

REVIEW

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Nyctanthes arbor-tristis Linn. (Night Jasmine): extraction techniques, phytochemical constituents, and biological impacts of extracts and essential oil

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Abstract

Background *Nyctanthes arbor-tristis* Linn. is a small, sacred ornamental tree used in prayer. It is renowned throughout India for its aromatic white blossoms. The entire plant was widely used for several health applications particularly root and bark were used to treat fever and cough, respectively. Also, the leaf was used for managing fever and diabetes, and its cholagogue, diaphoretic, and anthelmintic properties.

Main text The current review aimed to comprehensively analyze the botanical characteristics, phytochemistry, and pharmacology of *N. arbor-tristis* essential oil (NAEO) and extracts. Additionally, it wants to emphasize the latest advancements in phytochemistry and pharmacology related to this aromatic plant. Depending on the variety, origin, and plant parts used, the NAEO yield ranged from 0.002 to 0.10% on a dry basis. The NAEO has been investigated in only a few research studies and resulted, in the predominant levels of phytol and methyl palmitate chemical compounds. Furthermore, the NAEO was found to have significant volatile chemical constituents, including geranylgeraniol, phytoene, nonadecane, linalool, and various other miscellaneous chemical components. The plant extracts and NAEO have numerous biological properties, including antioxidant, antimicrobial, anticancer, anti-inflammatory, analgesic, larvicidal, and other miscellaneous activities.

Conclusion This paper analyzes and summarizes the diverse research potential associated with *N. arbor-tristis*. The results of the present study suggested that most of the biological and pharmacological investigations were carried out without including dosage, positive controls, and negative controls. Furthermore, several pharmacological investigations were exclusively carried out using cell lines and animal models. Hence, the following research endeavors aimed at assessing the medicinal properties of NAEO and extracts in human subjects would broaden the scope of its utilization.

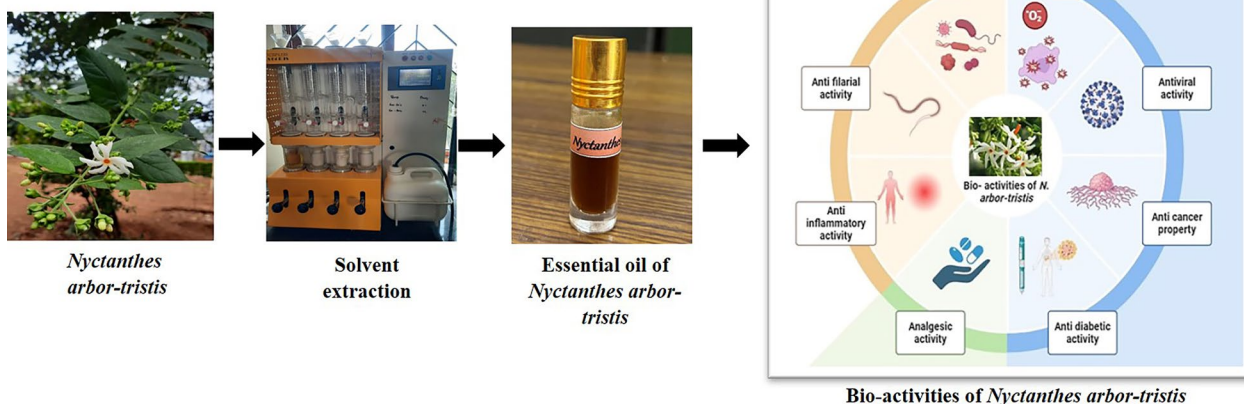
Keywords Botany, Biological activities, Essential oil, *Nyctanthes arbor-tristis*, Pharmacology

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Graphical abstract



Background

N. arbor-tristis is a little, sacred ornamental tree in Indian mythology used for prayer. The plant is widely recognized across the country for its aromatic white flowers. As per Hindu mythology, the Parijata tree is recognized as one of the five wish-granting trees associated with Devaloka [1]. *N. arbor-tristis* is commonly referred to as “Night Jasmine or Harsinghar.” The genus name “*Nyctanthes*” is derived from the Greek phrases “*Nykhta*,” meaning night, and “*anther*,” meaning flower. Within the botanical family of Oleaceae, Night Jasmine genus encompasses more than 600 species of little trees and vines [2]. These glabrous twining shrubs are commonly found in tropical Asia and warm temperate regions of Europe and Africa. Additionally, they are extensively cultivated in gardens within these areas [3].

The plant is distributed over several regions, namely southern India, northern Pakistan, Thailand, Malaysia, and Indonesia. Its original habitat is the subtropical Himalayas of Nepal and India [3]. The species is distributed over several regions in India, including the outer Himalayas, the Jammu and Kashmir region, East Assam, Bengal, Tripura, and the central region extending to the Godavari River in the southern part. The plant flourishes in soil that is reddish-black in color and has a pH level between 5.6 and 7.5. It is well-suited for dry and semi-arid conditions [4].

The aromatic blossoms are commonly generated in clusters. The flowers exhibit vibrant orange corolla tubes positioned at the core of their white petals, and

they produce many blooms during the nocturnal hours and gradually diminish in intensity before dawn [5]. The flowers’ tubular calyx, produce a chemical compound called crocetin [6]. The major chemical components of NAEO and extracts were phytol, methyl palmitate, *cis*-9-tricosene, geranylgeraniol, nonadecane, n-pentacosane, phytone, methyl myristate, eucarvone, and linalool [7–9].

