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Phytochemical Profile and Pharmacological Mechanisms of *Pandanus tectorius* Fruit: A Comprehensive Review

Profil Fitokimia dan Mekanisme Farmakologis Buah *Pandanus tectorius*: Suatu Tinjauan Komprehensif

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ABSTRACT

The fruit of *Pandanus tectorius*, commonly known as screw pine or sea pandan, contains various secondary metabolites with significant therapeutic potential but remains underutilized in clinical applications. This review summarizes findings from 2014 to 2025 regarding its phytochemical composition and pharmacological effects. Sixteen bioactive compounds have been identified, including pandanusin A, bergapten, scoparone, scopoletin, several lignans, isoamericanin A, kaempferol, chrysin, phenolic acids, betulinic acid, and β-sitosterol. These constituents demonstrate antioxidant, anti-inflammatory, analgesic, antidiabetic, antimicrobial, and anticancer activities. Mechanistic actions include inhibition of alpha-glucosidase, reduction of oxidative stress, and induction of cytotoxicity in cancer cells. The ethyl acetate fraction, in particular, exhibits strong activity against HeLa cells. Novel delivery systems, such as nanoemulsions, are being explored to enhance solubility and bioavailability. Additionally, preclinical studies suggest roles in immune modulation, wound healing, and pain relief. Although promising, further clinical validation and formulation standardization are needed. This review highlights the potential of *P. tectorius* fruit as a candidate for evidence-based phytotherapeutic development.

Kata kunci:
Aktivitas farmakologis
Analgesik
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Pandanus tectorius
Sistem penghantaran obat

ABSTRAK

Buah dari *Pandanus tectorius*, yang dikenal sebagai pandan laut atau screw pine, mengandung berbagai metabolit sekunder dengan potensi terapeutik yang signifikan, namun masih kurang dimanfaatkan dalam praktik klinis. Artikel ini merangkum temuan penelitian antara tahun 2014 hingga 2025 mengenai komposisi fitokimia dan aktivitas farmakologis buah ini. Telah diidentifikasi enam belas senyawa bioaktif, termasuk pandanusin A, bergapten, scoparone, scopoletin, beberapa lignan, isoamericanin A, kaempferol, chrysin, asam fenolat, asam betulinat, dan β-sitosterol. Senyawa-senyawa ini menunjukkan aktivitas antioksidan, antiinflamasi, analgesik, antidiabetik, antimikroba, dan antikanker. Mekanisme kerjanya meliputi penghambatan enzim alfa-glukosidase, penurunan stres oksidatif, dan induksi sitotoksisitas pada sel kanker. Fraksi etil asetat secara khusus menunjukkan aktivitas kuat terhadap sel HeLa. Sistem penghantaran baru seperti nanoemulsi tengah dieksplorasi untuk meningkatkan kelarutan dan bioavailabilitas. Studi praklinis juga menunjukkan peran dalam modulasi imun, penyembuhan luka, dan pereda nyeri. Meskipun menjanjikan, dibutuhkan validasi klinis dan standarisasi formulasi lebih lanjut. Artikel ini menyoroti potensi buah *P. tectorius* sebagai kandidat pengembangan fitoterapi berbasis bukti ilmiah.

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1. INTRODUCTION

Indonesia is globally recognized for its remarkable biodiversity, particularly its rich diversity of medicinal plants that have been used traditionally across various regions. Among these is *Pandanus tectorius*, commonly referred to as screw pine or pandan laut, a coastal plant with longstanding ethnomedicinal significance, especially in communities residing in littoral zones. Traditionally, various parts of the plant—particularly the fruit—have been employed to address digestive issues, inflammatory conditions, and to promote wound healing. Ethnobotanical studies reinforce the therapeutic promise of this species (Rustamsyah et al., 2022).

P. tectorius is widely distributed along tropical and subtropical coastal regions of Southeast Asia, including Indonesia, Malaysia, and the Philippines (Oksal et al., 2020). In Indian traditional medicine, it has been used to treat a range of conditions, including metabolic, hepatic, dermatological, neurological, and urinary disorders. In Indonesia, coastal communities often rely on the fruit of *P. tectorius* to alleviate gastrointestinal discomfort, reduce inflammation, and manage hypertension (Setiani & Herlina, 2025).

