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ARTICLE

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HARNESSING *CYPERUS* SPECIES FOR NATURAL FIBRE, INSECTICIDAL, AND ALGICIDAL INNOVATIONS IN RURAL DEVELOPMENT

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Cyperus spp., a genus within the Cyperaceae family, is widely recognized in South Asia as a perennial weed with long-standing traditional uses in health care and agriculture. Today, its potential in supporting rural development through industrial and environmental applications is gaining significant interest. The fibrous characteristics of Cyperus spp. position it as a promising source of biodegradable, renewable materials that can serve as sustainable alternatives to synthetic fibers. A possible green pest management solution in rural sector is exploiting the insecticidal potential of Cyperus sp. It contains the phytochemicals such as cyperene, α-cyperone, α-corymbolol, α-pinene, caryophyllene oxide, cyperotundone, germacrene D, mustakone, and zierone which exhibits pesticidal activity. In addition to this Cyperus spp. can have possible use for enhancement of the quality of rural water bodies against algal blooms as an algicide. The current review explores the multidimensional value of Cyperus spp. as a resource for natural fiber, and biopesticide applications in sustainable, rural development.

Introduction

There is increasing global interest in sustainable, and eco-friendly materials. Recently the Cyperaceae family has attracted attention for its role in sustainable practices. This is due to the assorted bioactive compounds found in *Cyperus* species, which show insecticidal, antimicrobial, and antioxidant properties with applications in medicine, agriculture, and industry. Cyperaceae includes about 5,600 species across.

100 genera, widely distributed except in Antarctica. *Cyperus*, the second-largest genus with around 950 species (80 in India)[1], is common in tropical wetlands and contributes significantly to primary productivity. Its tubers, shoots, and fruits support aquatic fauna, and the plants have long been used in traditional medicine[2]. Natural fibres and compounds with reported insecticidal and allelopathic effects have been reported from *Cyperus* spp. A widely distributed perennial weed genus of *Cyperus*, *Cyperus rotundus* is valued in traditional medicine for treating fever, digestive issues, and menstrual disorders[3-6]. A native species of the old world, *Cyperus esculentus*, produces edible tubers like tiger nuts which was used since ancient Egypt and still popular today[7-8]. Historically in ancient cultures of Mediterranean, *Cyperus papyrus* was historically crucial for papermaking[9]. For its fibre quality *Cyperus pangorei* is notable whose extracts also show antibacterial and anti-diabetic potential[10-12]. This review summarizes recent findings on *Cyperus* species, emphasizing their applications in fiber development, insecticidal and algicidal products.

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Fibre source

Natural fibers have become a preferred alternative to synthetic fibers due to ease of extraction, strict environmental regulations, and the need for eco-friendly production processes[13,14]. In the composite industry, natural fibers are of significant interest. There is a growing demand for exploring new sources of natural fibers. Notably, numerous researchers have dedicated their efforts to discovering and utilizing various natural resource-based fibers such as sisal, coir, pineapple, jute, hemp, palm, Borassus, banana, and tamarind for reinforcing polymer-matrix composites[15-17]. *Cyperus* plants can source an ecological and economical source of natural fibre, which has superior stiffness-to-weight ratio compared to glass fiber, resulting in lighter composite parts. Consequently, this fiber serves as an excellent alternative to synthetic fibers in textile applications.

***Cyperus pangorei* Rottb:** Among Cyperaceae species, *Cyperus pangorei* was the first used for fiber extraction. Mature plants were retted in water for about 30 days, then fibers were manually extracted. *C. pangorei* fiber (CPF) contained 68.5% cellulose, 17.8% lignin, 0.17% wax, 9.19% moisture, had a density of 1.102 g/cc, and 3.56% ash. Its water absorption was lower than that of napier grass fibers[14]. CPF also had lower wax content than wild date palm and veldt grape fibers[18], aiding chemical treatment and fiber–matrix bonding. CPF showed tensile strength of 196±56 MPa, Young's modulus of 11.6±2.6 GPa, was semi-crystalline (XRD, FT-IR), and thermally stable up to 221 °C. SEM revealed a rough surface that supports mechanical interlocking[10].

