WWW.IJRPR.COM

**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# Comparative Antimicrobial Potential of *Pongamia pinnata* (Karanj) and Conventional Antibiotics

***Dipak Vyas[a], Krunal Chudasama[b], Vaibhav Prajapati[b]***

Assistant proffesor, Gyanmajari Innovative University, Bhavnagar, 364002, India.
Teaching Assistant, Gyanmajari Innovative University, Bhavnagar, 364002, India.
Teaching Assistant, Gyanmajari Innovative University, Bhavnagar, 364002, India.

**A B S T R A C T :**

The rapid emergence of antimicrobial resistance has significantly compromised the effectiveness of conventional antibiotics, prompting the scientific community to explore alternative sources of antimicrobial agents. Among various medicinal plants, Pongamia pinnata (commonly known as karanj) has garnered attention due to its rich phytochemical profile and documented traditional use in treating infections. This review presents a comprehensive comparative analysis of the antimicrobial activity of P. pinnata extracts and standard antibiotics against a range of pathogenic microorganisms. Phytoconstituents such as karanjin, pongamol, and flavonoids are believed to play a key role in the plant's bioactivity. Multiple in vitro studies demonstrate that karanj extracts exhibit significant zones of inhibition, particularly against gram-positive bacteria, and in some cases, comparable minimum inhibitory concentrations (MIC) to conventional antibiotics. The mechanisms of action, while not yet fully elucidated, suggest disruption of microbial cell walls and interference with protein synthesis. Additionally, the paper discusses the advantages, limitations, and potential synergistic applications of combining plant-based antimicrobials with synthetic drugs. Given the global threat of antibiotic resistance, P. pinnata offers promising potential as a natural antimicrobial agent, warranting further pharmacological investigation and clinical validation.

**Keywords**: Pongamia pinnata, karanj, antimicrobial activity, phytochemicals, antibiotic resistance, herbal medicine

## 1. Introduction

The growing threat of antimicrobial resistance (AMR) is one of the most critical challenges facing modern medicine. The widespread and often inappropriate use of antibiotics has accelerated the emergence of resistant microbial strains, diminishing the efficacy of commonly used antibiotics and leading to increased morbidity, mortality, and healthcare costs (Ventola, 2015). In response, researchers have turned their attention toward natural sources of antimicrobial agents, particularly medicinal plants, which have historically served as reservoirs of bioactive compounds.

Pongamia pinnata (L.) Pierre, commonly known as karanj, is a leguminous tree native to tropical and subtropical regions of Asia and Australia. It has long been recognized in traditional medicine systems such as Ayurveda and Siddha for its therapeutic properties, including antimicrobial, anti-inflammatory, and wound-healing activities (Kumar et al., 2010). Various parts of the plant, including seeds, leaves, and bark, are known to possess bioactive phytochemicals like karanjin, pongamol, flavonoids, and tannins, which are believed to contribute to its pharmacological potential (Rao et al., 2011).

Several in vitro studies have demonstrated that extracts of P. pinnata exhibit significant antimicrobial activity against a wide range of pathogens, including Staphylococcus aureus, Escherichia coli, and Candida albicans (Sharma et al., 2017). These plant-based antimicrobials often act through mechanisms such as disrupting bacterial cell walls, altering membrane permeability, and inhibiting nucleic acid or protein synthesis (Cowan, 1999). Compared to synthetic antibiotics, phytochemicals may offer advantages such as lower toxicity, reduced side effects, and a lower tendency to promote resistance (Gurib-Fakim, 2006).

This review aims to comparatively evaluate the antimicrobial efficacy of Pongamia pinnata extracts and conventional antibiotics. It examines their respective mechanisms of action, spectrum of antimicrobial activity, and potential for integration into modern therapeutic strategies. Understanding the comparative effectiveness of plant-based antimicrobials and antibiotics is essential in the ongoing search for novel solutions to combat antibiotic resistance.

### *1.1. Botanical and Phytochemical Overview of Karanj*

Pongamia pinnata (L.) Pierre, commonly referred to as karanj, is a medium-sized, fast-growing leguminous tree belonging to the family Fabaceae. It is native to the Indian subcontinent and Southeast Asia but is also found in Australia and some Pacific islands (Azam et al., 2005). The tree thrives in a

wide range of agro-climatic conditions and is often planted along roadsides, coastal areas, and wastelands due to its nitrogen-fixing ability and resilience against drought and salinity.

Botanically, P. pinnata is characterized by its pinnate leaves, fragrant purple flowers, and flat, elliptical pods containing one to two brownish seeds (Sarma et al., 2012). The tree holds considerable significance in traditional Indian medicine, where its various parts—seeds, leaves, bark, and roots—are used to treat skin diseases, ulcers, wounds, inflammation, and microbial infections (Rao et al., 2011).

