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Cocos nucifera (Coconut Palm): A Holistic Appraisal of Its Bioactive Compounds, Therapeutic Potential, Industrial Utility, and Role in Sustainability

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ABSTRACT

Cocos nucifera, commonly known as the coconut palm or the "tree of life," is a versatile plant with significant nutritional, therapeutic, industrial, and ecological importance. This review highlights the bioactive compounds, health benefits, industrial applications, and sustainability contributions of the coconut tree. A comprehensive literature search across PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect was conducted using standardized inclusion and exclusion criteria. Findings reveal that coconut-derived phenolics, flavonoids, cytokinins, and medium-chain fatty acids contribute to robust antioxidant, antimicrobial, anti-inflammatory, wound-healing, and anti-cancer activities, supported by assays such as 2,2-diphenyl-1-picrylhydrazyl (DPPH), Ferric Reducing Antioxidant Power (FRAP), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and Anti-inflammatory. Virgin coconut oil demonstrates superior free-radical scavenging compared to refined oil due to its rich phenolic and lauric acid content, while coconut water shows significant cytoprotective and anti-ageing effects attributed to its cytokinins. Industrially, husk and shell by-products are valorized into bio-composites, activated carbon, biochar, and construction materials, advancing principles of the circular economy. In agriculture, coir pith enhances soil fertility and water retention, while copra meal serves as a protein-rich livestock feed. Emerging frontiers include nanotechnology, where coconut-derived carbon and nanocellulose are applied in drug delivery, water purification, and tissue engineering. Despite promising laboratory and preclinical results, translational research gaps remain, particularly in clinical validation of coconut's anti-cancer and metabolic benefits. Overall, this review highlights the coconut tree as a holistic bioresource with potential to address global challenges in health, sustainability, and renewable innovation, underscoring its enduring role as a "tree of life."

KEYWORDS: *Antioxidant activity, circular economy, natural therapeutics, sustainable agriculture, Coconut tree*

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1 INTRODUCTION

The coconut tree (*Cocos nucifera*), often referred to as the "**tree of life**," is one of the most versatile plant species within the family Arecaceae (Ignacio and Miguel, 2021). It is widely cultivated in tropical and subtropical regions and is highly valued for its economic, nutritional, and medicinal importance. Every part of the coconut plant, including the fruit, husk, shell, leaves, trunk, and roots, has significant economic applications, making it a cornerstone of sustainable agriculture and traditional medicine. The fruit is rich in dietary fiber, vitamins, minerals, and bioactive compounds such as phenolics, flavonoids, and lauric acid. These bioactive constituents are largely responsible for its diverse health-promoting properties, including antimicrobial, antioxidant, and anti-inflammatory activities (DebMandal & Mandal, 2011; Lima et al., 2015). Beyond nutritional and medicinal uses, almost every part of the tree provides valuable products. Innovations like coconut sugar, coconut-based composites, and nutraceutical extracts now complement traditional uses such as coconut water and coconut oil. The coconut also exemplifies principles of the circular economy, as by-products such as shells and husks are increasingly transformed into value-added products, including activated carbon, fiber composites, biochar, and even biogas, thereby minimizing waste and enhancing sustainability (Sakthivel et al., 2024; Ajien et al., 2023).

Despite extensive research, gaps remain in consolidating recent evidence on the coconut's therapeutic potential, ecological role, and industrial utility. This review, therefore, combines the evidence from the last decade to argue that the coconut tree is not only a traditional multipurpose crop but also a modern bioresource with significant therapeutic, nutritional, and environmental applications.

2 MATERIALS AND METHODS

2.1 Literature Search Strategy

A comprehensive literature search was conducted to gather peer-reviewed studies on the bioactive compounds, therapeutic potential, industrial applications, and sustainability roles of ***Cocos nucifera***. Searches were performed across PubMed, Scopus, Google Scholar, Web of Science, and ScienceDirect from January to May 2024, targeting publications from 2010 to 2024. Keywords included "***Cocos nucifera***," "**coconut bioactive compounds**," "**antioxidant activity**," "**antimicrobial properties**," "**coconut sustainability**," and "**circular bioeconomy**," combined with Boolean operators (e.g., ("***Cocos nucifera***" or **coconut**") and ("**bioactive compounds**" or "**antioxidant activity**"). Truncation (e.g., **coconut***) and phrase searching (e.g., "virgin coconut oil") were used to enhance precision.

