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Comparative Analysis of the Antimicrobial Efficacy of Selected Medicinal Plant Extracts and Conventional Antibiotics against Pathogenic Bacteria

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Annotation: Increased prevalence of antimicrobial-resistant microorganisms has prompted the quest globally for new antimicrobial agents, particularly from nature. In this study, an effort is made to compare and evaluate the antimicrobial activity of certain selected medicinal plant extracts—Azadirachta indica (neem), Ocimum sanctum (tulsi), and Curcuma longa (turmeric)—with reference antibiotics against some common pathogenic bacteria like Escherichia coli, Staphylococcus aureus, and Pseudomonas aeruginosa. The plant extracts were also obtained through both aqueous and ethanol-based extraction processes and tested for antimicrobial activity through the disc diffusion assay. Antibiotics ampicillin and ciprofloxacin were employed as control. The MIC and MBC of each extract were also ascertained. Initial results indicate that ethanol extracts contain greater inhibition zones than aqueous extracts, where Ocimum sanctum exhibited the highest antimicrobial activity. While the conventional antibiotics were generally more active, certain plant extracts had synergistic or similar effects, particularly against Gram-positive bacteria. The results suggest that some bioactive compounds from plants possess significant antimicrobial activity and could serve as complementing or supplementary therapies to conventional antibiotics. The study affirms the potential of ethnobotanical materials in the fight against the increasing menace of antimicrobial resistance.

Keywords: Antimicrobial, Medicinal Plant, Conventional Antibiotics, Antibiotics.

Introduction

The increasing rise and spread of antimicrobial resistance (AMR) are two of the world's greatest health dangers to public health in the 21st century. As specified by the World Health Organization (WHO), antibiotic resistance is rising to record-breaking levels across all regions of the world, and an especially terrifying number of bacterial infections are becoming increasingly—and often entirely—untreatable using existing antibiotics. The overuse and misuse of antibiotics in medicine for humans, animals, and agriculture have accelerated the development of resistance among a group of pathogenic bacteria. The most difficult-to-control multidrug-resilient microbes are Escherichia coli, Staph aureus, and Pseudomonas aeruginosa, all of which produce a wide range of infections acquired in hospitals and communities, including urinary tract infections, respiratory infections, infections of the wounds, and sepsis. The clinical implications of AMR are treatment failure, increased healthcare costs, increased length of hospital stay, and increased mortality rates [1, 2].

To fight this growing crisis, it is necessary to seek urgently and critically new antimicrobial agents that may serve as adequate replacements for, or synergistically complement, conventional antibiotics. A promising direction is the discovery of bioactive compounds from medicinal plants. For as long as anyone can remember, Ayurveda, Traditional Chinese Medicine, and other traditional medicine systems have all relied on the medicinal properties of plants. Medicinal plants yield a rich diversity of secondary metabolites in the forms of alkaloids, tannins, flavonoids, terpenoids, saponins, and phenolics, most of which have been found to have science-backed antimicrobial, anti-inflammatory, antioxidant, and immunomodulatory activities [3, 4].

Recent developments in phytochemistry and microbiology have enabled rational investigating of herbal isolates for antimicrobial activity and, hence, renewed interest in using natural consequences as the source of new drugs. Specifically, the neem plant, Azadirachta indica; tulsi or holy basil plant, Ocimum sanctum; and turmeric plant, Curcuma longa, have been the subject of significant interest based on their strong bioactivities. Azadirachta indica possesses antibacterial and antifungal activity, due mainly to compounds like nimbidin, azadirachtin, and quercetin. Ocimum sanctum has essential oils and flavonoids with documented antimicrobial and anti-inflammatory activity, while Curcuma longa is laden with curcumin, a polyphenolic in nature compound possessing documented antimicrobial as well as antioxidant activity [1, 2, 5]

Despite many studies confirming the antimicrobial properties of these plants, there is still a large gap in comparative research that could compare their efficacy with standard antibiotics. Furthermore, differences in extraction methods, solvent polarity, and susceptibility of the bacterial strain make it essential to standardize the protocols for the assessment of plant extract efficacy. To this end, the current research aims at filling the above gap through comparative evaluation of antimicrobial activity of some plant extracts achieved using aqueous and ethanol-based solvents and their inhibitory activities on clinically procured bacterial strains in combination with reference antibiotics ampicillin and ciprofloxacin. The study applies microbiological techniques including the disc diffusion assay to measure zones of inhibition, and broth dilution methods for determining minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of each plant. These steps will be employed in evaluating both the qualitative and quantitative antibacterial activity. By systematic comparison of plant antimicrobials and conventional antibiotics, this research hopes to contribute to the literature supporting the integration of phytotherapeutics into present antimicrobial strategies—especially following the increasing alarm for antibiotic resistance.