Numerous research studies reported that extracts from the flowers and leaves of *N. arbor-tristis* possess stomachic, carminative, colon astringent, expectorant, anti-bilious, hair tonic, and therapeutic properties [2, 3, 7–10]. These features make them effective in treating piles and several skin problems. Recent pharmacological research has shown floral extract to possess several properties, such as antioxidant, anthelmintic, antidiabetic, and central nervous system (CNS) depressive effects [11]. Furthermore, the leaf has medicinal properties that effectively treat fever and diabetes. It can also serve as a cholagogue, diaphoretic, and anthelmintic, as documented by Agarwal and Pal [10] and Sah and Verma [12]. In several previous studies reported the pharmacological potential of crude extracts from *N. arbor-tristis* and other organic chemicals. However, the phytochemical composition and biological activities of NAEO and active components have not yet been compiled. The objective of this study is to comprehensively analyze the NAEO yield, chemical composition, and biological properties based on published literature up to May 2024. The study also aims to identify areas that require further investigation.

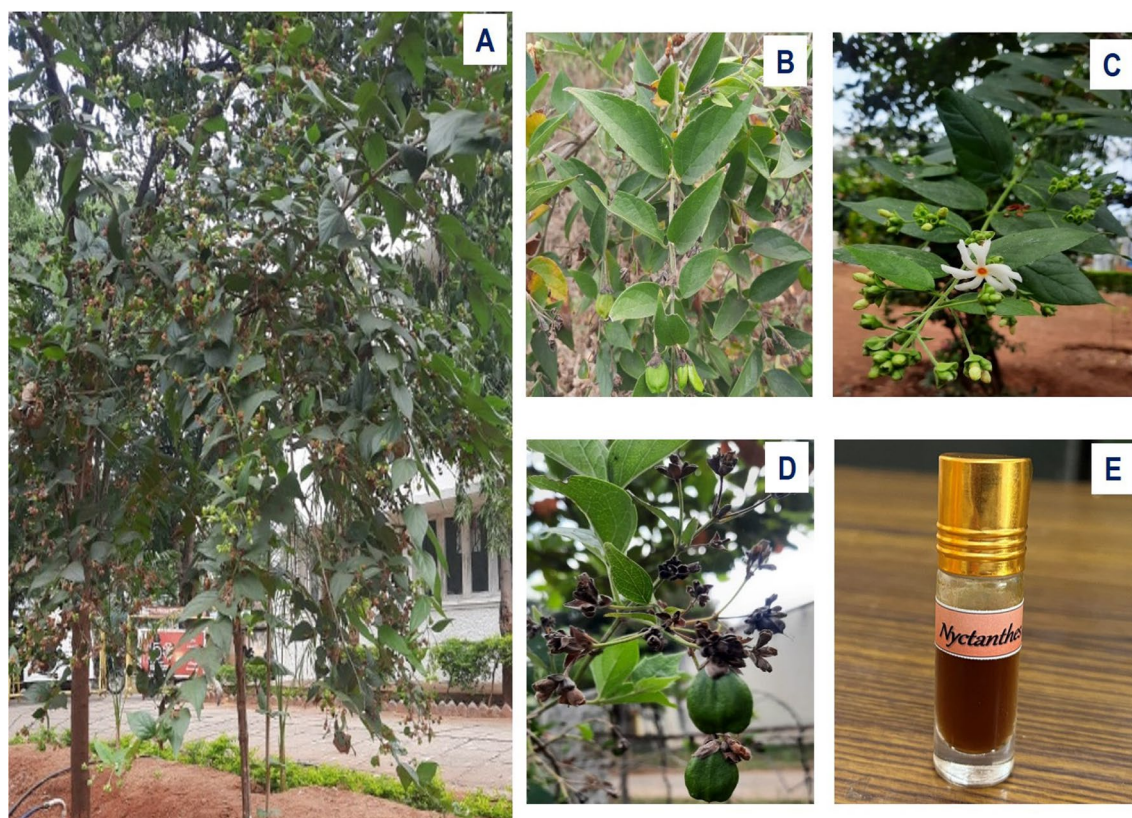


Fig. 1 Morphological identification of *N. arbor-tristis* **a** The young tree; **b** leaves of the plant; **c** flower; **d** fruit; **e** essential oil

Botanical profile of *N. arbor-tristis*

Taxonomic classification

Kingdom: Plantae
 Division: Magnoliophyta
 Class: Magnoliopsida
 Order: Lamiales
 Family: Oleaceae
 Genus: *Nyctanthes*
 Species: *arbor-tristis*
 Botanical Name: *Nyctanthes arbor-tristis* Linn.

Vernacular names

Tamil: Pavalamalli
 English: Night Jasmine
 Hindi: Harsingar
 Sanskrit: Parijatha
 Marathi: Parijathak
 Telugu: Pagadamalle
 Malayalam: Parijatakam [13].

N. arbor-tristis is a notable linear botanical specimen distinguished by its polygonal branches, which attain a vertical stature of 7–10 m. The bark displays a rough and granular gray hue [14]. The leaves are coarse and adorned with trichomes. The flowers tend to cluster together at the uppermost parts of the branches or within the axils of the leaves. The flowers are immobile, emit a nice scent, and have a hollow, bell-shaped coil. Chakraborty and De [13] have reported that fruits display a heart-shaped morphology and contain a brown coloration. The morphological identification of the complete *N. arbor-tristis* plant, with its leaves, fruit, and seed, is shown in Fig. 1.

