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REVIEW ARTICLE

Integrative potential of Palmyrah (*Borassus flabellifer*) in climate mitigation and pharmaceutical innovation

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Abstract

Borassus flabellifer L. the state tree of Tamil Nadu, offers a wide range of ecological, medicinal, economical and sociological benefits. This hardy palm species is highly resilient, capable of withstanding adverse climatic conditions and natural calamities. Nearly, every part of the Palmyrah palm is utilized, making it one of the most resourceful species. Importantly, it plays a role in mitigating climate change through significant carbon sequestration. The cultivation and maintenance of Palmyrah palm improves the local, National and International ecosystem through carbon sequestration. Furthermore, *B. flabellifer* exhibits various pharmaceutical and nutraceutical activities like anti-inflammatory, anti-arthritic, cytotoxic, antibacterial, analgesic, hypoglycaemic, antipyretic and antioxidant activity. This review provides an overview of Palmyrah's potential contributions to climate change mitigation and its pharmaceutical benefits.

Keywords: carbon sequestration; climate change; Palmyrah; pharmaceutical properties

Introduction

Borassus flabellifer Linn, (2n = 36), commonly known as Palmyrah, is a tall palm belonging to the family Arecaceae. It is referred as *Kalpagatharu* in Tamil, emphasizing its utility. Native to tropical Africa, Palmyrah is now widely cultivated in India, Sri Lanka, Myanmar, Thailand, Vietnam, Malaysia and in parts of Indonesia. All parts of the plant's roots, leaves, inflorescence, flowers, fruits and seeds are used for diverse applications. In India, Palmyrah grows naturally in forest and community lands across Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Bihar, Karnataka, Gujarat and Maharashtra. It is officially recognized as the state tree of Tamil Nadu (1). It is often regarded as a vital resource, earning the nickname "the tree of life" due to its nearly 800 uses. It can grow up to 30 m tall and is well known for its fan-shaped leaves and robust trunk. The tree is dioecious, with separate male and female plants, both of which produce flowers used for various purposes (2). Palmyrah has extensive economic and cultural significance, especially in countries like India, Sri Lanka and Cambodia, where it supports livelihoods through numerous products such as jaggery, toddy and timber. In addition to its environmental benefits, various parts of the Palmyrah tree offer valuable pharmaceutical properties, including antimicrobial, anti-inflammatory and wound-healing effects (3). This makes Palmyrah a promising crop for both climate change mitigation and medicinal applications This review underscores the potential of *Borassus flabellifer* as a sustainable crop for mitigating global warming through carbon sequestration and to explore its pharmaceutical value by identifying bioactive compounds with therapeutic properties.

Species of Palmyrah

Several species of the genus *Borassus* are distributed globally, including *B. aethiopium* (African palm), *B. akeassii* (Ake Assi's palm), *B. flabellifer* (Asian palm), *B. heineanus* (New Guinea palm), *B. madagascariensis* (Madagascar palm), *B. anbiranensis* (Sambi Rano palm) (4).

Description

Borassus flabellifer is a tall palm tree that typically grows in sandy soil, reaching a height of 20-30 m with a straight, columnar trunk. The roots are fibrous and exhibited slender transverse branches. The bark and wood are dark in colour. The leaves are palmately divided and fan-shaped, with petioles measuring 0.6-1.2 m in length; their margins are spiculose (4). The flowers are yellow and born in spadix. Female spadices are sparingly branched and bear a few scattered solitary flowers, while male flowers are small and mixed with scaly bracts. Female flowers are globose and larger. The fruits are large, fibrous and typically contain three nuts like segments and each enclosing a seed. Flowering and fruits occur from December to

August (5). Geographic distribution map of Palmyrah cultivation zones is represented in Fig. 1.

Fruit

The Palmyrah palm begins to produce fruit at the age of 15-20 years, yielding an annual harvest of approximately 50-200 fruits, arranged in 6-12 bunches per tree. Tender fruits are typically available from May to August, while the ripe fruits are harvested from July to October, with slight variation depending on locality (6). Each fruit contains seeds with a soft, sweet, jelly-like endosperm immersed in sap. Over time, the gelatinous pulp hardens into a woody kernel surrounded by a fibrous coat. Ripe fruits exhibit a colour range from light golden brown to nearly black at the base of the spadix (7).