Reference lists of key articles (e.g., DebMandal & Mandal, 2011) were screened, and citation chaining was performed via Scopus identified additional studies. No initial language restrictions were applied, but English-language articles were prioritized during filtering.

2.2 Inclusion & exclusion criteria

Inclusion criteria targeted peer-reviewed articles focusing on *Cocos nucifera*'s bioactive compounds (e.g., phenolics, lauric acid) characterized via antioxidant assays such as the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, the Ferric Reducing Antioxidant Power (FRAP) assay, or the 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS). Eligible studies included those reporting therapeutic effects (*in vitro, in vivo*, or clinical studies on antimicrobial, anti-inflammatory, or anticancer properties); industrial applications (e.g., husk in bio composites, shell in activated carbon); or sustainability roles (e.g., agroforestry, circular bioeconomy).

Exclusion criteria omitted non-English articles, non-peer-reviewed sources (e.g., editorials, abstracts), studies with weak or unclear methodology, and research focused on unrelated species. Screening involved a two-stage process: an initial title and abstract review conducted by the authors, followed by full-text evaluation to assess methodological quality and relevance.

To ensure consistency, a standardized data extraction form was employed, capturing essential data points related to various studies. This included bibliographic details such as the author, year, and country of study, alongside the specific plant parts analyzed, ranging from fruits and leaves to oils and water. The form also recorded the compounds investigated, highlighting the classes of bioactives like phenolics and fatty acids, as well as the assay types utilized, including antioxidant assessment via DPPH, FRAP, and ABTS, and antimicrobial tests such as Minimal inhibitory concentration (MIC) or inhibition zone methods. Additionally, it documented the experimental models applied, including *in vitro, in vivo*, or clinical settings. Results were extracted as quantitative values, such as IC_{50}, MIC, and inhibition zone diameters (mm), alongside qualitative insights into the therapeutic and sustainability implications, all situated by the year and specific study context.

Duplicates saved across multiple databases were managed using Zotero reference manager, combined with manual checking, ensuring that each study was only included once. Since this is a narrative review, the synthesis did not involve statistical combining but was instead structured thematically. Data were organized under four main themes: **bioactive compounds, therapeutic potential, industrial applications, and sustainability roles**. Within each theme, findings were further grouped by plant part (fruit, oil, husk, shell, leaves, roots, and water) to provide clarity and highlight the multipurpose nature of *Cocos nucifera*. Extracted data were synthesized narratively, integrating both quantitative outcomes (e.g., inhibition zones, IC_{50} values) and qualitative findings (e.g., applications in biotechnology and the circular bioeconomy). References followed the Harvard Referencing Guide.

3 RESULTS & DISCUSSION

3.1 Therapeutic and Nutritional Bioactivities

Cocos nucifera offers a variety of health and nutrition benefits, owing to its rich content of bioactive compounds. These include phenolics, flavonoids, cytokinins, and medium-chain fatty acids. Together, they contribute to a range of positive effects, such as fighting off oxidative stress, combating harmful bacteria, reducing inflammation, promoting wound healing, supporting anti-cancer activities, and helping with metabolism. Many of these benefits have been supported by both laboratory and animal studies conducted on different parts of the coconut plant.

3.1.1 Antioxidant Properties

Antioxidant activity is one of the most widely reported properties of *Cocos nucifera*, spanning coconut water, oil, husk, and roots.

Virgin coconut oil (VCO) exhibits significantly stronger antioxidant activity than refined oil, due to its higher phenolic content and medium-chain fatty acids. VCO contains up to seven times more total phenolics than refined oil, showing superior performance in DPPH assays (Lima et al., 2015).

