion Assay	*Micrococcus iuteus (MTCC 106)* *Bacillus subtilis (MTCC 121)* *Bacillus cereus (MTCC 430)* *Staphylococcus aureus (MTCC 96)* *Streptococcus pneumoniae (MTCC 2672)* *Enterobacter aerogenes (MTCC 111)* *Escherichia coli (MTCC 443)* *Klebsiella pneumoniae (MTCC 109)* *Proteus mirabilis (MTCC 1429)* *Pseudomonas aeruginosa (MTCC 429)* *Salmonella typhimurium (MTCC 98)* *Candida albicans (MTCC 183)* *Trichophyton rubrum (MTCC 296)* *Aspergillus niger (MTCC 16404)* *Aspergillus flavus (MTCC 1973)* *Aspergillus spinulosus (MTCC 16919)* *Aspergillus terreus (MTCC 1782)* *Cryptococcus albidus (MTCC 2661)* *Aspergillus nidulans (MTCC 11267)*	Ethanol extract has been more effective specifically on Gram negative bacteria such as *Escherichia coli, Proteus mirabilis* and *Salmonella typhimurium* over Gram positive bacteria such as *Staphylococcus aureus* and *Bacillus* spp. Extracts of *Plagiochasma appendiculatum* were found to be more effective on fungal species *Trichophyton rubrum*
Ammar *et al*. [50]	Extracted separately with water and methanol	Well Diffusion Assay	*Escherichia coli (ATCC 25922)* *Staphylococcus aureus (ATCC 25923)* *Bacillus subtilis (CTM 50077)* *Pseudomonas aeruginosa (ATCC 27853)* *Listeria monocytogenes (ATCC 43251)*	The extracts were more effective on Gram positive bacteria specifically against *Listeria monocytogenes*
Vittorazzi *et al*. [51]	Defatted with hexane and extracted with ethanol	Well diffusion assay and 96-well microtitre plate Triphenyltetrazolium chloride (TTC) Assay	*Staphylococcus aureus (ATCC 25923)* *Streptococcus agalactiae (ATCC 12386)* *Streptococcus mutans (ATCC 25175)* *Enterococcus faecalis (ATCC 29212)* *Escherichia coli (ATCC 8739)*	*Struthanthus vulgaris* extracts have been more effective on *Staphylococcus aureus.*
Agyare *et al*. [63]	70% Methanol	Well Diffusion Assay and 96-well microtitre plate dimethylthiazol diphenyltetrazolium bromide (MTT) Assay	*Staphylococcus aureus (ATCC 25923)* *Bacillus subtilis (NCTC 10073)* *Escherichia coli (ATCC 25922)* *Pseudomonas aeruginosa (ATCC 27853)* *Candida albicans*	Both plant species have demonstrated broad-spectrum antibacterial activity.
Biswas *et al*. [39]	Extracted with ethanol after removing the wax with petroleum ether	Well Diffusion Assay and 96-well microtitre plate Phenol red (NBGP) Assay	*Bacillus subtilis* *Staphylococcus aureus* *Escherichia coli* *Klebsiella pneumoniae* *Candida albicans* *Aspergillus niger*	*Klebsiella pneumoniae* was reported to be more sensitive to *Wedelia biflora* extracts.
Agra *et al*. [52]	Water	Well Diffusion Assay	*Staphylococcus aureus (ATCC 25923)* *Pseudomonas aeruginosa (ATCC 27853)*	*Bowdichia virgilioides* aqueous extracts were effective only on *Staphylococcus aureus*