Chemical constituent

The fruit of *B. flabellifer* contains several free amino acids, with lysine, aspartate, glutamate and phenylalanine being the most abundant. It also contains steroidal saponins, known as flabelliferins (8). The major digestible carbohydrates are simple sugars, predominantly sucrose, glucose and fructose. The fruit is also rich in carotenoids, including β-carotene, α-carotene, β-zeacarotene, lycopene and zeta-carotene. Additionally, it contains minor but important vitamins such as vitamin C and members of the vitamin B complex (9).

Global warming

Climate change and global warming are critical environmental challenges resulting from the excessive accumulation of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere (10). Global environment suffered with lot of carbon concentration produced by various anthropogenic activities at the rate of 3.5 billion metric tons per annum (11). Deforestation is the major factor in increasing carbon concentration from 280 ppm to 368 ppm in the year 2000 and 540 ppm by 2100. Carbon sequestration is the process of capturing and storing atmospheric carbon-dioxide reducing global climate change (12).

Palmyrah potential crop for carbon sequestration

The carbon sequestration rates of Palmyrah palm wood range from 49.82 % to 47.45 %, while the rate for Palmyrah palm leaves is 48.35 %. Due to the relatively hard nature of the Palmyrah palm petiole, once it reaches its storage capacity for carbon, it may transfer the stored carbon to the wood (13). Thus, the petiole functions as a conduit, facilitating carbon transfer between the leaf and the wood. The leaf scar also sequestrated good amount of carbon content 43.25 % even after the death of leaf (14).

The potential of carbon sequestration is determined by the age, height, girth size, biomass accumulation capacity and canopy diameter and most important wood specific density (15). Palmyra palm has potential role in conservation of an ecosystem as well as one step forward to climate change and global warming mitigation. Trees with higher wood density and greater adaptability to climatic conditions are better suited for maximizing atmospheric carbon sequestration. Palmyrah palm, with its robust physiological characteristics, is thus an ideal candidate for such purposes (16). Comparative carbon sequestration values of Palmyrah vs. other tree species are represented in Table 1.

Mitigating global warming

The Palmyra palm is efficient in capturing and storing carbon dioxide from the atmosphere which reduces the effect of greenhouse gases. It requires minimal amount for fertilizers and pesticides for its growth and improvement which actually reduces the greenhouse gas emissions from agricultural inputs (17). Bioethanol production from Palmyrah sap yields approximately 47.5 litres per ton. The fermentation process using *Saccharomyces cerevisiae* enhances ethanol output.