Coconut water, comprising 95–99% water along with sugars, electrolytes, amino acids, vitamins, and phytohormones such as cytokinins, exhibits strong antioxidant activity (Shi et al., 2025). Radical scavenging assays confirm this potential, with DPPH inhibition of 51–55%, notable FRAP activity, and ABTS inhibition reaching 91% in Makapuno coconut water (Sarun Na Nakorn et al., 2024; Phonphoem et al., 2022). It also reduces hydrogen-peroxide-induced Reactive oxygen species (ROS) in human fibroblasts, supporting cytoprotective effects. Phenolic compounds in coconut water show DPPH IC_{50} values comparable to ascorbic acid and higher anti-collagenase activity than epigallocatechin gallate (Lima et al., 2015). *In vivo*, CW (6 mL/100 g body weight) in CCl_4-intoxicated rats increased Superoxide dismutase (SOD) and catalase via enzymatic assays, reducing lipid peroxidation (Lima et al., 2015).

Additionally, **coconut milk** provides vitamin C and catechins, while a coconut wheatgrass gel demonstrated antioxidant capacity like ascorbic acid in vitro (Priyadharshini et al., 2023).

The coconut husk (mesocarp) is also phenolic-rich, with dried husk extracts reporting up to 129 mg GAE/g of polyphenols. Methanolic and ethyl acetate fractions scavenged DPPH radicals with IC_{50} values of 5.7–5.9 mg/mL (Muritala et al., 2018). These extracts also inhibited lipid peroxidation *in vitro*, further confirming their antioxidant capacity. In another study, husk extracts scavenge DPPH (IC_{50} 4.18-20.83 μg/mL), nitric oxide, and alkaline DMSO radicals, comparable to ascorbic acid (Lima et al., 2015).

Coconut Cotyledon methanolic extracts exhibit antioxidant activity in DPPH (EC_{50} 0.12 mg/mL), FRAP (EC_{50} 6.43 mg/mL), nitric oxide (EC_{50} 16.21 mg/mL), and β-carotene bleaching assays (EC_{50} 8.09 mg/mL), respectively (Nyayiru Kannaian et al., 2020).

Coconut haustorium extracts recorded notable antioxidative activity, with DPPH scavenging at 74.74 ± 1.05%, ABTS at 78.45 ± 0.86%, and hydrogen peroxide scavenging at 71.64 ± 0.68%, all measured at a concentration of 50 µg/mL (Yasodha S, S and Rajeshkumar S, 2025).

Phenolic-rich extracts from coconut inflorescence test show high DPPH radical scavenging (172–249 µmol Trolox equivalent/g) and strong FRAP/CUPRAC reducing power. Such activity correlates with the high total phenolic content (TPC) of the test (Ramesh et al., 2024).

Collectively, these findings highlight that the phenolics of *C. nucifera* exhibit robust antioxidant activity, as validated by DPPH, FRAP, and ABTS assays, demonstrating their potential as potent free radical scavengers capable of mitigating oxidative stress.

3.1.2 Antimicrobial and Antiviral Properties

Coconut oil is recognized for its high lauric acid content, which constitutes 45–52% of virgin coconut oil (VCO). The secret behind coconut oil's antimicrobial success lies primarily in lauric acid, a powerful medium-chain fatty acid (MCFA) that is abundant in its composition. Lauric acid is metabolized into monolaurin, a broad-spectrum antimicrobial lipid. Monolaurin disrupts microbial membranes and is effective against Gram-positive bacteria, fungi, and enveloped viruses (Nitbani et al., 2022; Akanksha et al., 2023). Numerous *in vitro* studies illustrate that lauric acid not only targets and kills Gram-positive bacteria but also exhibits broad-spectrum antimicrobial activity (Durgaprasad and Srivastava, 2008).

Recent *in vitro* studies have unveiled the remarkable antimicrobial power of **virgin coconut oil**. A striking experiment revealed that VCO at 75% concentration creates a substantial 22 mm inhibition zone against *Streptococcus mutans*, effectively halting bacterial growth, with a Minimum Inhibitory Concentration (MIC) of 75%. This impressive result outperformed penicillin G, which produced only a 14 mm inhibition zone in comparative tests (Vasquez Vereau and Guardia Méndez, 2021).