Phytochemical investigations have revealed that *P. tectorius* contains a broad spectrum of bioactive compounds, including phenolic acids, flavonoids, triterpenoids, steroids, saponins, glycosides and volatile constituents such as eugenol, camphor, germacrene B, and linalool (Baba et al., 2016; Andriani et al., 2019). These compounds are associated with diverse pharmacological properties, including antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and anticancer effects. Specific compounds—such as tangeretin, naringenin, and caffeoylquinic acids—have demonstrated mechanisms involving alpha-glucosidase inhibition, cytokine modulation, and scavenging of reactive oxygen species.

Recent pharmacological investigations have highlighted the analgesic properties of *P. tectorius* fruit extracts. Experimental models have shown that certain fractions possess significant pain-relieving activity, likely mediated through anti-inflammatory effects and modulation of central nociceptive pathways (Sriarumtias et al., 2020). Furthermore, *P. tectorius* exhibits cardioprotective and neuroprotective effects, indicating potential applications in managing degenerative diseases such as Alzheimer's and Parkinson's (Puspasari et al., 2020; Setiani & Herlina, 2025).

In addition to its medicinal uses, the flowers of the plant have demonstrated antioxidant, antibacterial, antidiabetic, and anti-inflammatory activities (Vedu et al., 2024). Nutritionally, the fruit is rich in carbohydrates, dietary fiber, beta-carotene, and essential fatty acids, making it a candidate for functional food development (Sarungallo et al., 2018). Despite its abundance and diverse bioactivity, *P. tectorius* remains underutilized in Indonesia. In some regions, such as Gunung Kidul, its fruits are often discarded and left to waste along the coastline (Rustamsyah et al., 2022).

Given these observations, the present review aims to synthesize current scientific knowledge on the phytochemical composition and pharmacological properties of *P. tectorius* fruit. It also seeks to elucidate its mechanisms of action—particularly in relation to antioxidant, anti-inflammatory, antidiabetic, analgesic, and anticancer effects—and explore its potential as a standardized herbal or pharmaceutical product.

2. METHODS

This literature review was conducted using peer-reviewed articles published between 2014 and 2025, sourced from both national and international scientific journals. Databases utilized for the search included Google Scholar, PubMed, DOAJ (Directory of Open Access Journals), and Semantic Scholar. The search strategy involved the use of specific keywords such as "*Pandanus tectorius*," "pharmacological activity of *Pandanus tectorius*," and "medical applications of *Pandanus tectorius*." Relevant articles were selected based on their focus on the phytochemical content, pharmacological properties, therapeutic mechanisms, and preclinical or clinical evaluations of *P. tectorius* fruit. Studies that met these criteria were reviewed to compile comprehensive insights into the plant's therapeutic potential.

3. RESULTS AND DISCUSSION

3.1. Taxonomic and Morphological Studies

P. tectorius belongs to the family Pandanaceae and is taxonomically classified under the kingdom Plantae, class Monocotyledonae, and order Pandanales. Its genus is *Pandanus* and the species is *tectorius*, with common synonyms including *Pandanus odoratissimus* and *Pandanus fascicularis* Lam.

Morphologically (**Figure 1**), the fruit is a large syncarp composed of multiple wedge-shaped drupes, characterized by an angular surface and rough texture. composed of multiple wedge-shaped drupes, characterized by an angular surface and rough texture. When ripe, the fruit typically reaches a diameter of 5–8 inches and a length of 6–10 inches, transitioning from green to a deep orange color. Upon maturation, the outer segments begin to separate naturally. The fruit's exterior is firm, while the inner flesh is sticky, exhibiting a distinctive sweet-sour aroma and flavor profile (Adkar & Bhaskar, 2014). This unique morphology not only contributes to the plant's identification but also influences its use in traditional and emerging pharmacological applications.

Figure 1. Morphology of a mature fruit of *Pandanus tectorius*.