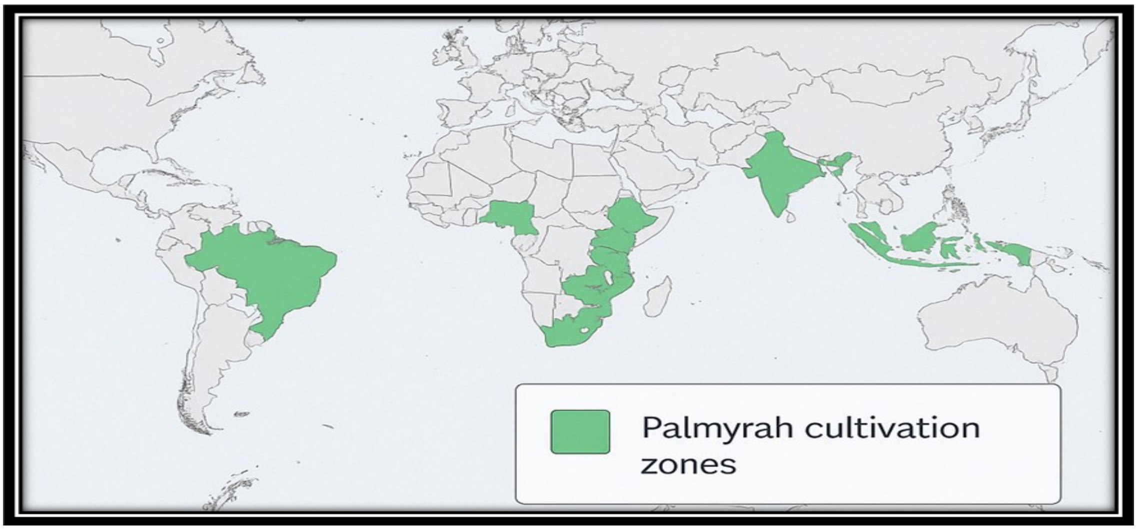

Fig. 1. Geographic distribution map of Palmyrah cultivation zones.

Table 1. Comparative carbon sequestration values of Palmyrah *vs.* other tree species

Carbon source	Palmyrah dominated forest	Native tree dominated forest (projected)	Percent change after transformation	References
Aboveground carbon (Mg C/ha)	4.3	2.7	−37.4 %	(21)
Soil carbon (Mg C/ha)	73.4	84.0	+14.5 %	(60)
Total carbon (aboveground + soil) (Mg C/ha)	77.6	86.7	+11.6 %	(16)
Total carbon (Mg C per hectare including all)	12564.9 MgC (total) across study area	14024.1 Mg C (total) across study area	+11.6 %	(21)

Compared to sugarcane ethanol, Palmyrah-based bioethanol offers higher carbon efficiency. Non-destructive tapping methods improve sustainability and long-term viability. Studies highlight its competitive energy efficiency relative to traditional biofuels. Palmyrah sap contains high sugar content, making it an efficient feedstock. Optimized fermentation conditions significantly boost ethanol yield (18). Schematic representation of Palmyrah role in climate change mitigation are represented in Fig. 2.

CO_2 absorption

Through photosynthesis, Palmyrah palm absorbs carbon dioxide from the atmosphere and stores it in the form of biomass. Palmyrah palms sequester about 40-50 tons of CO_2 per hectare annually, a rate competitive with certain fruit plantations like mangoes, which sequester between 47.66 and 62.33 tons CO_2/ha/year (19). This rate surpasses some oil palm plantations that average around 4.55 carbon stock tC/ha/year but is generally lower than mature tropical forests, which can sequester from 7 to 41 tC/ha/year depending on forest type and management. Transforming degraded lands into native forests can increase carbon storage by over 11 %. Mixed-species plantations typically outperform monocultures by approximately 7 %, highlighting ecosystem diversity's importance (20).

Durability and root carbon storage

Palmyrah wood is durable and used in construction, because the carbon remains stored for extended periods. Extensive root systems in Palmyrah have the ability to store carbon underground, contributing soil carbon levels (21).

Soil improvement and erosion control

The deep roots system of Palmyrah crop penetrates deep into the soil, which helps to stabilize the soil and prevent erosion. The Root system also improves soil porosity and aeration, which enhances water infiltration and retention (22). The fallen leaves, fruits and other organic debris enrich the soil with organic matter which contribute for the nutrient cycling in the soil. It promotes a healthy soil ecosystem by supporting beneficial microbes that aid in nutrient cycling and enhances microbial activity in the soil (23).

Drought resistance and water management

Palmyrah palm thrives in arid and semi-arid regions with minimal water requirements and it acts as an efficient drought tolerant crop and supports in water use efficiency and adaptation in the field (24). Palmyrah palm exhibits high drought tolerance, surviving 4-8 weeks of drought and thriving with minimal supplemental water once established (25). Cactus species, such as Opuntia, demonstrate exceptional drought resistance by storing water in stems and closing pores during the day to reduce water loss (26). Millets, including pearl millet and minor millets, are highly drought-tolerant crops adapted to arid regions, capable of maintaining productivity under low water conditions. Pearl millet shows diverse drought response mechanisms like osmotic adjustment and deep rooting, supporting resilience in harsh environments. Quantitative data on water use efficiency indicate millets require significantly less water than major cereals, making them more resilient to drought (27). Overall, while Palmyrah provides substantial drought endurance, millets and cacti possess specialized physiological traits offering comparative or superior drought resistance in different contexts (25).