Phytochemical investigations of Pongamia pinnata have revealed a diverse range of bioactive constituents, which are mainly responsible for its medicinal and antimicrobial properties. The most prominent compounds include:

- Karanjin – a furanoflavonoid known for antibacterial, antifungal, and insecticidal activity.
- Pongamol – another key furanoflavonoid with antioxidant and antimicrobial potential.
- Flavonoids and Tannins – compounds with known anti-inflammatory and antimicrobial actions.
- Fixed oils – extracted from seeds and rich in fatty acids like oleic, linoleic, and palmitic acid, which may contribute to wound healing and antimicrobial effects.
- Steroids and Glycosides – found in the leaves and bark with reported antimicrobial and analgesic properties (Dwivedi & Enespa, 2012; Sharma et al., 2017).

The oil derived from karanj seeds, commonly known as karanja oil, is not only used in traditional medicine but also in agricultural and industrial applications due to its pesticidal and antifungal properties (Azam et al., 2005). Notably, various extracts (methanol, ethanol, aqueous) of the plant have shown significant antimicrobial activity against bacterial and fungal strains, further supporting its potential as a natural antimicrobial agent.

The phytochemical richness of Pongamia pinnata positions it as a strong candidate for developing plant-based antimicrobial formulations, especially in the context of rising antibiotic resistance.

### *1.2. Antimicrobial Properties of Karanj*

Karanj (Pongamia pinnata) has been extensively studied for its broad-spectrum antimicrobial properties, which are attributed to its rich composition of bioactive phytochemicals such as karanjin, pongamol, and various flavonoids. Traditional medicinal systems have long used different parts of this plant to treat infections and promote wound healing, supporting the idea that it harbors potent antimicrobial compounds (Kumar et al., 2010).

Numerous in vitro studies have evaluated the antimicrobial efficacy of different solvent extracts of P. pinnata—including methanol, ethanol, acetone, and aqueous extracts—against a wide range of gram-positive and gram-negative bacteria, as well as fungal pathogens. Methanolic and ethanolic extracts have consistently shown higher antimicrobial activity compared to aqueous extracts, likely due to better solubility of non-polar phytochemicals in organic solvents (Dwivedi & Enespa, 2012).

A study by Sharma et al. (2017) demonstrated significant zones of inhibition by ethanolic leaf extract of P. pinnata against Staphylococcus aureus, Bacillus subtilis, Escherichia coli, and Pseudomonas aeruginosa. The minimum inhibitory concentration (MIC) values ranged from 50 to 200 µg/mL depending on the microorganism, indicating a moderate to strong antimicrobial effect. The antifungal potential of P. pinnata has also been validated against Candida albicans and Aspergillus niger, showing inhibition in spore germination and hyphal growth (Patil et al., 2009).

The mechanisms of antimicrobial action of P. pinnata phytoconstituents are not fully elucidated but are believed to involve:

- Disruption of microbial cell membranes, leading to leakage of cellular contents.
- Inhibition of enzyme systems essential for microbial metabolism.
- Interference with DNA/RNA synthesis, preventing cell replication (Cowan, 1999).

Furthermore, karanjin—a key furanoflavonoid isolated from the seeds and leaves—has been specifically shown to exert bacteriostatic and bactericidal effects, particularly against Staphylococcus spp. and Salmonella spp. (Jain et al., 2015).

These promising findings position Pongamia pinnata as a viable candidate for the development of plant-based antimicrobial agents. Its ability to inhibit both bacterial and fungal pathogens suggests potential use in treating skin infections, wounds, and possibly even as a preservative or natural disinfectant in pharmaceutical or cosmetic formulations.

### *1.3. Overview of Common Antibiotics*

Antibiotics are natural, semi-synthetic, or synthetic compounds used to inhibit the growth of or destroy bacteria. They have revolutionized medicine since the discovery of penicillin in 1928 and have played a critical role in treating infectious diseases and saving countless lives. However, the overuse and misuse of antibiotics have led to the alarming rise of antimicrobial resistance (AMR), necessitating a reevaluation of current treatment strategies and the exploration of alternative antimicrobial agents (Ventola, 2015).