The subsequent section is dedicated to related activities. The methods are delineated in Section 3. The results are illustrated in Section 4. The final section of this paper contains the notes that have been concluded.

Related work

The urgent need for novel antimicrobial agents has driven extensive research into natural sources, particularly medicinal plants, due to the alarming rise in antibiotic-resistant bacterial strains. Over recent decades, numerous studies have explored the antimicrobial assets of various herbs, revealing a diverse collection of bioactive compounds with promising therapeutic potential [6]. These plant-derived compounds offer an alternative or complementary approach to conventional antibiotics, which are increasingly compromised by resistant pathogens.

Among the widely studied medicinal plants, *Azadirachta indica* (neem), *Ocimum sanctum* (tulsi), and *Curcuma longa* (turmeric) have attracted considerable attention due to their long history of use in traditional medicine and documented antimicrobial activities. Neem extracts have demonstrated inhibitory effects against key pathogenic bacteria such as *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, largely attributed to phytochemicals like nimbidin and azadirachtin. Similarly, *Ocimum sanctum* contains essential oils and phenolic compounds capable of disrupting bacterial cell membranes, effectively inhibiting microbial growth. Curcumin, the effective complex in turmeric, exhibits broad-spectrum antimicrobial properties and has shown synergistic effects when combined with certain antibiotics, suggesting its role in overcoming resistance mechanisms [7, 8].

Comparative studies have evaluated the antimicrobial efficacy of these plant extracts alongside standard antibiotics. Some research indicates that ethanol extracts of medicinal plants can produce zones of inhibition comparable to antibiotics such as ampicillin, particularly against Gram-positive bacteria [8, 9, 10, and 11]. Moreover, synergistic interactions between plant extracts and conventional antibiotics have been reported, enhancing antibacterial activity and offering promising strategies to tackle resistant strains. The extraction method performs a detailed role in determining the potency of plant extracts. Solvent-based extractions, particularly using ethanol or methanol, often yield higher concentrations of bioactive compounds compared to aqueous extracts, resulting in stronger antimicrobial effects. This highlights the importance of carefully selecting extraction techniques to maximize the therapeutic potential of plant materials [12]. For instance, Bereksi et al [13] Evaluated the antibacterial efficiency of hydromethanolic extracts from Berberis vulgaris, Cinnamomum cassia, Cassia angustifolia, Withania frutescens, Cistus monspeliensis, Nigella sativa, Rhus tripartata, Punica granatum, and Zingiber officinale against various Gram-positive and Gram-negative reference Antibacterial activity of plant extracts was assessed utilizing disc diffusion and MIC determination. Plant extracts inhibited bacteria effectively with zones of reticence ranging from 06.0 to 23.0 mm and MICs from 0.1 to 12.8 mg/mL. Similar inhibitory diameters and MICs were observed in both Refluxed and Macerated extracts of these plants. Compared to other plant extracts, C. monspeliensis, P. granatum, and B. vulgaris showed strong action against E. faecalis, S. aureus, and E. cloacae. Chidinma et al [14] studied in NOH tested the effect of some antibiotics and leaf extracts by Garcinia Cola and Azadirchta Indica against bacteria from wound infection. From 96 samples, 15 (21.7%) produced pathogens - mostly E. coli, p. Eruginosa, Clabsiela spp., And S. Aryas - All Multidurg resistance. Some reacted to gentamycin, siprofloxacin and some others. With less antibacterial effect, herbal extracts some e. Coli, p. Eryinosa and S. Aryas affect isolates. The results emphasize the ongoing research for replacement antibiotics with a view to increasing drug resistance. Hemeg et al. [15] tested the antimicrobial influences of ethanolic extracts of five herbal vegetation: Sage (Salvia officinalis), Guava (Psidium guajava), Mulberry (Morusalba L.), Rhamnus (Ziziphusspina Christi), and Olive (Oleaeuropaea L) leaves against Mollicutes, Gram positive, and Gram negative: E. coli, S. aureus, Pasteurella multocida, Salmonella Enteritidis, B.