Furthermore, coconut oil has also proven its mettle against lipid-enveloped viruses like such as visna and cytomegalovirus, by disrupting their membranes, showcasing its versatility (Yasodha S and Rajeshkumar S, 2025).

Moreover, both purified lauric acid and monolaurin are effective in breaching the membranes of Gram-positive pathogens and certain viruses (Matsue et al., 2019; Durgaprasad and Srivastava, 2008). Consistently, VCO displays robust antimicrobial effects (Durgaprasad and Srivastava, 2008; Bose et al., 2025). In addition, it has been recognized for inhibiting notorious pathogens such as *Staphylococcus aureus* and *Candida*, making it a popular choice for topical use due to its antibacterial and antifungal properties (Durgaprasad and Srivastava, 2008). With such a powerhouse of benefits, it is no wonder that coconut oil is gaining traction in both health and wellness circles.

Coconut root extracts have also shown antibacterial activity. Methanolic root extracts inhibited *S. aureus* with an MIC of

~approximately 2 mg/mL and demonstrated broader but weaker effects against *E. coli* and *P. aeruginosa* (Belem-Kabré et al., 2023). These results align with traditional uses of coconut roots in treating infections.

Husk extracts inhibit *S. aureus* with an inhibition zone of 12-24 mm in disk diffusion, *C. albicans*, and *C. neoformans* via growth inhibition assays, attributed to tannins and catechins. MIC against *Listeria* was: 0.6-5.0 mg/mL in broth microdilution (Nyayiru Kannaian et al., 2020).

Haustorium extracts show zones of 13.33 mm for *E. coli* and 12.67 mm for *S. aureus* at 100 µg/mL in well diffusion (Yasodha S, S and Rajeshkumar S, 2025). The antimicrobial and antiviral effects of lauric acid, monolaurin, and phenolic-rich husk and root extracts position *C. nucifera* as a promising natural source of infection control, supporting its use in both traditional medicine and modern pharmaceutical development.

3.1.3 Anti-inflammatory and Wound-Healing Properties

Coconut water and **husk** extracts both demonstrate anti-inflammatory activity. *In vivo* experiments revealed that young and mature coconut water reduced acetic-acid-induced inflammation in rat models, with young water being more effective (Phonphoem et al., 2022).

Coconut husk aqueous extract (100 mg/kg) reduces rat paw edema by 42.52% in the carrageenan-induced inflammation model, surpassing the effect of ibuprofen. , via qPCR/Western blot analysis showing suppression of Nos2/iNOS expression (Lima et al., 2015). Husk extracts (150 mg/kg) reduce TNF-α in air pouch models via ELISA. Several studies document coconut's anti-inflammatory activity through molecular assays. A phenolic-rich acetone extract of coconut inflorescence (CnAE) markedly inhibited inflammatory enzymes and mediators in LPS-activated macrophages. At a concentration of 100 µg/mL, CnAE reduced COX activity by ≈68% and 5-LOX activity by ≈64%, and significantly lowered iNOS/NO and PGE_2 levels (Chithra et al., 2019). It also suppressed secretion of pro-inflammatory cytokines IL-1β, IL-6 and TNF-α ($p \leq 0.001$) in treated cells (Chithra et al., 2019). In vivo, the same extract (400 mg/kg) strongly attenuated inflammation in mice: carrageenan-induced paw edema was reduced by ~59.8% and formalin-induced chronic edema by ~52.9%. These effects are attributed to downregulating the NF-κB signaling cascade (Chithra et al., 2019).

Haustorium extracts inhibit egg albumin denaturation (up to 80%) and Human Red Blood Cell (HRBC) stabilization. The anti-inflammatory effects were assessed through the egg albumin denaturation assay, which showed an activity of 72.68 ± 0.87%, and the HRBC assay, which demonstrated 83.93 ± 0.90%. These results were comparable to the standard Diclofenac sodium, which showed 81.33 ± 0.95% inhibition in the egg albumin denaturation assay and 88.3 ± 0.66% in the HRBC assay at 50 µg/mL. (Yasodha S, S and Rajeshkumar S, 2025).