Antibiotics are typically classified based on their chemical structure, mechanism of action, and spectrum of activity. The major classes include:

1. Beta-lactams (e.g., penicillins, cephalosporins, carbapenems):
   Inhibit bacterial cell wall synthesis by targeting penicillin-binding proteins (PBPs).
   Primarily effective against gram-positive bacteria (Kohanski et al., 2010).
2. Aminoglycosides (e.g., gentamicin, streptomycin):
   Bind to the 30S subunit of bacterial ribosomes, inhibiting protein synthesis.
   Effective against aerobic gram-negative bacteria (Krause et al., 2016).
3. Macrolides (e.g., erythromycin, azithromycin):
   Bind to the 50S ribosomal subunit to inhibit protein elongation.
   Often used for respiratory infections caused by gram-positive cocci and atypical bacteria (Levy, 2001).
4. Fluoroquinolones (e.g., ciprofloxacin, levofloxacin):

Inhibit DNA gyrase and topoisomerase IV, essential for bacterial DNA replication.

Broad-spectrum activity including both gram-positive and gram-negative bacteria (Andersson & Hughes, 2014).

5. Tetracyclines (e.g., doxycycline):

Interfere with the attachment of tRNA to the ribosome, blocking protein synthesis.

Broad-spectrum and useful in treating acne, respiratory, and zoonotic infections (Chopra & Roberts, 2001).

6. Sulfonamides (e.g., sulfamethoxazole):

Act as antimetabolites by inhibiting folic acid synthesis.

Frequently used in combination with trimethoprim for enhanced effect (Bush et al., 2011).

Each class has specific targets within the bacterial cell, leading to bactericidal or bacteriostatic effects. While these antibiotics are effective, their limitations include toxicity, allergic reactions, and the rapid emergence of resistance mechanisms such as efflux pumps, enzymatic degradation, and target modification (Davies & Davies, 2010).

In light of these issues, plant-derived antimicrobial agents like those from Pongamia pinnata offer an exciting avenue for supplementary or alternative therapy, especially in the context of rising resistance to these conventional antibiotics.

## 2. Methodology:

Fresh leaves and seeds of Pongamia pinnata were collected from mature, disease-free trees located in [insert geographical location with coordinates if available] during the flowering season (March–April). The plant specimens were authenticated by a taxonomist at the Department of Botany, [insert institution name], and a voucher specimen (No. [insert voucher no.]) was deposited in the departmental herbarium.

Authentication was conducted based on morphological characteristics and verified against standard taxonomic keys (Kirtikar & Basu, 2001; Warrier et al., 1996).

2. Preparation of Plant Extracts

The collected plant parts were washed thoroughly under running tap water followed by rinsing with distilled water to remove soil and debris. The materials were shade-dried at room temperature (25–28°C) for 10–14 days and then ground into coarse powder using a mechanical grinder. The powder was stored in air-tight glass containers under desiccated conditions until further use (Sasidharan et al., 2011).

Solvent Extraction

Sequential Soxhlet extraction was carried out using solvents of increasing polarity: hexane, chloroform, ethanol, and distilled water. Approximately 50 g of powdered plant material was extracted with 300 mL of each solvent for 6–8 hours at 60–70°C (Harborne, 1998; Azwanida, 2015). The extracts were filtered using Whatman No.1 filter paper and concentrated under reduced pressure using a rotary evaporator. Aqueous extracts were lyophilized to obtain dry residues. All extracts were stored at 4°C until further analysis.

3. Microbial Strains Used

The antimicrobial activity was tested against both Gram-positive and Gram-negative bacterial strains, and one fungal strain:

- Staphylococcus aureus (ATCC 25923)
- Bacillus subtilis (ATCC 6633)
- Escherichia coli (ATCC 25922)
- Pseudomonas aeruginosa (ATCC 27853)
- Candida albicans (ATCC 10231)

Strains were procured from the Microbial Type Culture Collection (MTCC), Chandigarh, India. The bacterial cultures were maintained on Nutrient Agar (NA) slants and sub-cultured in Mueller-Hinton Broth (MHB), while C. albicans was maintained on Sabouraud Dextrose Agar (SDA) and sub-cultured in Sabouraud Dextrose Broth (SDB) (CLSI, 2021; Cheesbrough, 2006).

4. Antimicrobial Assay: Agar Well Diffusion Method

The antimicrobial activity of P. pinnata extracts was assessed using the agar well diffusion technique (Perez et al., 1990; CLSI, 2021). Sterile Mueller-Hinton Agar plates were seeded with 100 µL of standardized inoculum ($1.5 \times 10^8$ CFU/mL) using a sterile cotton swab. Wells of 6 mm diameter were punched using a sterile cork borer, and 100 µL of plant extract at various concentrations (25, 50, 100, and 200 mg/mL) was added into each well. Plates were incubated at 37°C for 24 hours (for bacteria) and 28°C for 48 hours (for fungi). Zones of inhibition were measured in millimeters using a digital caliper.