cereus, and M. gallisepticum utilizing regular extracts vary against the microorganism studied. All extracts except Psidium guajava are ineffective against Mycoplasma gallisepticum. The extracts had MIC and MBC values of 625 to 5000 µg/ml against six microorganisms. The herbal isolate inhibited the pathogen under research at varied MIC and MBC.

Despite these promising findings, several challenges remain. Many studies suffer from small sample sizes, lack standardized protocols for extraction and antimicrobial testing, and often do not evaluate cytotoxicity or in vivo effectiveness. Additionally, comprehensive comparative analyses that test multiple medicinal plants alongside conventional antibiotics under consistent conditions are limited. Addressing these gaps is essential for validating the clinical potential of plant-based antimicrobials and facilitating their integration into modern therapeutic regimens.

Methods

Plant Material Collection and Preparation:

Fresh leaves of Ocimum sanctum (tulsi), Azadirachta indica (neem), and Curcuma longa (turmeric) rhizomes were procured from known sources. Plant materials were cleaned repeatedly with distilled water to eliminate dirt and impurities and sun dried in open shade in a well-ventilated room for seven days at room temperature to prevent active ingredient degradation. The plant material was scraped into a reasonable gunpowder using a sterile mechanical grinder and saved in tightly confirmed packets at room temperature until the extraction process.

Extraction Procedures:

Two extraction techniques were employed to provide phytochemicals of antimicrobial character: aqueous extraction and ethanol extraction.

- Aqueous Extraction: A known quantity (50 g) of dried plant material was macerated in 500 mL of distilled water at room temperature (approximately 25°C) for 24 hours under intermittent stirring to favor solubility. The obtained mixture was streamed via Whatman No. 1 filter paper, and the deposit was freeze-dried to be concentrated as an extract.
- Ethanol Extraction: Fifty grams of powdered plant material was macerated in 500 mL of 70% ethanol at room temperature for 48 hours under frequent agitation. The extract, following maceration, was filtered in the same way and reduced pressure concentrated using a rotary evaporator at 40°C to avoid thermal decomposition. Concentrated extracts were stored at 4°C until antimicrobial activity testing.

The weight of dried extracts obtained from 50 grams of each plant material was almost:

- ✓ Azadirchata indica: 4.0 grams (aquatic), 6.5 grams (ethanol)
- ✓ Ocimum cantum: 5.5 g (aquatic), 8.0 g (ethanol)
- ✓ Curcuma Longa: 3.8 grams (aquatic), 5.2 grams (ethanol)

These results indicate that ethanol extraction was a larger amount of extracts than aquatic extractions, which is probably due to the better ethanol ability to dissolve bioactive compounds.

Antimicrobial Assays:

The antimicrobial activity of all the extracts was screened against three clinically relevant pathogenic bacteria, namely Escherichia coli (Gram-negative), Staphylococcus aureus (Gram-positive), and Pseudomonas aeruginosa (Gram-negative). Bacterial strains were received from a certified microbiological culture collection and stored on slants of nutrient agar.

- The disk proliferation analysis was included in the incorporated 6 mm sterile paper disc with 20 ules of each plant at 100 mg/ml of concentration, and they were included in drying under decaying conditions. 0.5 McFarland turbidity (about 1.5 × 10^8 CFU/ml) was injected on plates if Mueller-Hinton. The plate was incubated on vaccination plates at 37 ° C for 24 hours. Using a digital brake advertisement, the disc ban areas were measured in millimeters. The trial in Triple secured repetition.

- Mic and MBC were evaluated using a broth microdilusion technique. Two-wheeled serial dilutes of all extracts from 0.125 to 64 mg/ml were made in sterile nutritional broth. Standard bacterial inoculum was placed in dilutions and was organized at 37 ° C for 24 hours. The lowest extract concentration that interferes with the growth of bacteria was Mic. Mike was offered 24 hours for 24 hours to calculate Mike without development. The lowest concentration, MBC, has no bacterial colonies, indicating bactericidal effect.