Reddy *et al.* [70]	Extracted with methanol after removing the wax with hexane	Well Diffusion Assay and 96-well microtitre plate Phenol red (NBGP) Assay	*Bacillus cerculences*	*Holoptelea integrifolia* stem bark extract has demonstrated higher antibacterial activity over the leaf extract.
			Pseudomonas aeruginosa	
			Bacillus subtilis	
			Klebsiella aeruginosa	
			Staphylococcus aureus	
			Escherichia coli	
			Aspergillus niger	
			Sacharomyces cerviceae	
			Candida krusei	
			Candida albicans	
			Candida tropicana	
Bhatnagar *et al*. [64]	Extracted with distilled water and precipitated with isopropanol	Disc Diffusion Assay and Triphenyl tetrazolium chloride (TTC) Microdilution Assay	*Pseudomonas aeruginosa (ATCC 27853)*	Both plant extracts have demonstrated broad spectrum antibacterial activity.
			Escherichia coli (ATCC 25922)	
			Staphylococcus aureus (ATCC 25923)	
			Bacillus licheniformis (ATCC 12759)	
Steenkamp *et al*. [33]	Extracted separately with water and methanol	96-well microtitre plate Iodonitrotertrazolium (INT) Assay	*Staphylococcus aureus (ATCC 25923)*	Two species *Gunnera perpensa* and *Terminalia sericea* have been the most active. *Gunnera perpensa* root extract has demonstrated broad spectrum inhibition while *Terminalia sericea* bark extract has been effective only on Gram positive bacteria.
			Streptococcus pyogenes	
			Escherichia coli (ATCC 25922)	
			Pseudomonas aeruginosa (ATCC 27893)	
Suganya *et al*. [74]	Chloroform (80% v/v) and Methanol (20% v/v)	Disc Diffusion Assay	*Pseudomonas aeruginosa (MTCC 2297)*	*Tecomella undulata* bark extract has demonstrated broad-spectrum activity while being more effective on the Gram negative bacteria.
			Escherichia coli (IP406006)	
			Staphylococcus aureus (ATCC 933)	
Buru *et al*. [14]	Sequentially extracted with hexane, ethyl acetate, methanol and water	Disc Diffusion Assay and 96-well microtitre plate Resazurin Assay	*Staphylococcus aureus (ATCC 700637)*	*Cinnamomum* extracts were more effective on Gram positive bacteria, specially, *Staphylococcus* spp. The active components of the plants were present in stem bark and leaves.
			Staphylococcus aureus (ATCC 700689)	
			Staphylococcus saprophyticus (ATCC 15305)	
			Staphylococcus epidermidis (ATCC 12228)	
			Bacillus cereus (ATCC 10876)	
			Enterococcus feacalis (ATCC 29212)	
			Pseudomonas aeruginosa (ATCC 27853)	
			Escherichia coli (ATCC 25922)	
			Enterobacter aerogenes (ATCC 13048)	
			Burkholderia pseudomallei	
			Acinetobacter baumannii (ATCC 17978)	
			Yersinia enterocolitica (ATCC 23715)	
			Klebsiella pneumoniae (ATCC 700603)	
			Stenotrophomonas maltophilia (ATCC 13637)	
			Aeromonas hydrophilia (ATCC 7966)	
			Acinetobacter iwoffii (ATCC 17925)	
			Proteus mirabilis (ATCC 29906)	
			Vancomycin Resistant *Enterococci (ATCC 51299)*	
Roy *et al*. [57]	Methanol	Disc Diffusion Assay	*Bacillus subtilis*	*Escherichia coli* and *Candida albicans* were the most sensitive microorganism to *Pyrostegia venusta* extracts.
			Staphylococcus epidermidis	
			Streptococcus pyogenes	
			Staphylococcus aureus	
			Escherichia coli	
			Micrococcus luteus	
			Enterobacter aerogenes	
			Salmonella typhi	
			Pseudomonas aeruginosa	
			Candida albicans	
			Aspergillus niger	
			Candida tropicana	