Drought mitigation shade provision

The large leaves of Palmyrah provide shade and reduce soil and water evaporation in the field. In fact, it acts as a potential crop to mitigate drought in the field by providing proper shade. It acts as a windbreak tree, reducing wind speed and subsequently the soil erosion and ensures the protection of the field (28).

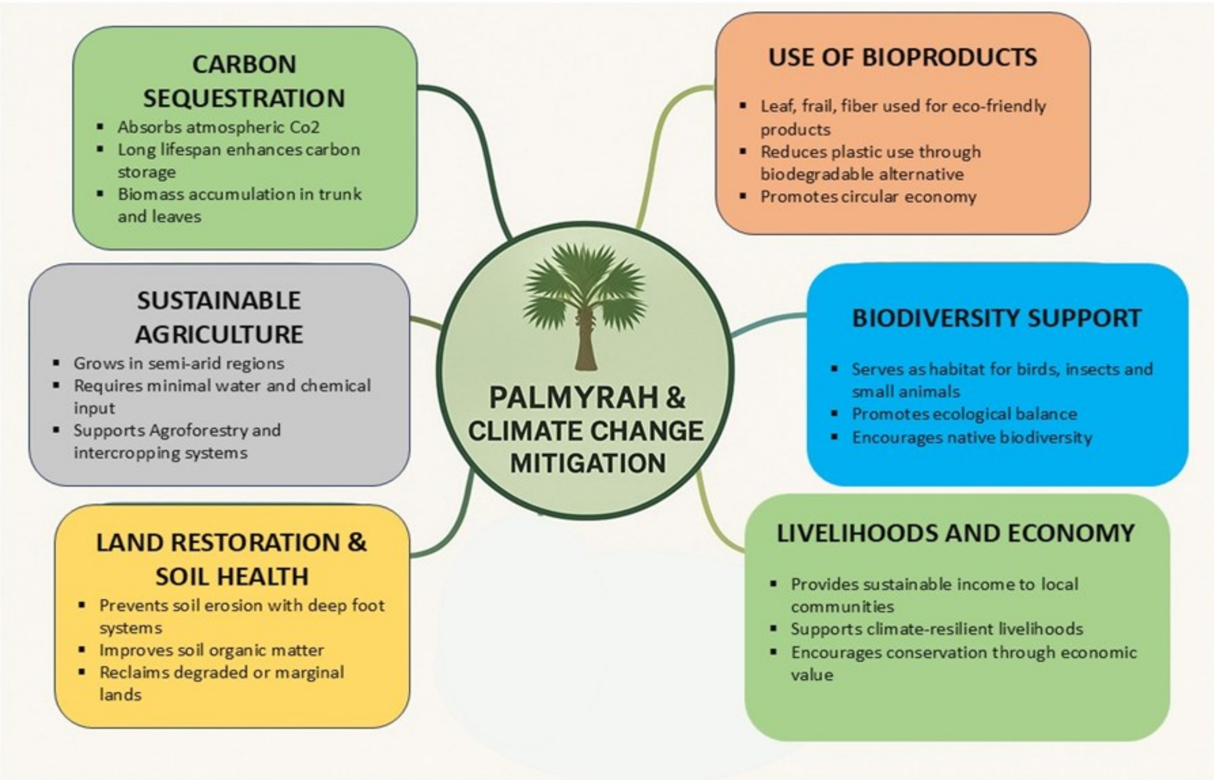

Fig. 2. Schematic representation of Palmyrah role in climate change mitigation.

Biodiversity enhancement

Palmyrah palm provides nesting sites for birds, habitats for insects and food for various animals and enhances biodiversity. Areas with Palmyrah cultivation often show higher biodiversity levels therefore it becomes the place of bio-diversity hot spot (29). The Palmyrah flower attracts bees, bats and other pollinators, enhancing local biodiversity and promotes more pollination among the crops in the field. The fruit and sap from the Palmyrah tree are consumed by humans, birds, insects and animals and enhances good biodiversity in the environment (28).