Controls and Standards:

Commercial antibiotics ampicillin and ciprofloxacin were employed as positive controls to compare antimicrobial activity. Solvent effects were ruled out with sterile distilled water and 70% ethanol as negative controls.

Antimicrobial Activity: Zone of Inhibition

The antimicrobial potentials of the screened plant extracts and reference antibiotics were determined by examining the zones of inhibition (ZOI) against Escherichia coli, Staphylococcus aureus, and Pseudomonas aeruginosa. The yield of extracts is different on the basis of extraction solvents, with a yield between 5.2 and 8.0 grams from the ingredients to 50 grams of ethanol extracts, while aquatic extracts are given between 3.8 and 5.5 grams. This high dividend in ethanol is correlated with their larger antimicrobial activity seen in the disk refund analysis, which supports the improved capacity of ethanol to extract active phytochemicals. Results are shown in Table 1.

Table 1. Comparison of antibacterial activity of medical plant extracts and standard antibiotic medicine using disk refund analysis

Sample	Extraction Method	*E. coli* (mm)	*S. aureus* (mm)	*P. aeruginosa* (mm)
Azadirachta indica	Aqueous	10.5 ± 0.5	12.3 ± 0.4	9.0 ± 0.3
	Ethanol	13.8 ± 0.6	15.7 ± 0.5	12.2 ± 0.6
Ocimum sanctum	Aqueous	14.2 ± 0.7	18.9 ± 0.6	13.0 ± 0.5
	Ethanol	18.6 ± 0.8	22.5 ± 0.7	16.3 ± 0.7
Curcuma longa	Aqueous	9.8 ± 0.4	11.5 ± 0.3	8.7 ± 0.2
	Ethanol	12.5 ± 0.5	14.0 ± 0.6	11.0 ± 0.4
Ampicillin	-	25.0 ± 1.0	28.2 ± 1.2	24.1 ± 0.9
Ciprofloxacin	-	28.5 ± 1.1	30.0 ± 1.3	27.5 ± 1.0
Negative Control	-	0	0	0

The findings reveal that ethanol extracts always yielded larger inhibition zones compared to aqueous extracts, confirming higher extraction of bioactive compounds using ethanol. Among the plants screened, Ocimum sanctum ethanol extract showed maximum antimicrobial activity alongside all the bacterial strains established with the largest zone against Staphylococcus aureus (22.5 mm).

Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC):

In addition, the MIC and MBC values also substantiated the aforementioned disc diffusion results in Table 2. Ethanol extract of Ocimum sanctum showed the lowest MIC and MBC values among plant extracts, especially against Staphylococcus aureus (MIC = 1 mg/mL, MBC = 2 mg/mL), though less effective than standard antibiotics.

Table 2. The lowest MIC and MBC values indicate the greatest potency of antimicrobial activity

Sample	Extraction Method	*E. coli* MIC (mg/mL)	*S. aureus* MIC (mg/mL)	*P. aeruginosa* MIC (mg/mL)	*E. coli* MBC (mg/mL)	*S. aureus* MBC (mg/mL)	*P. aeruginosa* MBC (mg/mL)
Azadirachta indica	Aqueous	16	8	32	32	16	64
	Ethanol	8	4	16	16	8	32
Ocimum sanctum	Aqueous	8	2	16	16	4	32
	Ethanol	4	1	8	8	2	16
Curcuma longa	Aqueous	32	16	64	64	32	128
	Ethanol	16	8	32	32	16	64
Ampicillin	-	0.25	0.12	0.5	0.5	0.25	1
Ciprofloxacin	-	0.125	0.06	0.25	0.25	0.12	0.5

Synergistic Effects

The preliminary tests combining plant extracts with antibiotics demonstrated enhanced antimicrobial activity. The combination of Ocimum sanctum ethanol extract with ciprofloxacin resulted in a 15% enhancement in zone of inhibition versus Staphylococcus aureus by ciprofloxacin alone (Figure 1).