Additionally, a topical oral gel containing coconut extract exhibited anti-inflammatory inhibition (90.1% at the highest dose) superior to diclofenac *in vitro* (Priyadharshini G et al., 2023). This assay proves that coconut phenolics and oil can mitigate inflammatory responses, supporting their traditional use in treating arthritis, pain, and skin inflammation.

Natural coconut-derived anti-inflammatory agents provide safer alternatives to corticosteroids, which suppress immunity and delay tissue repair (Martin & Leibovich, 2005). Research on Sri Lankan coconut water confirms its role as a wound-healing agent due to strong antioxidant and anti-inflammatory actions validated by DPPH, FRAP, and animal models (S. Shayanthavi, R. Kapilan and Wickramasinghe, 2024).

Coconut oil has proven benefits for skin and wound care. In a rat burn model, coconut oil significantly accelerated healing, where wounds treated with coconut oil (alone or with standard silver sulfadiazine) showed faster contraction and epithelialization, leading the authors to conclude "oil of *Cocos nucifera* is an effective burn wound healing agent" (Durgaprasad and Srivastava, 2008). This pro-healing effect is likely due to the combined anti-inflammatory and antiseptic action. Clinically, extra-virgin coconut oil is as effective and safe as mineral oil for skin moisturization, with no adverse reactions in patients with xerosis.

Thus, coconut water, coconut oil and husk extracts contribute significantly to both anti-inflammatory therapies and wound-healing applications, demonstrating translational potential in clinical practice.

3.1.4 Anti-cancer /Cytotoxic and Metabolic Potential

Emerging evidence suggests that coconut-derived compounds hold promise in cancer prevention and metabolic regulation. Bioactive peptides from coconut water demonstrated anti-proliferative effects in human cell culture models (Shi et al., 2025).

Coconut root extracts exhibited cytotoxicity against prostate cancer cells, with an IC_{50} of approximately 27 µg/mL against LNCaP cells (Belem-Kabré et al., 2023). These findings support traditional uses for treating infections and tumors, indicating that coconut root compounds can disrupt cancer cell viability and modestly inhibit bacterial growth (Belem-Kabré et al., 2023).

In metabolic health, **coconut husk** extracts have been shown to inhibit α-amylase activity, a key enzyme in carbohydrate metabolism, suggesting anti-diabetic potential (Muritala et al., 2018). Further, MTT assay proved that husk extracts reduce viability by 50% in Lucena 1 and K562 cells (Lima et al., 2015).

Coconut oil's medium-chain triglycerides may also aid in weight management and improve lipid profiles by raising HDL cholesterol (Beegum et al., 2024). And coconut oil's potential in supporting brain health, particularly in Alzheimer's disease management, has been investigated. Preliminary studies suggest that medium-chain triglycerides (MCTs) derived from coconut oil may enhance cognitive performance by providing ketones as an alternative energy substrate for neurons with impaired glucose metabolism (Fernando et al., 2015).

However, systematic reviews emphasize that current clinical evidence is limited and inconclusive, and thus coconut oil cannot yet be recommended as a therapeutic intervention for Alzheimer's disease (Eyres et al., 2016).

Haustorium extracts show IC_{50} in HepG2 cells as determined by the MTT assay (Yasodha S, S and Rajeshkumar S, 2025). CW peptides have an IC_{50} range of 1.25-1.85 mM against glioma cells in viability assays (Lima et al., 2015). Coconut-derived polyphenols have shown cytotoxicity against cancer cell lines. Notably, an ethyl acetate Proanthocyanidins fraction from coconut inflorescence (EASPA) exhibited cytotoxicity against HeLa cervical cancer cells an IC_{50} of ≈18.8 µg/mL). outperforming the drug tamoxifen. This showed an (IC_{50} ≈28.8 µg/mL) (Padumadasa et al., 2016). EASPA was less toxic to the prostate cancer line (PC_3, with an IC_{50} of ≈44.2 µg/mL), indicating some degree of selectivity. The authors concluded that coconut Proanthocyanidins "mediate cytotoxic activity against HeLa cells" and suggest their potential for exploration in cervical cancer therapy (Padumadasa et al., 2016).