Samy *et al.* [16]	Treated with 4% HCl (pH 2) and extracted with diethyl ether	Disc Diffusion Assay and Broth Dilution Method	*Escherichia coli* *Proteus vulgaris* *Staphylococcus aureus*	Two of the isolated compounds, vinyl hexyl ether and shellol has demonstrated broad spectrum antibacterial activity
Chusri *et al.* [60]	Dried plant formulations were extracted separately with water and ethanol	CLSI broth microdilution method and Time-kill assay	*Staphylococcus aureus(R001–R020)* *Staphylococcus aureus(S001–S020)* *Staphylococcus aureus (ATCC 29213)*	Ethanol extracts of the formulations were more effective than the aqueous extracts. The formulation consisted with *Curcuma longa, Areca catechu, Oryza sativa* and *Garcinia mangostana* has been more effective in inhibiting *Staphylococcus*spp.
Udegbunam *et al.* [53]	80% Methanol	Macro broth dilution method	*Pseudomonas aeruginosa* *Staphylococcus aureus* *Bacillus subtilis*	Leaf extracts of *Pupalia lappacea* were more effective on Gram positive bacterial spp.
Sanwal and Chaudhary [62]	Methanol	Disc Diffusion Assay	*Escherichia coli* *Bacillus subtilis* *Staphylococcus aureus* *Streptococcus spp.* *Aspergillus niger*	*Carissa spinarum* root extracts have demonstrated broad spectrum antibacterial activity. *Escherichia coli* and *Staphylococcus aureus* were the most sensitive species out of the five species tested.
Lai *et al.* [65]	Extracted with methanol, dried and resuspended in water. Partitioned sequentially with petroleum ether, chloroform, ethyl acetate and butanol. Aqueous phase was dried and fractionated with 10% (v/v) increments of water in methanol.	96-well microtitre plate Iodonitrotertrazolium (INT) Assay	*Bacillus cereus (ATCC 10876)* *Enterococcus faecalis (ATCC 14506)* *Micrococcus luteus (ATCC 49732)* *Staphylococcus aureus (ATCC 25923)* *Staphylococcus aureus (ATCC 43300)*	Plant extracts were tested only on Gram positive bacteria. The aqueous fractions have been able to inhibit Gram positive bacteria.
Park *et al.* [61]	Extracted with water and ethanol	Serially diluted extracts were loaded to Hyaluronic acid microneedles and incubated in culture medium (Luria-Bertani)	*Escherichia coli (KCTC 1041)* *Salmonella typhimurium (KCTC 2054)* *Pseudomonas putida (KCTC 1134)* *Bacillus subtilis (KCTC 2217)* *Staphylococcus aureus (KCTC 1916)*	Significant, broad spectrum inhibition was observed with *Camellia sinensis* extracts at and above 50% concentration.
Nithyakalyani *et al.* [32]	80% Methanol	Disc Diffusion Assay and AATCC-100 Test Method (assessment of antibacterial finishes on textile materials)	*Staphylococcus aureus(ATCC 6538)* *Escherichia coli (ATCC 8739)*	*Areca catechu, Ficus bengalensis* and *Cleome viscosa* extracts have been able to inhibit both Gram negative and Gram positive bacteria.
Ndhlala *et al.* [36]	Extracted separately with 70% Acetone and Water	96-well microtitre plate Iodonitrotertrazolium (INT) Assay	*Escherichiacoli (ATCC 11775)* *Klebsiella pneumoniae (ATCC 13883)* *Bacillus subtilis (ATCC 6051)* *Staphylococcus aureus (ATCC 12600)* *Candida albicans (ATCC 10231)*	Acetone and aqueous extracts of *Achyranthes aspera* from two geograpgical locations have shown significantly different antimicrobial potential.
Ghlissi *et al.* [56]	Methanol	Well Diffusion Assay	*Staphylococcus aureus (ATCC 25923)* *Micrococcus luteus (ATCC 4698)* *Escherichia coli (ATCC 25922)* *Klebsiella pneumoniae (ATCC 13883)* *Salmonella enterica (ATCC 43972)* *Listeria monocytogenes (ATCC 43251)*	*Globularia alypum* leaf eaxtract has demonstrated broad range antibacterial activity. However, it was evident that the extract was more effective on Gram negative bacteria such as S*almonella enterica, Escherichia coli* and *Klebsiella pneumoniae*.