Traditional medicine

N. arbor-tristis is well recognized as a highly efficacious medicinal plant within Ayurveda, Homoeopathy, Unani, and Siddha. In ethnomedicine, *N. arbor-tristis* therapy is beneficial in treating several disorders, such as persistent fever, rheumatism, malaria, wound healing, skin problems, stomachic issues, astringent effects, menstruation problems, and wound healing [15]. The native inhabitants of the Chittoor region in Andhra Pradesh, India, make considerable use of the entire plant for therapeutic purposes. The root possesses therapeutic properties for

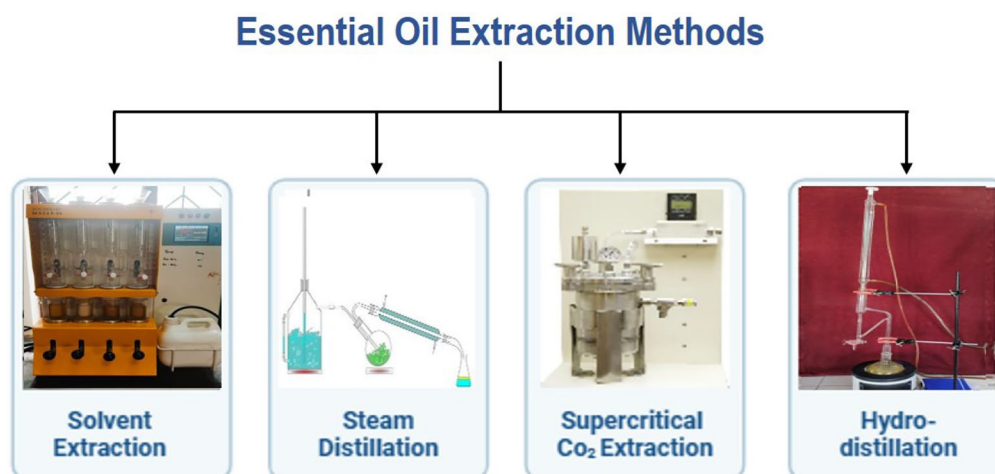


Fig. 2 Commonly used essential oil extraction methods in plants

managing fever, sciatica, and anorexia, while the bark is applied for its expectorant properties [10]. An extract derived from the leaves has been administered to children to expel roundworms and threadworms. Fresh leaves have been utilized in the preparation of homeopathic remedies [1]. The juice extracted from 3 to 7 leaves is employed by tribal communities in Orissa as a blood purifier, serving as a preventive measure against skin infections [1]. The floral components of *Nyctanthes arbor-tristis* are utilized in India, Indonesia (Java), and Malaysia as emmenagogues, stimulating menstrual flow. A heated concoction of these flowers is employed by a subset of elderly Buddhist monks in Sri Lanka for its sedative properties [16]. The oral intake of a decoction derived from these flowers has been found to alleviate flatulence, stimulate gastric secretions, and enhance pulmonary expectoration. This decoction has also been used in the management of gout. Furthermore, the juice extracted from these flowers is applied as a hair tonic, preventing hair graying and baldness [17].

Essential oil extraction methods

Essential oils find applications in a wide range of consumer products, including detergents, soaps, cosmetics, pharmaceuticals, perfumes, candies, soft drinks, alcoholic beverages, and insecticides. The global production and consumption of essential oils and perfumes have witnessed significant growth. Advanced production technologies play a pivotal role in enhancing both the quantity and quality of essential oils. Despite rapid advancements in production processes, many regions still rely on traditional methods for essential oil extraction. Common techniques include solvent extraction, steam distillation, supercritical CO₂ extraction, and

hydrodistillation. Figure 2 illustrates the predominant techniques for extracting essential oils from medicinal and aromatic plants.

Solvent extraction

Solvent extraction is a modern technique that uses liquid solvents to remove solute components from solid materials. According to Babazadeh and Arumugam [18], solvent extraction is a process that can be used to extract valuable molecules or detoxify solvents by eliminating undesirable components. Additionally, n-hexane solvent extraction is a method for extracting floral and seed essential oils [19]. The frequently employed solvents include hexane, petroleum ether, ethanol, isopropanol, acetone, chloroform, methanol, and 1-butanol [20]. Solvent extraction has the potential to produce a larger volume of oil and isolate a wider range of compounds. However, the presence of residual solvent in the extract could pose a problem. Additionally, this method could result in the degradation of some thermolabile compounds [19]. To the best of our understanding, more comprehensive research needs to be undertaken to estimate *N. arbor-tristis* flower essential oil using solvent extraction.

Steam distillation

Steam distillation is a very secure method for extracting essential oils from heat-sensitive plants and flowers, effectively safeguarding the integrity of volatile and aromatic chemicals. In contrast to alternative techniques, steam distillation effectively retains volatile compounds throughout heating, evaporation, separation, and reflux [21]. This approach demonstrates enhanced efficacy with reduced duration of distillation and yields superior oil production. Steam distillation involves the introduction

Table 1 Yield of essential oil from various parts of *N. arbor-tristis*

Parts	Location	Extraction method	Oil Yield (%)	References
Leaves	Ludhiana, India	Hydrodistillation	0.010%	[40]
Leaves	Biratnagar, Nepal	Hydrodistillation	0.002%	[7]
Bark	Biratnagar, Nepal	Hydrodistillation	0.005%	[7]
Flowers	Coimbatore, India	Hydrodistillation	Not reported	[9]
Flowers	Pannipitiya, Sri Lanka	Hydrodistillation	0.06%	[8]

of steam into the botanical material to harvest the essential oil. Steam undergoes evaporation of essential oil by interacting with botanical material [22]. To release essential oils without causing harm to their volatile components, it is necessary to heat the steam to a temperature range of 200–300 °C. Oil molecules are released from glandular trichomes located on the outer surfaces of the flowers and leaves of several fragrant plants through the process of steam. Concentrated steam destroys plant sacs, resulting in the release of oil molecules [23]. The essential oil yield was influenced by various factors, including the quantity of inherent essential oil present in the oil sacs of the botanical material, the duration of the distillation process, the temperature of the steam, and the applied pressure [24]. Higher temperatures during steam distillation can lead to the degradation of volatiles and the formation of undesirable chemical byproducts [2]. So far, no study has been undertaken using steam distillation to estimate essential oil derived from the flowers of *N. arbor-tristis*.