Sustainable agriculture practices

Palmyrah can be intercropped with legumes, vegetables and other crops, maximizing land use efficiency which is compatible for intercropping practices and also beneficial for other intercropped plants (28). Intercropping with Palmyrah can improve overall farm productivity and crop resilience. It produces fruit, sap, leaves and timber, offering multiple revenue streams. It also fits well in agroforestry systems, promoting sustainable land management practices and helps the farmers to get more yield and income through cultivation (25).

Environmental benefits of Palmyrah

While most of the palm plants have a fibrous root system, Palmyrah has a tap root system that shoots straight downward vertically. It could store a huge volume of water in the tubular roots and increases the water table level of the locality (30). It has a greater capacity to turn arid land into highly fertile land with rich groundwater resource. This could be a major reason for our ancestors planting palm trees around the water resources like rivers, tanks and wells (31).

Natural barrier

This plant is too sturdy that could withstand natural calamities like a magical wall. Tamil Nadu has witnessed several natural calamities. Scientific evidence state that many of the strong and sturdy. Palmyrah stood strong and tall even withstanding Tsunami in 2004, while many age old trees and buildings were flattened to the ground (32). This fact intrigued Tamil Nadu government to take emergency measures to replant many felled plants as a natural barrier. This plant even has the potential to block and reduce the speed of the storms and hurricanes and could also prevent soil erosion to a greater extent (33).

Palmyrah palm male inflorescence activated carbon

Environmental pollution has always been a significant issue that has hampered the industrialization process and human health. One contaminant that is very apparent in water is artificial colour dye which has an impact on human health and environment (34). One of the most influential and adaptable options for removing organic and inorganic contaminants from waste water is adsorption on activated carbon (AC) (35). Palmyrah palm male inflorescence activated carbon (PPMIAC) contains several beneficial compounds and functional groups that contribute to its effectiveness in effluent remediation. The key compounds identified includes alkaloids, steroids, saponins, flavonoids, tannins and phenols. These compounds provide antioxidant, antimicrobial and adsorptive properties aiding in pollutant removal. This adsorption method is used to eliminate the surplus methylene blue (MB) dye from the aqueous solution (36).

Pharmacological activities of Palmyrah

Various parts of *B. flabellifer* are used to treat various disorders in traditional medicines and they have been used to treat abscess, anemia, asthma, constipation, cough and various pulmonary complaints, dermatitis, diabetes, diarrhea, dysentery, dysuria, fever, flatus, gonorrhea, heartburn, hiccup, hyperdipsia, hypertension, indigestion, inflammations, liver problems, nasal complaints, nausea, stomach pain, stomach ulcer, typhoid and vomiting (37). Compounds including *borassoside* A to F; uracil; nicotinamide; 2,3,4-trihydroxy-5-methylacetophenone;and(17α)-23-(E)-dammara-20,23-diene-3β,25-diol have been isolated from *B. flabellifer* (38). Various parts of the Palmyrah that are used for therapeutic and medicinal properties are represented in Fig. 3.

Various parts of *B. flabellifer* showed anthelmintic, anti-arthritic, antibacterial, anticancer, antidiabetic, antifungal, anti-inflammatory, antioxidant, antipyretic, diuretic, hypersensitivity, immune modulatory and wound healing activities. Flower, fruit, leaf, root, seed and tuber of this plant species exhibited pharmacological activities. However, the flower showed the greatest number of pharmacological activities (39).

Various extracts such as acetone, chloroform, ethanol, ethyl acetate, hexane, petroleum ether, methanol and water unveiled pharmacological activities (40). Anyway, ethanol extract displayed pharmacological activities in most studies. Some uses of *B. flabellifer* in traditional medicine have scientific evidence now. For example, both flower and root are used to treat diabetes in traditional medicine (41). Summary of pharmacological activities of different parts of Palmyrah are represented in Table 2.

Anti-diabetic activity

An extract from immature endosperm at a concentration of 200 mL was administered against randomly selected 30 numbers of type 2 patients for 28 days and discovered immature endosperm is a good diet for diabetic patients (42).

Fig. 3. Various parts of the Palmyrah that are used for therapeutic and medicinal properties.