In addition, lauric acid itself has been reported to enhance apoptosis and sensitivity to chemotherapy in various cancer models (Bose et al., 2025). These findings, though limited, suggest that coconut's bioactive compounds warrant further study as anticancer agents.

These findings support the role of *Cocos nucifera* in addressing chronic health conditions such as cancer, diabetes, and cardiovascular disease, while also aligning with its traditional use in promoting overall metabolic health.

3.2 Industrial Applications and the Circular Economy

3.2.1 Industrial Materials

The fibrous husk (mesocarp) of the coconut yields coir, a durable and strong fiber traditionally used in ropes, mats, and brushes. Today, coir has advanced into high-performance composites with applications in construction, automotive, and packaging industries. Pretreatments such as alkali, acetylation, or nanoparticle reinforcement enhance fiber matrix bonding, tensile strength, and moisture resistance, enabling their use in particleboards, cement composites, and biodegradable polymers (Hasan et al., 2021; Ramu et al., 2024).

Coconut shell, a dense lignocellulosic by-product, also contributes to sustainable material innovation. Crushed shell has been incorporated into lightweight concrete, floor tiles, and asphalt, reducing structural load while enhancing thermal insulation and acoustic performance (Sankar et al., 2023). In decorative applications, shell fragments are used in terrazzo flooring, mosaic inlays, and handicrafts, supporting artisanal economies. The coconut fruit itself is the primary economic product, yielding copra and coconut oil that are widely used in food, cosmetics, and pharmaceuticals (DebMandal and Mandal, 2011).

Coconut water and milk have also gained global market value due to their nutritional and functional properties, driving export growth (Prades et al., 2016). Beyond the fruit, the husk and shell are economically valuable by-products. The husk provides coir fiber used in matting, brushes, and biodegradable products, while the shell is utilized for activated carbon and handicrafts (Rosairo, Kawamura and Peiris, 2004).

Coconut wood from older, unproductive trees is now a sustainable alternative for furniture and construction materials (Fathi et al., 2023).

Moreover, **coconut leaves** are used for thatching and weaving traditional crafts, contributing to local cottage industries.

These material applications illustrate how coconut by-products can serve as an alternative to synthetic fibers and non-renewable construction materials, aligning with the principles of sustainable and circular materials science.

3.2.2 Bioenergy and Biochemicals

Coconut husks and shells, rich in lignocellulose, provide an abundant feedstock for renewable energy and chemical production. Pyrolysis of coconut shell at ~450°C yields high-value outputs such as bio-oil, phenolic compounds (up to 4717 mg GAE/100 g), and acetic acid (~11.4%), which can serve as natural antimicrobials and preservatives (Silaban et al., 2024). Shell charcoal is widely used in cooking stoves and incense production, while activated carbon derived from shells exhibits exceptional microporosity and surface area, making it ideal for water purification, air filtration, and in gas masks (Sakthivel et al., 2024).

Biodiesel production from **coconut oil** has also been extensively studied. Coconut biodiesel blends display favorable fuel properties, including high cetane number, reduced greenhouse gas emissions, and improved combustion performance compared with fossil diesel (Silitonga et al., 2020). Enzymatic transesterification further enhances conversion efficiency and reduces processing costs, making coconut-based biodiesel a viable renewable energy source (Ribeiro et al., 2022). These developments highlight the role of coconut as an input for renewable energy, biochemicals, and clean fuel systems that contribute to global decarbonization.