3.2. Phytochemical Composition of P.tectorius Fruit

Phytochemical studies have demonstrated that the fruit of *P. tectorius* contains a wide variety of secondary metabolites, including flavonoids, triterpenoids, phenolic compounds, saponins, and glycosides (Ningrum et al., 2023). These bioactive substances have been identified in different solvent extracts such as ethanol, methanol, ethyl acetate, and aqueous fractions. Notable compounds include tangeretin, chrysin, naringenin, vanillin, and trans-ethyl caffeate, each associated with distinct pharmacological activities. For instance, tangeretin and naringenin have been reported to exert lipid-lowering and antioxidant effects (Kurowska & Manthey, 2004; Tutunchi et al., 2020), while vanillin and trans-ethyl caffeate contribute to anti-inflammatory mechanisms (Tai et al., 2011; Kamiloglu et al., 2006). Caffeoylquinic acid derivatives, such as 3-CQA and 3,5-CQA, identified predominantly in aqueous fractions, are linked to antidiabetic activities through inhibition of alpha-glucosidase (Wu et al., 2015; Nguyen et al., 2016).

Table 1. Bioactive Compounds, Structural Classes, and Pharmacological Profiles of *Pandanus tectorius* Fruit Extracts

No	Compound Name	Metabolite Group	Extract/Fraction	Dosage/Content/IC_{50}	Pharmacological Activity	Reference
1	Naringenin	Flavonoid	Ethanol extract	~5.12 mg/g	Antioxidant, Antidiabetic, Anti-inflammatory	Raj et al., 2014
2	Tangeretin	Flavonoid	Methanol, Ethyl acetate	500 mg/kg BW	Hypolipidemic, Anti-atherosclerotic	Andriani et al., 2020; Kang & Kim, 2024
3	Chrysin	Flavonoid	Ethanol extract, Effervescent formulation	125 mg/kg BW	Analgesic, Antioxidant	Febrina et al., 2016; Sriarumtias et al., 2020
4	Trans-ethyl caffeate	Phenolic acid	Ethyl acetate fraction	IC_{50} = 14.4 μM	Antidiabetic, Antioxidant, Anti-inflammatory	Nguyen et al., 2016; Andriani et al., 2019
5	Vanillin	Aromatic aldehyde	Ethyl acetate fraction	Not specified	Anti-inflammatory, Antioxidant	Andriani et al., 2020
6	3-O-Caffeoylquinic acid (3-CQA)	Phenolic acid	Aqueous extract	2.3 mg/g BW	Antidiabetic, Antidyslipidemic	Wu et al., 2014; Andriani et al., 2019
7	3,5-Di-O-caffeoylquinic acid (3,5-CQA)	Phenolic acid	n-Butanol fraction of ethanol extract	100 mg/kg BW	Antihyperlipidemic, Lipid-lowering via PPARα and AMPK	Zhang et al., 2013
8	Pandanusin A	Glycoside	Ethyl acetate fraction	IC_{50} = 14.4–84.7 μM	Antidiabetic	Nguyen et al., 2016

The enrichment of these compounds in ethyl acetate and methanol fractions underscores their pharmacological relevance, particularly in the context of metabolic and oncological disorders. A detailed overview of the main phytochemicals, their extract types, chemical classifications, reported bioactivities, inhibitory concentration values, and supporting references is presented in **Table 1**.

3.3. Pharmacological Activities Based on Mechanism and Target Systems

Over the past decade, *P. tectorius* fruit has attracted considerable pharmacological interest due to its diverse secondary metabolites and wide-ranging therapeutic activities. The pharmacological effects can be categorized into four principal domains: (1) modulation of inflammatory and nervous systems, (2) regulation of microbial populations and gut microbiota, (3) antioxidant and cytotoxic responses, and (4) metabolic and cardiovascular regulation.

3.3.1. Modulation of Inflammatory and Nervous Systems

Analgesic Activity. Studies have shown that alcohol extracts and several fractions of *P. tectorius* fruit exhibit significant analgesic effects in mice, demonstrated through writhing tests. The alcohol extract provided the highest protective effect (70.05%), followed by the aqueous fraction (60.25%), n-hexane (32.14%), and ethyl acetate (13.02%) (Febrina, 2016). Effervescent granules formulated with *P. tectorius* extract at 125 mg/kg exhibited an even higher effect, reaching 83.68% protection (Sriarumtias et al., 2020). These effects are attributed primarily to flavonoid constituents that modulate nociceptive signaling. The aqueous fraction displayed the strongest activity, offering 89.10% protection in animal models (Febrina et al., 2016).