***Cyperus compactus* Retz.:** A new fiber was extracted from the stem of *Cyperus compactus*. Stems were submerged in water for 35 days, and after retting, the moist fibers were manually removed, washed with double-distilled water, and sun-dried for seven days. The resulting *C. compactus* Retz fiber (CCF) had lengths of 309.22–398.12 ìm (mean 379.11 ìm) and diameters of 17.44–19.91 ìm (mean 19.31 ìm). Its Slenderness Ratio was 19.63, with a Runkel ratio of 65.25 and Flexibility Coefficient of 0.56. These dimensions were comparable to fibers such as *C. pangorei*, jute, flax, and hemp[19].

***Cyperus papyrus*:** Fibers from the *Cyperus papyrus* plant were extracted using water retting and alkaline extraction methods. The fibrous interior is exposed with the removal of the outer green layer of *C. papyrus* plant. The striped stems were then sun dried for a couple of days and weighed to determine the fibre output. The dried stems were washed and treated with 3% sodium hydroxide at 45ºC for 30 mins with a material-to-liquor ratio of 1:20. Extraction with water required submerging the stems in water at normal temperature for 10 to 40 days. This facilitates natural retting by organisms to decompose the lignin and liberate the fibres. The chemical composition of the fibres was analysed: alkaline-extracted fibres comprised 61.82% cellulose, 11.82% hemicellulose, 23.6% lignin, 3.86% ash, and 2.75% extractives, whereas water-retted fibres contained 57.98% cellulose, 13.45% hemicellulose, 25.42% lignin, 6.07% ash, and 3.15% extractives. The fibers exhibited thermal degradation temperatures as high as 150 ºC. Based on these properties, the extracted fibers have the potential to replace conventional fibers[20].

***Cyperus digitatus* Rox b:** Fibres obtained from water retting degradation of *Cyperus digitatus* (CDF) and *Cyperus exaltatus* (CEF) were characterised in investigations. These studies revealed that both CDF and CEF had uneven and rough surface textures, were semi-crystalline, and contained cellulose. The tensile strength and Young's modulus of CDF were approximately 342.6 MPa and 89.5 GPa, respectively, which were higher than those of CEF. Thermal studies confirmed the stability of CDF and CEF up to 232ºC and 203ºC, respectively. These results indicate that CDF and CEF are suitable substitute materials for traditional synthetic fibers making them ideal for use in the rural mat-making small-scale industry[21].

***Cyperus platystylis* R.Br.:** The study found that a higher cellulose content and lower lignin content in natural fibers result in greater tensile strength. Relative high cellulose content (66.1%) was obtained in *C. platystylis* fiber, contributing to its high tensile strength of 657 MPa this makes it high-quality bio-composite raw material. Cellulose content showed a correlation between tensile strength and Young's module. Additionally, hemicellulose and wax content correlated positively with Young's modulus. The unique properties of *C. platystylis* stem fiber make it a potential candidate for reinforcement in bio-composites[22].

***Cyperus dichrostachus* A.:** The fiber from the *Cyperus dichrostachus* A. Rich plant has a chemical composition of 60.27% cellulose, 22.72% hemicellulose, and 16.59% lignin. It has a density of 1010 kg/m³, good tenacity of 105.76 cN/Tex, and low elongation of 4.88%. Thermal stability analysis revealed that the cellulose degraded at a temperature of 377.1°C. Fourier transform infrared spectroscopy confirmed that *C. dichrostachus* fiber is rich in cellulose[23].