Table 2. Summary of pharmacological activities of different parts of Palmyrah

Parts	Pharmacological activities	Key bioactive compounds	Reference
Roots	Anti-inflammatory, neuropharmacological effects, antidiabetic	Steroidal saponins, flavonoids	(51)
Leaves	Antiarthritic, analgesic, anti-inflammatory, anticonvulsant	Flavonoids, phenolic compounds	(61)
Male flowers (inflorescence)	Analgesic, antipyretic, anti-inflammatory, immunomodulatory	Spirostane-type steroidal saponins (borassosides)	(9)
Fruit pulp	Antioxidant, anti-inflammatory, antipyretic, antimicrobial, wound healing	Flavonoids, saponins, phenolics	(39)
Seed coat/soft shell	Antimicrobial, anticancer, antimitotic	Steroidal saponins, phenols	(62)
Seed shoots/flour	Neurotoxic effects (synergistic steroidal saponins and amines), detoxified by heat and washing	Steroidal saponins, primary amine compounds	(39)
Sap/Neera	Antioxidant, antimicrobial, anti-inflammatory, hepatoprotective	2,3,4-Trihydroxy-5-methyl acetophenone, vitamins	(31)
Sprouted endosperm	Antioxidant, antidiabetic	Flavonoids, steroids, sugars	(51)
Haustorium	Antioxidant, antimicrobial	Polyphenols, phenols, flavonoids	(2)

Ethanolic extract was screened for anti-diabetic potential against Alloxan induced diabetic rats. Recent experimental work with Nile rats demonstrated statistical significance with *p* -values less than 0.05 and meaningful confidence intervals correlating oil palm phenolics intake to blood glucose reduction, supporting anti-diabetic effects robustly. There was a significant decrease in fasting blood glucose levels (43).

Wound healing activity

A preliminary human trial was conducted with 7 volunteers to evaluate the efficacy of locally applied *Flabelliferin B* (FB) ointment, prepared from fruit extract at a concentration of 4 mg/mL, for wound healing over one week (44). The FB ointment promoted wound healing without causing any adverse effects. Metronidazole was used as the positive control in this study for comparison (41).

Anti-arthritic activity

An ethanolic extract at the dose of 200 mg/kg from the flower was employed using Freund's Complete Adjuvant (FCA) induced poly arthritis model for 21 days to screen anti-arthritic potential. Results showed significant anti- arthritic activity, as compared to control (Diclofenac sodium) at 100 mg/kg (7).

Anti-cancer activity

The anticancer activity of root methanol extract at the concentration of 1 µg/mL in human colorectal cancer cell lives for 28 days. They found that Trans-Scirpusin inhibited the growth of colorectal cancer Her2/CT26 cells in mice and it is not stated the positive control used in this study (45). Ethanolic leaf extract was evaluated for anticancer activity. The plant showed good cytotoxic effect (46).

Anti-inflammatory activity

An extract at the concentration of 150 mg/kg was prepared from the flower using ethanol and applied to acetic acid-induced writhes. Eventually, the extract was able to prevent damage to red blood cell membranes and promote the stabilization of the membrane (47). In this study, indo methacin and morphine were used as positive controls at the concentration of 10 mg/kg (48).

Antipyretic activity

Palmyrah is found with antipyretic element which makes Palmyrah tree superior in the pharmaceutical properties. One kilogram of Palmyrah flower was collected and an ethanolic extract was prepared at a dose of 150 mg/kg (49). The extract was tested on yeast-induced pyrexia in mice and rats and results showed that the extract significantly reversed hyperthermia (50).

Diuretic activity

The diuretic effect of tuber using the ethanol extract at the concentration of 200 mg/kg was investigated in mouse for 5 hr period and the result was compared with standard drug furosemide (100 mg/kg) and extract has shown a significant increase in the urinary level of Na^+, K^+ and Cl (51).

Hypersensitivity

An ethyl acetate extract of tuber was tested in the mouse at the concentration of 0.4 mg/kg (effective dose) (*ED50*) to study the potent immune suppressant activity for 5 hr and this was compared with cyclosporin A (52).