Antipyretic Activity. Administration of chloroform extracts of *P. tectorius* fruit (400 mg/kg) significantly reduced rectal temperature in mice with Brewer's yeast-induced pyrexia, decreasing from 38.7 ± 0.45 ºC to 37.83 ± 0.37 ºC (Vedu et al., 2024). This antipyretic effect is believed to result from the inhibition of prostaglandin synthesis in the hypothalamic thermoregulatory center, a mechanism comparable to non-steroidal anti-inflammatory drugs. Flavonoids such as naringenin and chrysin are thought to contribute to this activity by downregulating cyclooxygenase pathways.

Anti-inflammatory Activity. Preclinical studies have confirmed notable anti-inflammatory effects of *P. tectorius* fruit extracts. In carrageenan-induced paw edema models, chloroform extracts (200 and 400 mg/kg) significantly reduced swelling, showing comparable activity to aspirin (Vedu et al., 2024). The ethyl acetate fraction inhibited edema by 68.75%, surpassing the effect of ibuprofen at similar doses (Andriani et al., 2019). Histological analysis revealed decreased infiltration of inflammatory cells, reduced epidermal hyperplasia, and downregulation of COX-2 expression, indicating activity on both prostaglandin- and cytokine-mediated inflammatory pathways.

3.3.2. Antimicrobial and Gut Microbiota Regulation

Antimicrobial Activity. Ethanolic extracts of *P. tectorius* fruit have demonstrated notable broad-spectrum antimicrobial effects. These extracts inhibited the growth of Gram-positive bacteria such as *Staphylococcus aureus* and Gram-negative strains including *Proteus mirabilis*, with Gram-positive bacteria showing greater susceptibility due to thinner cell walls (Andriani et al., 2019; Girsang et al., 2024). Comparative studies further revealed that *P. tectorius* extracts exhibited stronger inhibitory activity against *Bacillus subtilis*, *Escherichia coli*, and *Candida albicans* compared to rosemary extracts (Basudan, 2023). These findings highlight its potential as a natural antimicrobial agent.

Gut Microbiota Modulation. Beyond direct antimicrobial effects, *P. tectorius* extract influences gut microbial ecology. In vivo studies demonstrated an increase in beneficial bacteria such as *Lactobacillus*, along with reductions in opportunistic or pathogenic genera such as *Bacteroides* and *Alistipes* (Wu et al., 2019). This dual regulatory effect suggests potential applications of *P. tectorius* in supporting gastrointestinal health and metabolic regulation, positioning it as a candidate for functional foods or therapeutics targeting the gut microbiome.

3.3.3. Oxidative Stress Reduction and Cytotoxicity

Antioxidant Activity. Extracts of *P. tectorius*, particularly the ethyl acetate fraction, demonstrated potent antioxidant activity with IC_{50} values ranging from 0.3 to 2.4 mg/mL, approaching the activity of quercetin (IC_{50} = 0.2 mg/mL) (Raj et al., 2014). Alcohol-based extracts showed high radical-scavenging potential, inhibiting DPPH radicals by 81.3%, compared to 49.0% inhibition by rosemary extracts (Basudan, 2023). These effects are attributed to high concentrations of flavonoids and phenolic compounds, including caffeoylquinic acids and naringenin. Furthermore, dietary administration in fish models enhanced endogenous antioxidant defenses such as superoxide dismutase and catalase, along with improved immune responses, suggesting systemic protective benefits (Cheng et al., 2022).

Cytotoxic and Anticancer Activity. Flavonoid-rich ethanol and methanol extracts of *P. tectorius* have shown strong cytotoxic effects across several cancer cell lines, including HeLa, AGS, and HepG2. These extracts induced apoptosis, promoted tumor suppressor gene WT1a expression, and downregulated oncogenic signaling pathways such as Hippo and Notch (Raj et al., 2014; Kang & Kim, 2024; Cheng et al., 2022). Notably, the ethyl acetate fraction demonstrated potent cytotoxicity with an IC_{50} of 12 μg/mL against HeLa cells (Musa et al., 2017; Awad et al., 2019). These results support the potential role of *P. tectorius* in cancer chemoprevention.