Supercritical CO₂ extraction

Supercritical CO₂ extraction is a modern technique to extract essential oils from various parts of the plant [25]. Carbon dioxide (CO₂) is employed as a solvent in the supercritical fluid extraction of essential oils [26]. Plant material that has been pulverized is introduced into an extraction vessel, where carbon dioxide (CO₂) is subjected to supercritical conditions at elevated pressures and temperatures [27]. Carbon dioxide was supercritical at a pressure of 78.3 bar and a temperature of 31.1 °C, allowing it to form bonds with plant volatiles [24]. The carbon dioxide emitted by a pump facilitates the interaction between plant material and the extraction vessel. Carbon dioxide (CO₂) degrades glandular trichomes that carry oil molecules, isolating them. A low-pressure and temperature separator extracts all essential oils from CO₂ [28, 29]. The extraction of botanical oil is influenced by fluid density and dissolving power, particularly in the case of supercritical CO₂ [30]. The recyclability of supercritical CO₂ extraction makes it an environmentally beneficial technology. CO₂ extraction is FDA-approved for industrial applications, unlike solvents like hexane, which

leave residues and emit pollutants. This feature enhances the safety and sustainability of many processes. Furthermore, this innovative methodology for extracting essential oils from the flowers of *N. arbor-tristis* has not been implemented thus far. Hence, future studies must evaluate the quantification of essential oils using supercritical CO₂ extraction since it holds potential advantages for the fragrance sector.

Hydrodistillation

Hydrodistillation is a conventional method that utilizes water vapor to extract plant essential oils. The aromatic raw material was filled with water and subjected to boiling until it reached its boiling point. Plant cells undergo thermal decomposition, resulting in the emission of aromatic chemicals into the atmosphere. The condenser facilitates the cooling and condensation of steam containing aromatic chemicals [31]. Hot water and steam facilitate the release and transport of bioactive chemicals from the plant matrix. The vapor mixture undergoes condensation via indirect cooling, separating essential oils and oil-based bioactive chemicals from water. The process of desiccation using anhydrous sodium sulfate is followed by the chromatographic analysis of essential oils and oil-based bioactive substances [32–34]. This method routinely extracts essential oils from spices, medicinal plants, and aromatic crops [35–39]. Nevertheless, there is a need for more research that has explicitly concentrated on examining the process of extracting essential oil from the blooms of *N. arbor-tristis*. The study's findings revealed a decrease in oil production, with percentages ranging from 0.002 to 0.10% [7–9]. It is vital to undertake additional study investigations using this approach.

Chemical composition

Nyctanthes arbor-tristis essential oil (NAEO) and its composition

The NAEO yield ranged from 0.002 to 0.10% on a dry basis, depending on the variety, origin, and plant parts employed (Table 1). The flowers of *N. arbor-tristis* yielded 0.06% essential oil, whereas the barks yielded 0.005% [7, 8]. Different soil types, locations, origins, extraction techniques, and environmental factors could all have an

Table 2 Major constituents of *Nyctanthes arbor-tristis* essential oils from various geographical origin

Geographical origins	Parts	Major constituents	References
Sri Lanka	Flowers	Phytol (32.2%), Methyl palmitate (14.7%), <i>cis</i> -9-Tricosene (3.6%), Geranylgeraniol (2.7%), n-Nonadecene (2.2%), Phytone (1.4%), Methyl stearate (1.1%), n-Benzyl salicylate (1.1%), and Heptacosane (0.8%),	[8]
Nepal	Leaves	Hexadecanoic acid (26.4%), phytol (13.6%), Hexenyl benzoate (11%), Linalool (11.3%), Octadecanoic acid (6.2%), Methyl salicylate (5.6%), n-Dodecanol (5.5%), Alpha-Terpineol (4.7%), and Geraniol (3.7%),	[7]
	Barks	Hexadecanoic acid (34.3%), Alpha-Eudesmol (8.7%), Beta-Eudesmol (17.1%), Elemol (5.8%), Cryptomeridiol (4.8%), Octadecanoic acid (3.9%), n-Dodecanol (6.8%), Methyl palmitate (1.8%), Methyl stearate (1.4%), and 1,8-Cineole (1.3%)	[7]
India (Tamil Nadu)	Flowers	1-octanol (74.81%), 2-hexadecen-1-ol, 3,7,11,15-tetra (6.8%), Bis (2-ethylhexyl) phthalate (5.88%), 2,4-cycloheptadiene-1-one, 2,6,6-trimethyl (4.23%), Hexadecanoic acid methyl ester (2.07%), and Benzoic acid (1.21%)	[9]

impact on the variations in *N. arbor-tristis* essential oil yields.