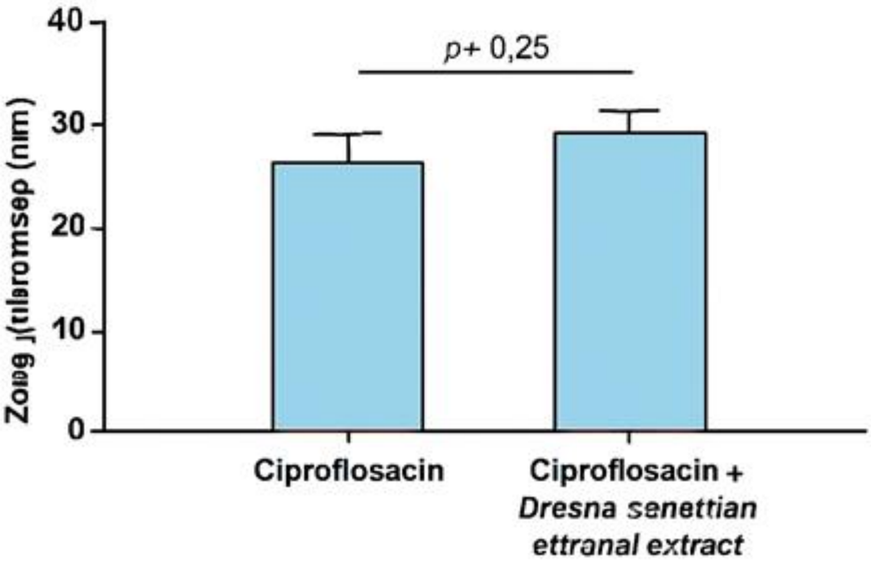

Figure 1: Bar graph of zone of inhibition (mm) of ciprofloxacin alone and ciprofloxacin with Ocimum sanctum ethanol extract against Staphylococcus aureus. Combined therapy had significantly larger zones ($p < 0.05$).

Interpretation

The results demonstrate that ethanol extracts deliver stronger antimicrobial effects than aqueous extracts, likely due to better solubility and extraction of active phytochemicals such as flavonoids and phenolics. *Ocimum sanctum* outperformed neem and turmeric extracts, particularly against Gram-positive bacteria. Although conventional antibiotics showed superior potency, plant extracts displayed promising antimicrobial activity, especially when used in combination with antibiotics. These synergistic effects suggest that plant extracts could reduce antibiotic dosages, potentially mitigating resistance development.

Discussion

The findings validate that ethanol extracts of Azadirachta indica, Ocimum sanctum, and Curcuma longa show greater antimicrobial activity compared to aqueous extracts. Phytochemical solubility profiles suggest that ethanol removes bioactive components such as flavonoids, phenol and alkaloids more with antimicrobial effects. Ocmum Sanctuary has the highest antibacterial activity against all bacterial types, especially Staphylococcus aureus. Its bioactive components, possibly eusical and ursolic acid, are anti-antimicrobial, especially against gram-positive infections.

Although conventional antibiotics (ciprofloxacin and ampicillin) were stronger and had broader antibacterial activities, the comparable activities of some of the plant extracts alongside Gram-positive bacteria and their seeming synergistic activity with antibiotics indicate complementary therapeutic promise. The synergy observed would also reduce effective antibiotic doses, which is critical in avoiding the development of antibiotic resistance—a critical global health issue.

The limitations of this research are the in vitro nature of assays that may not truly reflect in vivo conditions. In addition, the exact mechanisms of synergy and the clear identification of bioactive compounds require further biochemical and molecular research. Future research must isolate active phytochemicals, identify toxicity profiles, and conduct clinical trials to determine safety and efficacy.

Conclusion

This study affirms the potential of medicinal plant extracts, here ethanol extracts of Ocimum sanctum, as useful complementary or alternative antimicrobial remedies. Although conventional antibiotics remain the gold standard of treatment for bacterial infection, these bioactive constituents of these plants offer promising adjunctive action, most significantly against Gram-positive bacteria and in combination therapy. Utilization of these ethnobotanical resources can be expected to mitigate antibiotic resistance and expand the arsenal of antimicrobial agents. More research and development are required to apply these findings to beneficial medical uses.

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