Anthelmintic activity

The anthelmintic property of leaf extract extracted using methanolin *Pheretima posthuma* at the concentration of 10 mg/mL and the results revealed that extract has effective anthelmintic activity against Indian adult earthworms (53).

Toddy palm Sap shows best anthelmintic activity. In this experiment earth worms were splits into three groups, tested with extract of various concentrations. Reference standard was Albendazole. Control group is treated with normal saline (54).

Antibacterial activity

A methanol extract at the concentration of 100 µg/mL from leaf was tested for its antibacterial property against *Bacillus subtilis*, *Klebsiellap neumonia*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *Staphylococcus aureus* and *Staphylococcus epidermidis* and the extract revealed significant inhibition of growth of selected bacterial strains. In this study, the researchers used amoxicillin and ciprofloxacin as a positive control at the concentration of 100 µg/mL (55).

Antifungal activity

The methanol extract prepared by the Palmyrah leaf showed an antifungal property against selected fungal strains (*Aspergillus flavus*, *Aspergillus fumigatus*, *Aspergillus niger*, *Candida albicans*, *Candida blanki*, *Microsporum canis*, *Saccharomyces cerevisiae*) at the concentration of 100 µg/mL (100 µg/mL). Therefore, the Palmyrah leaves extract actually ensures antifungal activities against many fungal strains and supports an organic antifungal activity (56).

Antioxidant activity

An extract prepared from seeds using methanol demonstrated antioxidant activity through DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) radical scavenging assays. At a concentration of 1 µg/mL, the extract exhibited an IC50 value comparable to that of ascorbic acid tested at the same concentration (57).

Antimicrobial activity

Seed coat extract (methanolic) was screened for five bacterial strains. Anti-microbial activity screened for *Staphylococcus aureus*, *Bacillus subtilis*, *Klebsiella* spp. and *Pseudomonas aeruginosa* by disc diffusion and agar well diffusion methods (58).

Toxicity

Determination of median LD50 study indicates no acute toxicity at a dose of 2000 mg/kg, it does not cover long-term toxicity or potential side effects from repeated exposure. Subchronic toxicity studies, typically lasting 28 to 90 days and chronic studies extending beyond 90 days, are essential to assess cumulative and delayed adverse effects (59). The absence of subchronic or chronic data represents a significant limitation in fully understanding the safety profile of the substance was done for fixing the therapeutic dose using ethanolic flower extract. This acute toxicity study revealed that even at the higher dose (2000 mg/kg) there were no mortality or any toxic reactions with oral administration of the extract (41).

Analgesic activity

Acetic acid induced writhing, hotplate and tail-clip method were used for investigation of analgesic activity. The ethanolic extract of male flowers (inflorescences) produced significant inhibition of pain (58).

Conclusion

Various parts of Palmyrah palm (*B. flabellifer*), exhibit a wide range of pharmacological activities, including anti-inflammatory, analgesic, anticancer, cytotoxicity, anti-hyperglycemic, antioxidant, antibacterial, antifungal, anthelmintic activity and hemolytic activity. These properties make Palmyrah a valuable plant for pharmacological research, with the potential to benefit both public health and scientific advancement.

Palmyrah palms play a vital role in environmental sustainability by effectively sequestering carbon dioxide, thereby aiding in the reduction of greenhouse gases. Their exceptional drought resistance makes them well-suited for cultivation in arid and semi-arid regions where many other crops struggle to survive. Additionally, their deep root systems contribute to soil fertility and stabilization, enhancing overall soil health. Beyond ecological advantages, Palmyrah supports economic development through its versatile applications in food, fiber and medicinal products, making it a valuable resource both environmentally and economically. In conclusion, the integration of Palmyrah into agricultural and agroforestry systems present a strategic approach to mitigating global warming. Its ecological resilience and economic versatility make it an asset for promoting sustainable development and enhancing the livelihoods of communities in vulnerable regions.

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Authors' contributions

DJ and PIV has done conceptualization. JA and NM performed formal analysis. MIM carried out supervision and validation and MA has checked language. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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