Insecticidal Attributes

An array of bioactive chemicals is found in *Cyperus* plants which include essential oils, alkaloids, flavonoids, and terpenoids. These chemicals have pesticidal action, seen in several species and have been regarded as an alternative to chemical pesticides in pest management. Essential oil derived from the rhizomes of *Cyperus* *rotundus* L. exhibits potent insecticidal properties. Management of insect pests by *Cyperus* essential oils in considerable due to their toxicity and capacity to interfere with the normal physiological functions of insects. Primarily the insecticidal characteristics of *Cyperus* spp. are chiefly recognized for the presence of monoterpenes, sesquiterpenes, and other phytochemicals in their essential oils. These chemicals may function as growth retardants and neurotoxins, affecting the nervous system of target insects and resulting in paralysis or mortality. They may also function as repellents, hence diminishing the chance of infestation. Thirty-five components were identified, with α-cyperone (29.38%), cyperene (13.97%), caryophyllene oxide (6.71%), and β-selinene (6.47%) as major constituents. Bioactivity-guided fractionation isolated cyperene and α-cyperone, the latter showing higher contact toxicity against *Liposcelis bostrychophila* (LC_{50} = 41.32 μg/cm²) than cyperene (LC_{50} = 50.08 μg/cm²), while the whole oil recorded an LC_{50} of 102.11 μg/cm². Another study confirmed sesquiterpenes such as elemenone (13.59%), α-cyperone (13.41%), and caryophyllene oxide (13.03%) observed as the dominant insecticidal components, showing toxicity against *Callosobruchus maculatus*, *Oryzaephilus surinamensis*, and *Trogoderma granarium* with LC_{50} values of 0.36, 0.51, and 0.2 μL/cm², respectively. Repellency reached 94% for *O. surinamensis* and *T. granarium* and 80% for *C. maculatus* after 2 hours[24]. The n-hexane fraction of methanolic root extract as reported by Singh et al. (2024) caused high toxicity to *Aphis craccivora* (LD_{50} = 1.12 μg/insect) and *Planococcus lilacinus* (LD_{50} = 0.94 μg/insect). A total of 35 volatile compounds were detected, with cyperotundone, cyperene, mustakone, isolongifolen-5-one, and boronia butenal dominant. Essential oils extracted using deep eutectic solvents (DES-6, DES-7) showed even stronger toxicity (LD_{50} = 0.59–0.87 μg/insect). NMR identified cyperotundone, cyperene, and cyperene epoxide as key active compounds, all effective against *P. lilacinus* and inhibitory to acetylcholinesterase and GST[25].

Algicidal Properties

An effective strategy to supress harmful algae is to use plant based algicidal substances. The *Cyperaceae* family, in addition to its known allelopathic effects on crops, also exhibits inhibitory actions against algae. For example, *C. alternifolius* has been found to inhibit the growth of *Microcystis aeruginosa*. Previous studies have conclusively shown that numerous allelochemicals produced by *C. alternifolius* collect in the water and inhibit the growth of M. aeruginosa. The retarding effects of these aqueous solutions against *M. aeruginosa* were 29%, 44%, and 59% after 5, 10, and 15 days of culture, respectively[11]. compounds including fatty acids and phenolic compounds were identified in GC/MS studies that had anti-cyanobacterial activity. The study suggests that artificial floating-bed plants may potentially control harmful cyanobacteria[26,27]. *C. rotundus* aqueous extract also showed promising activity in inhibiting the growth of *Phaeocystis globosa*, a harmful algal bloom species, in a separate study. Differential concentrates of the extracts showed varying inhibition levels of algal growth compared with untreated controls. Test groups exposed to 48 hours with concentrations of 4, 8, and 16 mg/mL of extract produced significant levels of inhibition. This was shown as there was reductions in the chlorophyll-a content and photosynthetic efficiency. Phenolic acids, primarily quinic acid, were identified as the key algicidal substances in the aqueous extracts, with an effective concentration of 22 mg/L at 96 hours[28].

Conclusion

Due to their diverse biological and material features, *Cyperus* species provide sustainable rural development. These plants provide natural fibres, botanical pesticides, and algicidal substances in addition to their ethnomedicinal properties like antioxidant, anti-inflammatory, neuroprotective, antibacterial, and anticancer benefits. Their strong, flexible fibres support rural lives through mat weaving, rope manufacturing, fencing, and thatching. Research suggests that *Cyperus* fibre and nanocellulose can generate sustainable, high-performance materials that may replace synthetic fibres.

Cyperus insecticides are environmentally safe and effective in rural areas, while their algicidal properties protect pond and aquaculture water quality. Non-medicinal research could provide new value-added commodities, boost rural economies, and promote sustainable use of local plant resources despite being less studied than therapeutic applications.

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