In all the studies, the hydrodistillation method was used for NAEO extraction (Table 1). Siriwardena et al. [8] investigated the chemical constituents present in the essential oil from *Nyctanthes arbor-tristis* L. flowers cultivated in Sri Lanka. The essential oils were extracted through hydrodistillation. The analysis of the volatile samples was conducted using GC–MS method, and 48 chemical components were identified from the essential oil. Among these components, phytol (32.2%) and methyl palmitate (14.7%) are the predominant constituents in the essential oil. Additionally, notable volatile constituents such as *cis*-9-tricosene (3.6%), geranylgeraniol (2.7%), nonadecane (2.3%), n-pentacosane (1.6%), phytone (1.4%), methyl myristate (1.1%), eucarvone (0.9%), and linalool (0.8%), were identified in the essential oil [8]. However, south India-grown *Nyctanthes arbor-tristis*, 1-octanol (74.81%), 2-hexadecen-1-ol, 3,7,11,15-tetra (6.8%), 2,4-cycloheptadiene-1-one, 2,6,6-trimethyl (4.23%) chemical components are predominant in flower essential oil [9]. The major chemical constituents of NAEO across growing regions are summarized in Table 2.

Minor constituents of flowers from Sri Lanka are linalool (0.8%), benzaldehyde (0.3%), and terpineol (0.2%) [8]. Minor constituents of leaves from Nepal are *m*-cymen-8-ol (0.6%), *p*-cymen-8-ol (0.5%), and phenylacetaldehyde (0.3%). Minor constituents of flowers from India are tetradecane (0.68%) and heneicosane (0.51%) [7–9]. The variation in the minor constituents of NAEO might be due to the essential oil used in various plant parts of *N. arbor-tristis*.

Biological and pharmacological potentials

The NAEO and extracts have various pharmacological and biological properties, such as antioxidant, antimicrobial, antidiabetic, anticancer, larvicidal, and other miscellaneous activities listed in Table 3. The potential

biological and pharmacological effects of *N. arbor-tristis* are diagrammatically shown in Fig. 3.

Antioxidant activity

In response to oxidative stress, plants employ intricate defensive systems that depend on a synergistic interplay of metabolites and enzymes to address environmental complications effectively. An earlier study reported that methanolic leaf extract with a IC_{50} of 63.6% showed significant antioxidant activity [41]. According to Gulshan et al. [42], the ingestion of chloroform extracts derived from leaves and flowers, along with a 50% ethanolic extract of leaves, showed decrease in the level of SGPT, SGOT, cholesterol, and triglycerides in the blood. Additionally, it leads to an increase in the levels of catalase (CAT) and superoxide dismutase (SOD). A recent study examined the antioxidant properties of *N. arbor-tristis* using several methodologies, such as the assessment of total antioxidant capacity, the DPPH test, free radical scavenging activity, and reducing power assay. *N. arbor-tristis* exhibits antioxidant activity due to its ability to counteract different physiologically crucial reactive oxygen species, reducing lipid peroxidation and DNA damage [43]. In another study, results remarked that the ethanolic extract of the *N. arbor-tristis* leaves with IC_{50} values of 30.75 μ g/ml and 30.83 μ g/ml showed significant antioxidant activity using DPPH and ABTS assays, respectively [44]. The *N. arbor-tristis* flower extracts demonstrate noteworthy antioxidant activity, indicating their potential suitability for utilization in the food industry. It has the potential to be both powerful antioxidant and viable food dye [12]. These occurrences, various benefits, highlight its potential significance in improving both human welfare and industrial utilization. Nevertheless, most of the antioxidant properties were evaluated using DPPH assays, which no longer have pharmacological significance. It is necessary to investigate their potential under both in vitro and in vivo conditions [45].

Table 3 Biological and pharmacological potential of *N. arbor-tristis*

Health benefits	Plant parts	Study extract	In vitro/In vivo	Model used	IC ₅₀ /LD ₅₀ (Dosage)	Control	Results/remarks	References
Antioxidant activity	Flower	Ethanollic, Ethyl acetate, and Aqueous extract	In vitro	DPPH	EC ₅₀ : 406.34 µg/ml (ethanollic extract), EC ₅₀ : 564.35 µg/ml (ethyl acetate extract), EC ₅₀ : 723.90 µg/ml (aqueous extract)	–	The ethanollic extract of the flower exhibits superior free radical scavenging activity compared to the other two extracts	[5]
Antioxidant activity	Leaves	Betulinic acid	In vitro	DPPH	IC ₅₀ : 18.03 µg/ml	Positive: Ascorbic acid	Betulinic acid isolated from ethanollic leaf extract exhibited potential antioxidant activity	[59]
Antioxidant activity	Leaves	Ethanollic extract	In vitro	DPPH ABTS	IC ₅₀ : 30.75 µg/ml IC ₅₀ : 30.83 µg/ml	Positive: Ascorbic acid Negative: Ethanol	The leaf extracts showed significant antioxidant potential in both DPPH and ABTS assays	[44]
Antioxidant	Leaves	Aqueous extract	In vitro	DPPH	IC ₅₀ : 125 µg/ml	–	The study reveals that the leaf extract with IC ₅₀ : 125 µg/ml exhibits antioxidant activity	[2]
Antimicrobial activity	Leaves	Petroleum ether extract	In vitro	<i>S. aureus</i> , <i>E. coli</i> , <i>P. aeruginosa</i> , <i>A. niger</i> , <i>A. flavus</i> , <i>F. culmorum</i> , <i>R. stolonifer</i>	IC ₅₀ : 24.3 mg/ml	–	The petroleum ether extract showed the largest area of inhibition against <i>P. aeruginosa</i> , measuring 20.3 mm	[49]
Antibacterial activity	Leaves	Ethanollic extract	In vitro	<i>Aeromonas salmonicida</i>	IC ₅₀ : 113.40 mg/mL	Positive: Kanamycin	The leaf extract in ethanol exhibited substantial antibacterial efficacy against <i>Aeromonas salmonicida</i>	[44]
Antibacterial activity	Flower	Ethanollic extract	In vitro	<i>Pseudomonas aeruginosa</i>	IC ₅₀ : 125.85 mg/mL	Positive: Kanamycin	The floral extract dissolved in ethanol showed significant antibacterial effects against <i>Pseudomonas aeruginosa</i>	[44]
Antibacterial activity	Leaves extract	Aqueous extract	In vitro	<i>Staphylococcus aureus</i> <i>Acinetobacter baumannii</i>	MIC: 12.5 mg/ml MIC: 3.13 mg/ml	–	The maximum zone of inhibition against <i>A. baumannii</i> and <i>S. aureus</i> was found to be 0.5 mm and 7 mm, respectively	[60]