Whilst some plants have a higher yield when extracted with an aqueous extraction method [45,50], others produced greater results with organic solvents [48] hence, no specific organic solvent is preferable over another. Instead, extraction yield is dependent upon the type and polarity of compounds present within the target plant. Adetutu and colleagues [48] showed that ethanolic extracts compared with the aqueous counterpart provided higher yields from the *Bridelia ferruginea* plant. Whilst Singh and colleagues [45] reported that water and ethanol yields were greater than non-polar organic solvents when extracting compounds contained within *Plagiochasma appendiculatum*. At times, combinations of different solvents have been used to improve yield [63,64]. Comparative studies have also been undertaken to determine the efficacy of the extraction process using different solvents [14,38,47]. While many of the extraction procedures included single or several solvents during the separation process, some methods were complex and used solvents sequentially, in an attempt to extract different compounds with varying polarities and properties [47]. Plant extracts are comprised of a large and diverse number of biochemical compounds. Samy and colleagues [16] recovered nine partially purified compounds from the *Tragia involucrate* plant. In another study, phytochemicals partially purified from the aqueous extract of *Blechnum* were shown to effectively inhibit five gram-positive bacteria including MRSA, compared with the raw aqueous extract which was not as efficacious [65]. Analysis of leaf extract obtained from *Pupalia lappacea* revealed eight compounds including sitosterol and stigmasterol [53] were contained within the extract and are recognized for their potential antibacterial activity [66].

13. Effectiveness of Plant Extracts

A large number of plant species used traditionally have been screened for their bioactivities, with most displaying promising antimicrobial activity [67]. The concentration of plant extract and whether it was partitioned or purified varies broadly in each investigation. Further, plant extracts, their source and concentration tested against various bacteria differs greatly. Thus, it is very difficult to compare and draw conclusions concerning the effectiveness of each type of plant extract unless all parameters remain constant. For a plant extract to have pharmacological relevance and be considered therapeutically beneficial, it must have minimum inhibitory concentration values below 2.0 mg/ml [68]. The variable depth and extent of ethnopharmacological bioassays used to corroborate the observed health claims of traditionally used medicinal plants, ultimately contribute to evidence-based medicine. Although a lot of studies mentioned in this review have supported traditional usage, none were shown to have superior bactericidal activity when compared to the current antibiotic controls. In ethnopharmacology, the conclusive negative results may be as important as positive, since they too, contribute significantly to evidence-based medicine [69]. However, extensive scientific evidence for the development of antimicrobial products derived from plants has led to the successful lodgment of numerous patents [38]. Methanolic extracts from leaves of *Napoleona imperialis*, *Psidium guajava* and the roots of *Anthocleista djalonensis* were reported to have remarkable inhibitory effects against multi-resistant bacterial isolates taken directly from wounds [46]. Solvent extracts of *Bergia ammannioides* were shown to be effective inhibitors of *S. aureus* growth in contrast to other bacterial strains [47]. Ethanolic extracts from *Bridelia ferruginea* were more effective than aqueous extracts with regards to the inhibition of *S. aureus, B. subtilis, E. coli* and *P. aeruginosa* [48], thereby indicating that different solvents not only extract disparate compounds, but the antibacterial potency of the bioactive compounds in question, are varied. Results of an investigation carried out on 11 plant species from South Africa demonstrated that the antibacterial effect of the different extracts, based on the solvent used, differed [38]. In the same study, the chloroform extract of *Aloe ferox* and dichloromethane extract of *Aloe arborescens* were more effective than the other nine plant extracts. In contrast, water and ethanol extracts obtained from *Plagiochasma appendiculatum* were found to be more effective than the non-polar extracts with regards to antibacterial effects [45]. *In vitro* analysis of the antimicrobial effect of aqueous extracts of *Bowdichia virgilioides* were shown to have an inhibitory effect against the gram-positive bacterium *S. aureus*, but not against gram-negative bacteria such as *P. aeruginosa* [52]. The study by Molgaard and colleagues [40] showed that Huilliche medicinal plants used traditionally in Chile, also have the ability to successfully inhibit the staphylococcal species i.e. *S. aureus*. In contrast, *Holoptelea integrifolia* bark extract was found to be more effective than the leaf extract obtained from the same plant, against fungal species *Saccharomyces* and *Candida* [70]. Buru and colleagues [14] reported that stem bark extracts from four species of *Cinnamomum* had better antibacterial activity than other parts of the plants. Further, the authors found that the polar extracts (methanol and water) elicited superior bactericidal effects than other non-polar extracts. In the same study, *S. epidermidis* and MRSA were shown to be more susceptible to *Cinnamomum* extracts. Ghlissi and colleagues [56] found that the methanolic extract of *Globularia alypum* exhibited significant antimicrobial activity against both gram-positive and gram-negative bacteria, therefore supporting traditional Tunisian folk usage of