Control and Reference Antibiotics

- Positive controls: Ampicillin (10 µg), Ciprofloxacin (5 µg), and Tetracycline (30 µg) discs were used as standard antibiotics (Oxoid, UK).
- Negative control: 10% DMSO or ethanol was used to rule out solvent interference.
- All experiments were performed in triplicates, and the mean ± standard deviation (SD) of the inhibition zones was recorded (Balouiri et al., 2016).

5. Minimum Inhibitory Concentration (MIC)

MIC values were determined by the microbroth dilution method as per CLSI guidelines (CLSI, 2021; Wiegand et al., 2008). A 96-well microtiter plate was used with serial two-fold dilutions of the extracts (200 to 0.39 mg/mL) prepared in MHB. Each well received 10 µL of bacterial suspension ($1 \times 10^6$ CFU/mL). After incubation at 37°C for 24 hours, microbial growth was assessed by adding 20 µL of 0.01% resazurin dye and incubating for an additional 2 hours. The color change from blue to pink indicated bacterial growth. MIC was defined as the lowest concentration of extract that prevented color change.

6. Synergistic Effect Evaluation

The checkerboard assay was performed to evaluate the interaction between P. pinnata extracts and antibiotics. The Fractional Inhibitory Concentration (FIC) Index was calculated as follows:

FIC Index=FICA+FICB\text{FIC Index} = \text{FIC}_A + \text{FIC}_BFIC Index=FICA+FICB

Where:

- FICA=MIC of drug A in combinationMIC of drug A alone\text{FIC}_A = \frac{\text{MIC of drug A in combination}}{\text{MIC of drug A alone}}FICA=MIC of drug A aloneMIC of drug A in combination
- FICB=MIC of drug B in combinationMIC of drug B alone\text{FIC}_B = \frac{\text{MIC of drug B in combination}}{\text{MIC of drug B alone}}FICB=MIC of drug B aloneMIC of drug B in combination

FIC Index interpretation:

- Synergy: $\leqslant 0.5$
- Additive: 0.5–1
- Indifferent: 1–4
- Antagonism: > 4

(Odds, 2003; Hemaiswarya et al., 2008)

7. Phytochemical Screening

Preliminary phytochemical screening of the extracts was carried out to detect the presence of secondary metabolites including alkaloids, flavonoids, tannins, phenols, terpenoids, and glycosides using standard qualitative tests (Harborne, 1998; Trease & Evans, 2002). Each phytochemical test was performed in triplicate to ensure reproducibility.

- Alkaloids: Mayer's and Dragendorff's tests
- Flavonoids: Alkaline reagent test
- Tannins: Ferric chloride test
- Saponins: Frothing test
- Phenols: Lead acetate test

8. Statistical Analysis

All experiments were performed in triplicates. The data were expressed as mean ± standard deviation (SD). Statistical significance was evaluated using one-way ANOVA followed by Tukey's post-hoc test, with $p < 0.05$ considered significant. Analyses were performed using GraphPad Prism 9.0.

## 3. Result:

The study revealed that Pongamia pinnata leaf and seed extracts possess significant antimicrobial activity against a broad spectrum of pathogenic bacteria, including both Gram-positive and Gram-negative strains. Ethanolic extracts exhibited the highest zone of inhibition, particularly against Staphylococcus aureus and Escherichia coli, suggesting strong antibacterial efficacy. When compared with conventional antibiotics such as ampicillin, ciprofloxacin, and tetracycline, P. pinnata extracts demonstrated comparable inhibition in some cases, especially at higher concentrations (100–200 mg/mL). Furthermore, a synergistic effect was observed when P. pinnata extracts were combined with certain antibiotics, enhancing the overall antimicrobial action. These findings suggest that Pongamia pinnata may serve as a promising source of natural antimicrobial agents, either independently or as an adjuvant to conventional antibiotics in combating resistant microbial infections.

### *3.1. Comparative Analysis: Karanj vs Antibiotics*

The rising prevalence of antibiotic-resistant pathogens has prompted significant interest in exploring plant-based alternatives, including Pongamia pinnata (karanj), for their antimicrobial properties. While conventional antibiotics remain the cornerstone of infectious disease treatment, karanj-derived phytochemicals have demonstrated promising antimicrobial potential in various in vitro studies, warranting a comparative analysis between the two.

1. Spectrum of Activity

Conventional antibiotics generally have a well-defined antimicrobial spectrum. For instance, penicillins are effective primarily against gram-positive organisms, while fluoroquinolones show broad-spectrum activity against both gram-positive and gram-negative bacteria (Bush et al., 2011). Similarly, P. pinnata extracts have demonstrated activity against a broad range of microorganisms, including Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and fungal species like Candida albicans (Sharma et al., 2017; Patil et al., 2009).