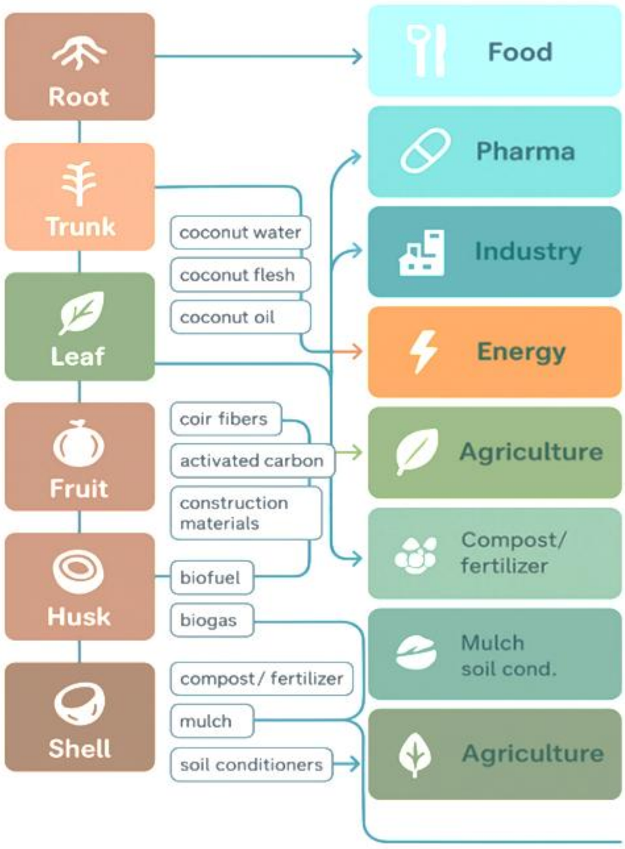

Figure 1. A schematic flowchart illustrating the holistic value chains of the coconut tree, mapping its parts (root, trunk, leaf, fruit, husk, and shell) to diverse applications across food, pharmaceutical, industrial, energy, and agricultural sectors.

3.2.3 Waste Valorization in Agriculture

Coconut coir pith, a by-product of husk processing, has become a key material in sustainable agriculture. It is widely employed as a soil-less growing medium and a peat substitute due to its high water and nutrient retention. Its use in horticulture and hydroponics has reduced reliance on peat moss, thus conserving fragile wetland ecosystems. Coir pith is also processed into erosion-control mats that significantly reduce soil loss in slope stabilization projects (Sutherland & Ziegler, 2007).

Other waste valorization approaches include converting coir pith and shell residues into biochar, which improves soil fertility, enhances water-holding capacity, and sequesters carbon (Ajien et al., 2023).

Copra meal, a protein-rich by-product of oil extraction, is incorporated into livestock and aquaculture feed, improving digestion and animal growth (Mat et al., 2022). However, anti-nutritional factors such as tannins and lignin require pretreatment (fermentation, soaking) before use, ensuring maximal feed efficiency.

By transforming agricultural residues into soil amendments, feed, and biochar, coconut cultivation supports regenerative agricultural practices and minimizes waste, reinforcing the tree's role in the circular bioeconomy.

3.3 Emerging Frontiers and Future Directions

3.3.1 Nanotechnology and Advanced Materials

Nanotechnology is rapidly expanding the value of coconut-derived materials. **Coconut shell-derived** activated carbon has been converted into carbon nanoparticles with high surface area and adsorption properties, useful for water purification, wastewater treatment, and even drug delivery (Hashim et al., 2022). Similarly, magnetically modified coir biochar has achieved >80% removal of water hardness, showcasing its promise for low-cost water treatment (Balasuriya et al., 2021).

Nanocellulose isolated from coconut fibers has demonstrated biocompatibility, positioning it for biomedical applications such as scaffolds in tissue engineering and wound dressings (Silva et al., 2021). In parallel, **coconut husk** composites are evolving into advanced bioplastics and filaments for 3D printing, offering lightweight, biodegradable alternatives for automotive, packaging, and construction industries (Prabhu et al., 2023).

These innovations highlight how coconut waste streams are being transformed into next-generation nanomaterials and sustainable products at the interface of green chemistry, engineering, and healthcare.

3.3.2 Pharmacological and Nutraceutical Innovation

Coconut-derived compounds are being increasingly evaluated for pharmaceutical and nutraceutical applications. Medium-chain fatty acids such as lauric and myristic acid, along with their derivative monolaurin, are recognized as safe and effective broad-spectrum antimicrobials (Joshi et al., 2020). Novel antimicrobial peptides (Cn-AMPs) isolated from **coconut water** have shown anti-proliferative activity against cancer cells (Shi et al., 2025), while phenolic-rich **husk** and **kernel** extracts are being explored for anti-diabetic, cardioprotective, and neuroprotective applications.