Table 3 (continued)

Health benefits	Plant parts	Study extract	In vitro/ In vivo	Model used	IC ₅₀ /LD ₅₀ (Dosage)	Control	Results/remarks	References
Anti-fungal activity	Leaves	Ethyl acetate extract	In vitro	<i>A. flavus</i> , <i>A. niger</i>	MIC: 1 mg/ml	Negative: Ethyl acetate	The ethyl extract of <i>N. arbor-tristis</i> exhibits potent antifungal properties	[61]
Anti-fungal activity	Flower	Aqueous extract	In vitro	<i>A. alternata</i> , <i>A. niger</i> , <i>B. cinerea</i> , <i>F. oxysporum</i> , <i>P. expansum</i>	MIC: 16 µg/ml	–	It aids in overcoming the challenges in managing fungal diseases caused by the emergence of resistance to common fungicides	[62]
Antiviral activity	Seeds	n-Butanol fraction of 50% ethanolic extract. Arbotristoside-A, and Arbotristoside C	In vivo	Encephalomyocarditis Virus infected Swiss Albino mice	125 mg/kg body weight/day	–	The ethanolic and n-butanol fractions, as well as the individual chemicals arbotristoside-A and arbotristoside C, exhibited virus inhibitory effects	[63]
Anti-inflammatory activity	Leaves	Petroleum ether extract	In vivo	carrageenan-induced hind paw edema method	50 mg/kg body weight	Positive: Pentazocine	Justified its use in various inflammatory conditions	[64]
Analgesic activity	Leaves	β-sitosterol isolated from petroleum ether extract	In vivo	Mice placed individually on the hot plate maintained at 55 °C,	5, 10 and 20 mg/kg, i.p	Positive: Pentazocine	The isolated β-sitosterol had a dose-dependent activity that was comparable to the standard drug pentazocine	[64]
Antiproliferative activity	Flowers	Crude aqueous fraction Methanol fraction Hexane fraction	In vitro In vitro In vitro	Peripheral blood mononuclear cells (PBMC) from acute myeloid patients Jurkat cells MCF7 breast cancer cell line	IC ₅₀ : 1262 µg/mL IC ₅₀ : 733 µg/mL IC ₅₀ : 717.6 µg/mL	Positive: Doxorubicin	PBMC from acute myeloid leukemia patients were highly inhibited by the aqueous extract. The methanol fraction had higher inhibition in Jurkat cells, followed by the aqueous extract and hexane fraction. However, the hexane fraction inhibits MCF7 breast cancer cells better than methanol, ethyl acetate, and chloroform fractions	[65]

Table 3 (continued)

Health benefits	Plant parts	Study extract	In vitro/ In vivo	Model used	IC ₅₀ /LD ₅₀ (Dosage)	Control	Results/remarks	References
Hepatoprotective activity	Flowers	Aqueous extract	In vitro	Carbon tetrachloride-induced liver damage in Wistar rats	200 mg/kg body weight	–	Ethanol and aqueous extracts showed effective activity	[66]
Hypoglycemic and hypolipidemic activity	Flower	Aqueous extract	In vitro	Alpha amylase assay and glucose absorption were tested in Male mice	250, 500, 750 mg/kg body weight	Positive: Acarbose Negative: Distilled water	The hypoglycemic and hypolipidemic activities are present with a dosage of 500 mg/kg body weight of boiled aqueous extract of flowers (AEF) from <i>N. arbor-tristis</i>	[57]
Hypoglycemic and hypolipidemic activity	Leaves	Ethanol extract	In vivo	Oral glucose tolerance test (OGTT)	400 mg/kg body weight	Positive: Streptozotocin Negative: Saline water	The findings indicate that <i>N. arbor-tristis</i> extract has a hypoglycemia and hypolipidemic effect that depends on the dosage. This effect is effective in regulating the early biochemical indicators of kidney function and lipid levels	[67]
Antidiabetic activity	Stern bark	Ethanol extract	In vivo	Oral administration of ethanol extract (EENA)	250 and 500 mg/kg body weight	Positive: Glibenclamide	The stem bark of <i>N. arbor-tristis</i> contains an ethanol extract that has both potent and safe antidiabetic properties	[68]
Hepatoprotective activity	Leaves	Petroleum ether extract	In vivo	Albino Wistar male rats	125, 250 and 500 mg/kg body weight	Positive: silymarin Negative: Distilled water	The oral administration of a 500 mg/kg dose of leaf extract resulted in a considerable decrease in the levels of AST, ALT, ALP, and TBL in the body weight	[69]

Table 3 (continued)