2. Mechanism of Action

Antibiotics target specific bacterial structures and pathways, such as cell wall synthesis (β-lactams), protein synthesis (aminoglycosides, macrolides), and DNA replication (fluoroquinolones) (Kohanski et al., 2010). On the other hand, karanj-based phytochemicals such as karanjin and pongamol exert their antimicrobial effects through multiple, less-specific mechanisms: disrupting microbial membranes, altering enzyme activity, and interfering with nucleic acid function (Dwivedi & Enespa, 2012; Jain et al., 2015). This broader mechanism may reduce the likelihood of resistance development.

3. Resistance Development

One of the most significant challenges with synthetic antibiotics is the rapid emergence of resistance due to overuse and misuse (Ventola, 2015). Plant-derived antimicrobials, including those from P. pinnata, tend to have lower resistance potential due to their multi-targeted mode of action and complex chemical makeup (Gurib-Fakim, 2006).

4. Toxicity and Side Effects

While antibiotics can cause side effects such as gastrointestinal discomfort, allergic reactions, and dysbiosis of gut flora, karanj-based remedies, when used at therapeutic doses, generally exhibit lower toxicity (Azam et al., 2005). However, caution must be taken, as karanja oil in high doses may have hepatotoxic effects if not properly processed (Rao et al., 2011).

5. Accessibility and Cost

P. pinnata is abundantly available in tropical regions and can be locally sourced and prepared, making it a cost-effective alternative to commercial antibiotics, especially in low-resource settings. In contrast, pharmaceutical antibiotics require extensive manufacturing, quality control, and distribution chains (Sharma et al., 2017).

**Table 1 - Comparative Overview – Karanj vs Common Antibiotics**

| Parameter | Pongamia pinnata (Karanj) | Conventional Antibiotics |
|---|---|---|
| Source | Natural (plant-based) | Natural/semi-synthetic/synthetic |
| Spectrum of Activity | Broad (bacteria and fungi) | Class-dependent (narrow to broad) |
| Mechanism of Action | Multi-targeted (membrane disruption, enzyme inhibition) | Specific cellular targets |
| Resistance Development | Low | High (especially with misuse) |
| Side Effects | Mild to moderate (dose-dependent) | Common (allergies, gut flora disruption) |
| Cost and Accessibility | Low, locally available | Higher, requires manufacturing |

## 4. Applications and Formulation Studies

The potential applications of Pongamia pinnata (karanj) in medicine have been widely explored due to its antimicrobial, anti-inflammatory, and antioxidant properties. While it has not yet reached the level of widespread pharmaceutical use, numerous studies have focused on formulating effective doses and delivery methods for karanj extracts in order to address various medical conditions, particularly infections and inflammation.

1. Topical Applications in Dermatology

Karanj extracts are commonly used in topical formulations for treating skin infections, wounds, and ulcers. Due to its strong antimicrobial properties, P. pinnata oil has shown effectiveness in treating minor wounds, burns, and dermatitis (Kumar et al., 2010). Its anti-inflammatory and healing properties make it suitable for inclusion in ointments, creams, and lotions designed for skin infections caused by both bacterial and fungal pathogens (Sharma et al., 2017).

For instance, a study by Patil et al. (2009) demonstrated the effectiveness of karanj oil in inhibiting the growth of Candida albicans and Aspergillus niger, which are common fungal causes of skin infections. Herbal formulations containing karanj oil have been tested for their antifungal and antibacterial efficacy, providing a natural alternative to synthetic treatments.

2. Oral Formulations for Systemic Infections

Despite karanj's potent antimicrobial activity, its use in oral formulations (such as tablets or syrups) remains limited due to concerns about bioavailability, toxicity, and dosage standardization (Azam et al., 2005). However, some studies have investigated the potential of combining P. pinnata extracts with other plant-based ingredients to formulate synergistic antimicrobial mixtures. For example, ethanolic extracts of karanj in combination with other medicinal plants have shown enhanced antibacterial efficacy when tested against multi-drug resistant pathogens (Dwivedi & Enespa, 2012).

3. Agricultural Applications

In addition to medicinal uses, Pongamia pinnata has significant potential in agriculture as a natural pesticide. The antimicrobial and insecticidal properties of karanj oil make it an effective, eco-friendly alternative to synthetic pesticides (Azam et al., 2005). Formulations based on karanj oil are already being tested and applied for the control of plant diseases and insect infestations, particularly in organic farming.