3.3.4. Metabolic and Cardiovascular Regulation

Antidiabetic Activity. Bioactive compounds such as caffeoylquinic acids and pandanusin A isolated from *P. tectorius*fruit have demonstrated significant inhibition of alpha-glucosidase, in some cases exceeding the activity of the standard drug acarbose

(Nguyen et al., 2016). In vivo studies using 200 mg/kg of the extract revealed reductions in fasting blood glucose, body weight, and insulin resistance. These effects were mediated through enhanced glucose uptake via pathways involving GLUT4, AMPK, and AS160 (Wu et al., 2014). Additionally, neuroprotective effects were observed in models of diabetic peripheral neuropathy, with modulation of the Nrf2/Keap1 signaling pathway contributing to improved neuronal outcomes (Zhang et al., 2025).

Cardiovascular and Antidyslipidemic Activity. Compounds such as caffeoylquinic acids, tangeretin, and ethyl trans-caffeate derived from *P. tectorius* fruit have been associated with lipid-lowering and anti-atherosclerotic properties, demonstrated in both in vitro enzyme assays and in vivo models (Wu et al., 2014; Andriani et al., 2019; Andriani et al., 2020). In hypercholesterolemic rats, methanol and ethyl acetate fractions administered at 500 mg/kg reduced total cholesterol and increased HDL without signs of hepatotoxicity (Zhang et al., 2013; Andriani et al., 2020). Furthermore, ethanol extracts from the roots, stems, and leaves improved lipid profiles in alloxan-induced diabetic rats, restoring triglyceride, LDL, and total cholesterol levels (Sundus et al., 2021). Mechanistically, these benefits are attributed to inhibition of HMG-CoA reductase activity and upregulation of scavenger receptor-B1 expression (Andriani et al., 2020). While nanoformulations such as SNEDDS have been reported for improving antioxidant effects of the fruit extract (Kholieqoh et al., 2022), their applications for cardiovascular disorders remain to be fully explored. These findings collectively highlight the strong pharmacological potential of *P. tectorius* fruit as a natural agent for managing hyperlipidemia and atherosclerosis (Oksal et al., 2020).

4. CONCLUSION

The fruit of *Pandanus tectorius* represents a valuable yet underutilized resource with wide-ranging pharmacological potential. Phytochemical analyses have identified diverse bioactive compounds, including flavonoids, phenolic acids, lignans, and triterpenoids, which contribute to antioxidant, anti-inflammatory, analgesic, antidiabetic, antimicrobial, and anticancer activities. Experimental studies have elucidated mechanisms such as alpha-glucosidase inhibition, modulation of inflammatory mediators, reduction of oxidative stress, and induction of apoptosis in cancer cells. Furthermore, evidence supports its beneficial roles in lipid regulation, neuroprotection, cardioprotection, and gut microbiota modulation. Advanced delivery systems, such as nanoemulsions, have also been explored to address solubility and bioavailability challenges. Despite promising preclinical results, the absence of standardized formulations and clinical validation remains a significant limitation. Future research should focus on dosage standardization, safety assessments, and clinical trials to substantiate the therapeutic applications of *P. tectorius* as an evidence-based phytotherapeutic agent.

AUTHOR CONTRIBUTIONS

Conceptualization, Lusi Agus Setiani; methodology, Lusi Agus Setiani and Nina Herlina; investigation, Nina Herlina and Cyntia Wahyuningrum; resources, Nabilah Yuliana Putri; data curation, Nina Herlina and Cyntia Wahyuningrum; writing—original draft preparation, Nina Herlina and Cyntia Wahyuningrum; writing—review and editing, Lusi Agus Setiani; visualization, Cyntia Wahyuningrum; supervision, Lusi Agus Setiani; project administration, Lusi Agus Setiani; funding acquisition, Lusi Agus Setiani. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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