In the nutraceutical sector, coconut water is marketed globally as a natural isotonic beverage, while Medium-chain triglycerides (MCT) rich coconut oil is sold in capsules for weight management and cognitive support. Coconut flour is gaining attention as a gluten-free, high-fiber ingredient, while coconut sugar is being promoted as a low-glycemic sweetener.

Innovations such as microencapsulation and enzymatic modification are extending shelf life and enhancing bioavailability of coconut-derived nutraceuticals (Dayrit, 2014; Mat et al., 2022).

In the cosmetics industry, **virgin coconut oil** is commonly used in moisturizers, sunscreens, and shampoos due to its emollient, antimicrobial, and UV-protective properties. Many hair oils incorporate coconut oil as a base to reduce protein loss and enhance shine (Ravi

Pandiselvam et al., 2019; Vieira et al., 2024). Additionally, phenolic compounds derived from coconut husks have been formulated into sunscreens, where a study reported SPF values of approximately 16 (Vieira et al., 2024).

Coconut water is often marketed as a facial toner or mist due to its hydrating minerals and cytokinins (Shi et al., 2025). Derivatives of coconut sap, including sugars and acids, are utilized in toners and mild exfoliating peels.

Coconut shell powder is sometimes included as a natural exfoliant in scrubs. Coconut notes are also featured in various fragrance oils. Thus, Shi et al. (2025) reported that coconut components are considered safe and biodegradable, aligning with the growing consumer demand for "natural" cosmetics (Shi et al.,2025).

These pharmacological and nutraceutical innovations highlight coconut's versatility beyond traditional use, showing its growing potential to supply health-promoting compounds across food, cosmetic, and pharmaceutical industries, while also offering nutritional, therapeutic, industrial, and environmental benefits. This review has provided a holistic appraisal of the past decade's research evidence on *Cocos nucifera*, highlighting its bioactivities, industrial applications, and emerging frontiers, while setting the stage for future innovations and applications.

4. CONCLUSION & RECOMMENDATIONS

From a therapeutic perspective, coconut products exhibit strong antioxidant, antimicrobial, anti-inflammatory, and wound-healing properties, as demonstrated by assays such as **DPPH, FRAP**, **ABST** and **ABTS**. Lauric acid, phenolic compounds, and bioactive peptides enhance anti-cancer and anti-diabetic potential, aligning traditional uses with modern biomedical validation. Industrial applications reinforce the role of coconut in the circular bioeconomy. To lessen reliance on non-renewable resources, husk-derived coir and shell-based activated carbon are being developed into sustainable composites, filtration materials, and bioenergy products. Biochar, soil amendments, and animal feed exemplify waste valorization techniques and strategies that enable the transformation of all parts of the palm into value-added products, thereby reducing waste and promoting regenerative agriculture. Prospects are created by developing areas such as pharmacology and nanotechnology. Nanocellulose and carbon nanoparticles derived from coconut waste are being utilized in water purification, tissue engineering, and advanced materials. Pharmacological and nutraceutical innovations, spanning antimicrobial peptides and nutraceutical oils, and cosmeceutical formulations, highlight the expanding role of coconut in global health and wellness industries. Few clinical trials have validated coconut's claimed health benefits, especially in metabolic disorders and cancer prevention.

Despite these advancements, significant knowledge gaps remain. Addressing these gaps through rigorous translational research will be vital to unlocking the full therapeutic potential of coconut-derived compounds. In addition, collaboration between policymakers and industry stakeholders is necessary to scale up coconut's contribution to climate mitigation, sustainable agriculture, and green technologies. In summary, the coconut tree exemplifies the principles of a zero-waste, circular bioresource, integrating traditional knowledge with modern science. Its versatile applications, ranging from food and medicine to renewable energy and nanotechnology, underscore its significance as a vital natural resource for tackling in healthcare, sustainability, and resource security challenges of the 21st century. Thus, by advancing research, innovation, and sustainable utilization, the coconut palm can continue to be a "**tree of life**" for communities and ecosystems well into the future.

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