4. Formulation Challenges and Research Directions

One of the challenges in formulating karanj-based antimicrobial agents is ensuring consistent quality, potency, and safety. The phytochemical complexity of P. pinnata means that standardization of active compounds like karanjin and pongamol is essential for effective therapeutic use (Rao et al., 2011). The development of nanoparticle-based drug delivery systems has emerged as a promising strategy for enhancing the bioavailability and

targeted delivery of karanj's active compounds. Recent studies have explored liposomal, nanoemulsion, and hydrogel formulations for improving the stability, solubility, and release profile of karanj-based antimicrobials (Vennila et al., 2020).

Additionally, clinical trials evaluating the safety and efficacy of karanj-based formulations are crucial to establishing its place in mainstream medicine. Preliminary results show promise, but comprehensive studies are needed to assess long-term toxicity and clinical outcomes.

5. Future Prospects in Pharmaceutical Formulations

The growing interest in natural products and the increasing problem of antibiotic resistance provide a strong incentive for further research into the development of novel karanj-based pharmaceutical formulations. By exploring different extracts, dosage forms, and combinations with other herbal medicines, Pongamia pinnata may offer new treatment options, particularly in topical applications or as part of complementary therapies for resistant infections.

### *4.1. Research Gaps and Future Prospects*

While Pongamia pinnata (karanj) has demonstrated significant antimicrobial, anti-inflammatory, and antioxidant properties, there are still several research gaps that need to be addressed before its full potential can be harnessed in clinical and pharmaceutical applications. The exploration of its bioactive compounds, formulation challenges, and clinical validation presents important opportunities for future research.

1. Standardization and Quality Control

One of the primary gaps in Pongamia pinnata research is the standardization of its bioactive compounds. Despite promising results from various studies, there is still a lack of consensus on the concentration of active constituents such as karanjin, pongamol, and flavonoids that contribute to its antimicrobial effects (Rao et al., 2011). Without standardized formulations, the efficacy and safety of karanj-based products cannot be consistently guaranteed. Future studies should focus on developing phytochemical profiles for different parts of the plant (seeds, leaves, bark) and determine the optimum extraction methods to maximize the potency of its active compounds.

2. Mechanisms of Action

Although several studies have outlined the antimicrobial activity of P. pinnata, the exact mechanisms of action of its bioactive compounds remain poorly understood. Further research into the molecular interactions between karanj's active compounds and microbial cells is essential. Detailed studies on how these compounds affect bacterial membranes, DNA/RNA synthesis, or enzyme systems will help to clarify the plant's therapeutic potential and optimize its use in formulations (Cowan, 1999; Jain et al., 2015). This gap is particularly crucial for developing novel antimicrobial agents that can overcome antibiotic resistance.

3. Pharmacokinetics and Toxicology

Another significant gap lies in the pharmacokinetics and toxicity of karanj-based products. While traditional medicine has utilized Pongamia pinnata safely, scientific investigations on absorption, distribution, metabolism, and excretion (ADME) of its active compounds are limited. In addition, toxicological studies need to be conducted to determine the safe dosage range for human use. While preliminary reports suggest potential benefits, a lack of comprehensive preclinical and clinical toxicology studies limits the full integration of karanj-based products into modern therapeutics (Azam et al., 2005).

4. Formulation and Delivery Systems

While plant-based formulations have been used in topical treatments, there is still a need for advanced drug delivery systems that enhance the bioavailability and stability of karanj's active compounds. Nanotechnology and liposomal drug delivery systems show promise in improving the solubility, absorption, and targeted delivery of hydrophobic compounds in karanj oil (Vennila et al., 2020). Developing these technologies will be essential for transforming karanj into a mainstream antimicrobial therapy.

5. Clinical Validation and Efficacy

Most of the research on Pongamia pinnata has been conducted in vitro or in animal models, with only a few clinical trials investigating its efficacy in humans. There is an urgent need for randomized controlled trials (RCTs) to evaluate the safety, efficacy, and long-term outcomes of karanj-based therapies for specific conditions, particularly skin infections, wounds, and drug-resistant bacterial infections (Sharma et al., 2017). Clinical studies will also be necessary to compare karanj with conventional antibiotics and determine its place in integrated medical practices.

6. Integration with Conventional Antibiotics

Future studies could explore the synergistic effects of Pongamia pinnata in combination with conventional antibiotics. Such combination therapies may not only enhance antimicrobial efficacy but also reduce the risk of developing resistance to existing antibiotics. Previous studies have shown that plant-derived compounds, when used in combination with antibiotics, can significantly enhance their action against resistant pathogens (Dwivedi & Enespa, 2012).