this plant as a poultice for ulcers and wounds. An investigation to determine antibacterial effects of plant extracts based on solvent, determined that pooled ethanol extracts were more effective against MRSA than combined aqueous extracts [60]. Udegbunam and colleagues [53] reported that methanolic extracts of *Pupalia lappacea* leaves reduced the bacterial load in a wound, which was comparable to the positive antibiotic (gentamicin) control. Phenolic compounds which are well known phytochemicals and found in all plants, consist of simple phenols, benzoic and cinnamic acid, coumarins, tannins, lignins, lignans and flavonoids [71]. Agyare and colleagues [63] reported that *Lannea welwitschii* extracts were effective against gram-positive and gram-negative bacteria as well as the fungus *Candida albicans* thus, indicating that the activity was exclusively due to the presence of secondary metabolites such as flavonoids, tannins, glycosides, and alkaloids as they have strong antimicrobial and antioxidant properties. *Wedelia biflora* leaf extract was shown to successfully inhibit *K. pneumoniae* while being less effective against *B. subtilis* [39]. Such a favorable effect could be due to the presence of terpenes and flavonoids as they are well known to elicit strong antibacterial activity. Samy and colleagues [16] demonstrated that shellsol from *Tragia involucrata* leaf extracts was most active against *Proteus vulgaris* and *S. aureus*. In the same study, the authors reported that vinyl hexyl ether and shellsol were shown to be potent inhibitors against a wide range of bacterial species, but in particular against *S. aureus*. The major compound b-sitosterol isolated from *Bergia ammannioides* was also shown to possess antibacterial activity against *S. aureus* [72]. In contrast, the antimicrobial activity of the methanolic extract derived from *Carissa spinarum* roots has been attributed to the presence of flavonoids and terpenes [62]. Bhatnagar and colleagues [64] reported that *Moringa oleifera* seed extracts is comprised of cationic Flo polypeptide that acts directly and non-specifically upon bacterial cell membranes, thereby causing the leakage of cytoplasmic content, whilst *Acasia arabica* gum extract contains glycosides that exhibit antibacterial properties. A study on the sedimentation effect of the seed-derived peptide termed "Flo" indicated that it mediates bacterial disinfection and as such, is able to kill antibiotic resistant bacteria, including several human pathogens [73]. Nanofibers from blend electrospinning have been shown to be suitable as a drug release model to kill bacteria in a short period of time that would otherwise require a large amount of drug to elicit the same effect [74]. Polycaprolactone and polyvinyl pyrrolidone nanofiber mats loaded with herbal drugs possess efficient antibacterial properties that can be used in the treatment of wounds or dermal infections, thereby proving a potential application for use as a novel drug delivery system and wound dressing agent [74]. Plasma treated non-woven polypropylene fabric coated with a combination of herbs was found to exhibit better antibacterial activity against both gram-positive and gram-negative bacteria compared to non-herbal finished fabric [32]. Park and colleagues [61] reported that green tea has strong antibacterial effects and its activity remains even when incorporated into a polymer matrix. Topical applications of drugs are effective both as microbicide agents and for augmenting the wound healing rate due to a greater availability at the infected wound site [52].

14. Conclusion

Traditional or indigenous medicines across the globe have identified a number of plants that are highly effective as antibacterial therapies. However, until recently, there has been a dearth of scientific investigation with regards to the identification of bioactive compounds and their mode of action that elicits the medicinal effects. Currently, antimicrobial resistance continues to increase worldwide, thus indicating that current antibiotics are no longer effective against various bacterial pathogens. As a result, there is now greater demand and need for scientific validation of plant bioactive compounds that have reported antimicrobial activity in an effort to resupply our depleted stock of efficacious antibiotics. Recently, significant efforts have been made globally to discover both novel and potent compounds capable of eliminating antibiotic-resistant bacteria. However, the search continues as a large number of plants used in folkloric medicine may hold the key to discovering a superior antimicrobial, thus becoming the next generation of therapeutic in the fight against resistant microbial pathogens.

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