Health benefits	Plant parts	Study extract	In vitro/In vivo	Model used	IC ₅₀ /LD ₅₀ (Dosage)	Control	Results/remarks	References
Antiulcer activity	Seeds	Abortristoside-A (AT) and 7-O-trans-cinnamoyl-6-hydroxy-loganin (6-HL)	In vitro & In vivo	Ulcer induced female rats	20 mg/kg, p.o	Positive: Sucralfate	The compounds AT and 6-HL had notable anti-ulcer effects against ulcers induced by ethanol, providing 72.41% and 80.67% protection, respectively. In comparison, the reference drug sucralfate (SUC) provided 65.67% protection	[70]
Larvicidal activity	Flowers	Chloroform extract	In vitro	<i>Culex quinquefasciatus</i>	–	–	Exhibit larvicidal activity against <i>Culex quinquefasciatus</i>	[12]
Larvicidal activity	Leaves	Methanol extract	In vivo	<i>Aedes aegypti</i> , <i>Culex quinquefasciatus</i> , <i>Anopheles stephensi</i>	LC ₅₀ : 244.4 ppm	–	Possess larvicidal activity against 3 major mosquito vectors	[48]
Larvicidal activity	Leaves	Chloroform extract	In vivo	<i>Aedes aegypti</i> , <i>Culex quinquefasciatus</i> , <i>Anopheles stephensi</i>	LC ₅₀ : 747.7 ppm	–	larvicidal activity observed against all the tested mosquitos	[48]

–, Not reported; DPPH, 2,2-diphenyl-1-picrylhydrazyl; IC₅₀, Inhibitory concentration; MIC, Minimum inhibition concentration; MBC, Minimum bactericide concentration; MFC, Minimum fungicidal concentration; LC₅₀, Lethal concentration

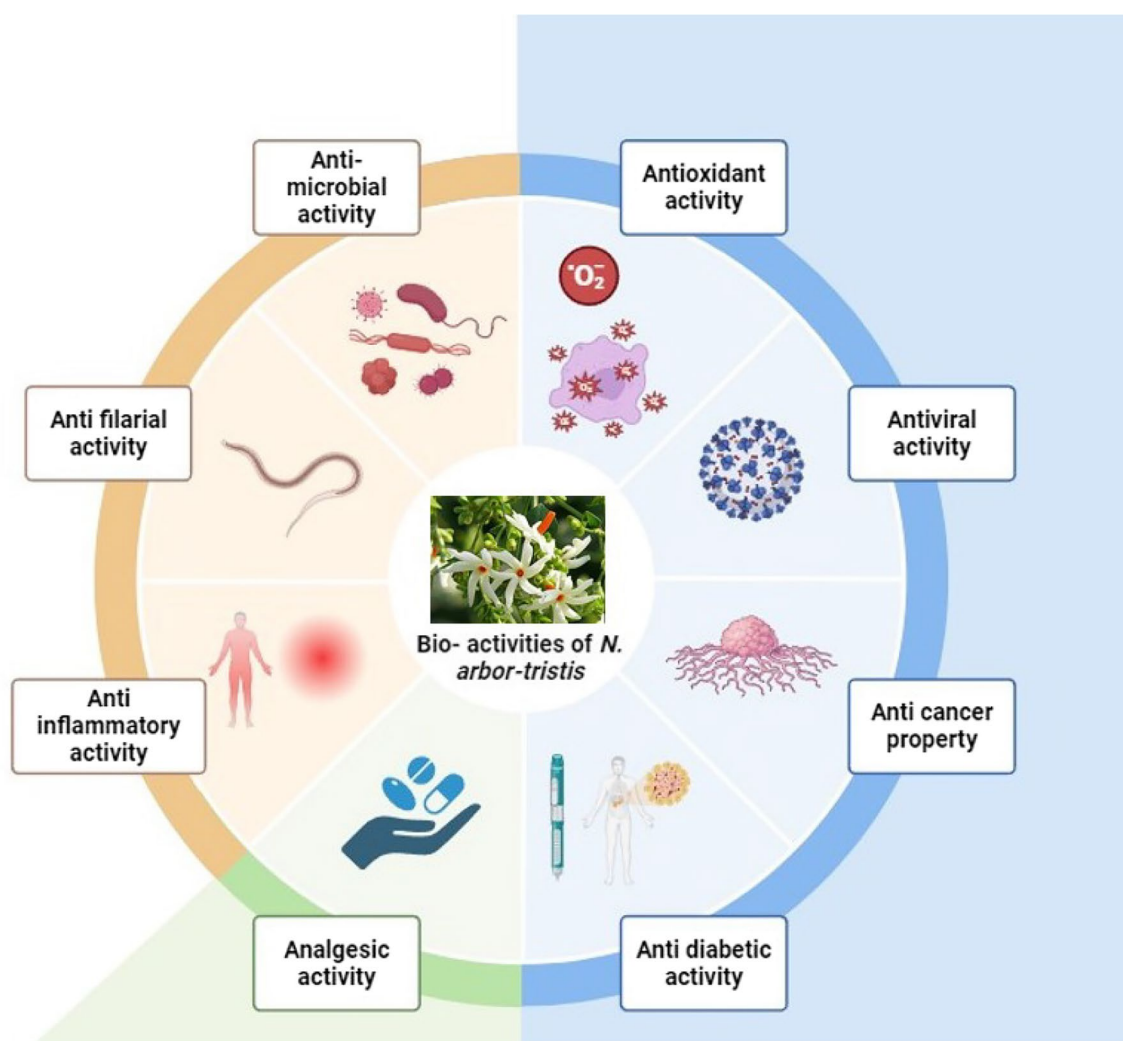


Fig. 3 Diagrammatic representation of the pharmacological potential of *N. arbor-tristis*

Antimicrobial activity

The essential oil of *N. arbor-tristis* (NAEO) and its extracts exhibit notable antifungal properties, spanning from mild to potent levels. According to Al-Reza et al. [46], *N. arbor-tristis* extract demonstrates significant efficacy against a range of fungi and bacteria, such as *Botrytis cinerea*, *Colletotrichum capsici*, *Fusarium oxysporum*, *Fusarium solani*, *Phytophthora capsici*, *Rhizoctonia solani*, and *Sclerotinia sclerotiorum*. In addition, a recent study demonstrated that the leaf extract exhibits significant inhibitory effects on the radial growth of rice fungal diseases, such as *Cochliobolus miyabeanus*, *Pyricularia oryzae*, and *R. solani*. Furthermore, the methanolic extract derived from the leaves of *N. arbor-tristis* exhibits its significant antibacterial properties against *Salmonella typhi*, *Salmonella aureus*, *Staphylococcus epidermis*, and *Salmonella paratyphi*. The minimum inhibitory

concentrations (MIC) of methanolic extract ranged from 1 to 8 mg/ml [4].