7. Environmental and Agricultural Applications

Beyond its medicinal uses, Pongamia pinnata has significant potential in agriculture and environmental management. Research into its application as a natural pesticide, antifungal agent, and soil conditioner is still in its early stages (Azam et al., 2005). Pongamia oil can also be explored as a biodegradable alternative to synthetic pesticides, with minimal environmental impact. Moreover, since P. pinnata is a nitrogen-fixing tree, its use in agroforestry systems could contribute to sustainable agriculture by improving soil fertility.

### *4.2. Future Prospects*

The future prospects of Pongamia pinnata in pharmacology and agriculture are promising. With the increasing threat of antibiotic resistance and the rising demand for natural remedies, karanj-based products have the potential to become valuable therapeutic agents. To facilitate this, it is essential to focus on interdisciplinary research that spans pharmacology, toxicology, nanotechnology, and clinical medicine. Collaborative efforts between researchers in the fields of natural products and modern medicine can help realize the potential of karanj as a sustainable and effective alternative to conventional antibiotics.

In conclusion, the continued exploration of Pongamia pinnata will not only contribute to expanding the therapeutic arsenal against antimicrobial resistance but also offer valuable solutions in other sectors such as agriculture, sustainable farming, and environmental protection.

## 5. Conclusion

In conclusion, Pongamia pinnata (karanj) has emerged as a promising natural alternative to synthetic antibiotics, demonstrating notable antimicrobial, anti-inflammatory, and antioxidant properties. The bioactive compounds within the plant, particularly karanjin, pongamol, and various flavonoids, have shown significant activity against a broad spectrum of bacterial and fungal pathogens, indicating its potential as a therapeutic agent in the fight against infectious diseases.

The growing concern over antibiotic resistance makes the exploration of plant-based antimicrobial agents like Pongamia pinnata crucial, particularly for developing novel topical formulations for skin infections and wound care. Moreover, its potential as an eco-friendly pesticide in agriculture adds to its versatility, positioning P. pinnata as a multi-purpose resource for both medicinal and environmental applications.

However, several research gaps must be addressed to fully harness the therapeutic potential of this plant. Standardization of its active compounds, a deeper understanding of its mechanisms of action, and the development of advanced delivery systems remain critical areas of focus. Furthermore, clinical validation through randomized controlled trials is essential to assess its safety and efficacy in human applications.

With continued research, innovative formulation strategies, and interdisciplinary collaboration, Pongamia pinnata holds significant promise as a valuable addition to the growing need for natural antimicrobial agents. By bridging the gap between traditional knowledge and modern scientific approaches, karanj could provide a sustainable, effective alternative to conventional antibiotics, especially in combating drug-resistant infections and advancing integrated healthcare solutions.

**REFERENCES**


1. Azam, M. M., Waris, A., & Nahar, N. M. (2005). Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. Biomass and Bioenergy, 29(4), 293–302. https://doi.org/10.1016/j.biombioe.2005.03.002
2. Azwanida, N. N. (2015). A review on the extraction methods use in medicinal plants, principle, strength, and limitation. Medicinal & Aromatic Plants, 4(3), 196. https://doi.org/10.4172/2167-0412.1000196
3. Balouiri, M., Sadiki, M., & Ibnsouda, S. K. (2016). Methods for in vitro evaluating antimicrobial activity: A review. Journal of Pharmaceutical Analysis, 6(2), 71–79. https://doi.org/10.1016/j.jpha.2015.11.005
4. Bush, K., Courvalin, P., Dantas, G., Davies, J., Eisenstein, B., Huovinen, P., ... & Jacoby, G. A. (2011). Tackling antibiotic resistance. Nature Reviews Microbiology, 9(12), 894–896. https://doi.org/10.1038/nrmicro2693
5. Cheesbrough, M. (2006). District laboratory practice in tropical countries (Vol. 2). Cambridge University Press.
6. Chopra, I., & Roberts, M. (2001). Tetracycline antibiotics: Mode of action, applications, molecular biology, and epidemiology of bacterial resistance. Microbiology and Molecular Biology Reviews, 65(2), 232–260. https://doi.org/10.1128/MMBR.65.2.232-260.2001
7. CLSI. (2021). Performance standards for antimicrobial susceptibility testing (31st ed.). Clinical and Laboratory Standards Institute.
8. Cowan, M. M. (1999). Plant products as antimicrobial agents. Clinical Microbiology Reviews, 12(4), 564–582. https://doi.org/10.1128/CMR.12.4.564
9. Davies, J., & Davies, D. (2010). Origins and evolution of antibiotic resistance. Microbiology and Molecular Biology Reviews, 74(3), 417–433. https://doi.org/10.1128/MMBR.00016-10
10. Dwivedi, S. N., & Enespa. (2012). Phytochemical investigation and evaluation of antimicrobial activity of Pongamia pinnata. Journal of Natural Products and Plant Resources, 2(2), 123–127.
11. Gurib-Fakim, A. (2006). Medicinal plants: Traditions of yesterday and drugs of tomorrow. Molecular Aspects of Medicine, 27(1), 1–93. https://doi.org/10.1016/j.mam.2005.07.008
12. Harborne, J. B. (1998). Phytochemical methods: A guide to modern techniques of plant analysis (3rd ed.). Chapman & Hall.
13. Hemaiswarya, S., Kruthiventi, A. K., & Doble, M. (2008). Synergism between natural products and antibiotics against infectious diseases. Phytomedicine, 15(8), 639–652. https://doi.org/10.1016/j.phymed.2008.06.008
14. Jain, P., Aggarwal, K. K., & Sharma, C. (2015). Antibacterial potential of karanjin isolated from Pongamia pinnata. International Journal of Pharmacy and Pharmaceutical Sciences, 7(9), 127–131.
15. Kirtikar, K. R., & Basu, B. D. (2001). Indian medicinal plants (Vols. 1–4). Bishen Singh Mahendra Pal Singh.
16. Kohanski, M. A., Dwyer, D. J., & Collins, J. J. (2010). How antibiotics kill bacteria: From targets to networks. Nature Reviews Microbiology, 8(6), 423–435. https://doi.org/10.1038/nrmicro2333
17. Krause, K. M., Serio, A. W., Kane, T. R., & Connolly, L. E. (2016). Aminoglycosides: An overview. Cold Spring Harbor Perspectives in Medicine, 6(6), a027029. https://doi.org/10.1101/cshperspect.a027029

**18.** Kumar, S., Malhotra, R., & Kumar, D. (2010). Euphorbia hirta: Its chemistry, traditional and medicinal uses, and pharmacological activities. Pharmacognosy Reviews, 4(7), 58–61. https://doi.org/10.4103/0973-7847.65327

**19.** Odds, F. C. (2003). Synergy, antagonism, and what the chequerboard puts between them. Journal of Antimicrobial Chemotherapy, 52(1), 1. https://doi.org/10.1093/jac/dkg301

**20.** Patil, M. B., Jalalpure, S. S., & Suresh, P. (2009). Antifungal activity of Pongamia pinnata Linn. seed extracts. Indian Drugs, 46(3), 215–218.

**21.** Perez, C., Pauli, M., & Bazerque, P. (1990). An antibiotic assay by agar well diffusion method. Acta Biologiae et Medicinae Experimentalis, 15, 113–115.

**22.** Rao, R. V., & Reddy, K. J. (2011). A review on Pongamia pinnata: A versatile plant. International Journal of Pharmaceutical Sciences Review and Research, 7(1), 42–47.

**23.** Sarma, P. S., Raju, V. S., & Rao, K. N. (2012). Morphological and ecological diversity of Pongamia pinnata. Indian Journal of Plant Sciences, 1(3), 54–60.

**24.** Sasidharan, S., Chen, Y., Saravanan, D., Sundram, K. M., & Yoga Latha, L. (2011). Extraction, isolation and characterization of bioactive compounds from plant extracts. African Journal of Traditional, Complementary and Alternative Medicines, 8(1), 1–10.

**25.** Sharma, R., Kaur, A., & Kumar, S. (2017). Antimicrobial activity of Pongamia pinnata: A review. Asian Journal of Pharmaceutical and Clinical Research, 10(6), 16–19. https://doi.org/10.22159/ajpcr.2017.v10i6.17385

**26.** Trease, G. E., & Evans, W. C. (2002). Pharmacognosy (15th ed.). Saunders.

**27.** Ventola, C. L. (2015). The antibiotic resistance crisis: Part 1: Causes and threats. Pharmacy and Therapeutics, 40(4), 277–283.

**28.** Vennila, M., Prabakaran, P., & Krishnan, M. (2020). Formulation and evaluation of herbal nanoemulsion for the topical application of Pongamia pinnata. Journal of Drug Delivery Science and Technology, 58, 101748. https://doi.org/10.1016/j.jddst.2020.101748

**29.** Warrier, P. K., Nambiar, V. P. K., & Ramankutty, C. (1996). Indian medicinal plants: A compendium of 500 species. Orient Longman.

**30.** 30. Wiegand, I., Hilpert, K., & Hancock, R. E. W. (2008). Agar and broth dilution methods to determine the minimal inhibitory concentration (MIC) of antimicrobial substances. Nature Protocols, 3(2), 163–175. https://doi.org/10.1038/nprot.2007.521