The leaves, roots, and shoots of *N. arbor-tristis* exhibit antibacterial solid properties against various pathogenic bacteria, such as *Klebsiella pneumoniae*, *S. epidermidis*, *Bacillus subtilis*, *S. aureus*, *E. coli*, *Listeria monocytogenes*, and *P. aeruginosa*, when extracted with methanol and water. In another study, Ankita et al. [47] revealed that the leaf extract demonstrates the highest level of inhibition against *K. pneumoniae*, *E. coli*, and *L. monocytogenes*. Conversely, the root extract exhibits the highest level of inhibition against *S. epidermidis*, and the shoot extract demonstrates the highest level of inhibition against *Bacillus subtilis*. The inhibition of Semliki Forest Virus (SFV) and the Encephalomyocarditis Virus (EMCV) is effectively demonstrated by arbortristoside-A and arbortristoside C, which have been extracted from *N. arbor-tristis*. Furthermore, the inhibitory efficacy against

these viruses is also shown in the ethanolic extract and n-butanol fractions obtained from *N. arbor-tristis* [48]. In most of the research studies, the antimicrobial properties of *N. arbor-tristis* extracts and NAEO have primarily utilized the disk diffusion method [44, 49]. However, due to its inherent limitations, it is necessary to complement this method with the more appropriate MIC assay [50].

Anticancer and cytotoxic activity

Khatune et al. [51] found that floral extracts of *N. arbor-tristis* obtained from petroleum ether, chloroform, and ethyl acetate showed notable cytotoxic action. A further study was carried out to examine the possible anticancer activities of methanol extracts derived from the fruit, leaves, and stem of *N. arbor-tristis* in an in vitro setting. The methanol extract obtained from *N. arbor-tristis* fruit showed a substantial 71% reduction in dry nitrogen. The dosage of 30 mg/ml demonstrated a reasonable level of effectiveness. However, at a concentration of 10 mg/ml, the methanol extract from the leaves of *N. arbor-tristis* demonstrated the least inhibitory efficacy [42]. The study also indicated that the dried fruit methanol extract of *N. arbor-tristis* may have anticancer properties due to the presence of glycosides, tannins, phenols, and steroids. Only a limited number of studies have examined the anticancer properties of *N. arbor-tristis* extracts and NAEO, and these investigations were carried out using animal models rather than human subjects. Therefore, future research should prioritize exploring the pharmacological capabilities of NAEO in diverse human clinical trials.

Analgesic activity

The analgesic effectiveness of the ethanolic, chloroform, and aqueous leaf extracts of *N. arbor-tristis* was evaluated using Eddy's hot plate analgesiometer in 250, 500, and 1000 mg/kg body weight mice. Results showed that ethanolic extract with a dosage of 1000 mg/kg body weight had a maximum reaction time of 76.17 min, which was comparatively higher than the standard drug Tramadol hydrochloride [52]. Sharma et al. [53] have discovered that the petroleum ether extract and β -Sitosterol obtained from *N. arbor-tristis* leaves have the potential to be used as sources of analgesic activity. However, researchers have not conducted any studies to test the analgesic activity of NAEO. Also, limited studies only showed that *N. arbor-tristis* extracts tested for analgesic activity in animals. Therefore, future studies need to investigate the analgesic activity of NAEO and its bioactive compounds in animals and humans.

Anti-inflammatory activity

The in vivo tests showed that administering 1000 mg/kg and 2000 mg/kg of *N. arbor-tristis* water extract reduced

the augmented vascular permeability and leukocyte migration induced by D-glucose. The study proposed a potential correlation between the anti-inflammatory properties of *N. arbor-tristis* and the abundant presence of flavonoids and saponins in its leaves [54]. Gulshan et al. [42] conducted a study using ethanol to extract arbortristoside-A from *N. arbor-tristis* seeds. The study findings indicated that the arbortristoside-A demonstrated a substantial and dosage-dependent reduction in inflammation. Sana et al. [55] remarked that the ethanol extract of fresh and uncrushed aerial portions of *N. arbor-tristis* contains a fraction insoluble in petroleum ether. Researchers have discovered that this fraction possesses anti-inflammatory properties by suppressing reactive oxygen species (ROS). Only a limited number of studies have investigated the anti-inflammatory properties, and all of them were conducted using animal models instead of human subjects. Subsequent investigations should focus on examining the bioactivity of *N. arbor-tristis* in diverse clinical trials involving human subjects.

Hypoglycemic activity

The hypoglycemic effect of the ethanolic extract of *N. arbor-tristis* leaves was evaluated in albino rats with alloxan-induced diabetes. Administering an ethanolic extract at a dosage of 200 mg/kg body weight resulted in a considerable reduction in blood sugar levels in diabetic albino rats [56]. The administration of a 500 mg/kg body weight aqueous extract derived from the flowers of *N. arbor-tristis* has hypoglycemic and hypolipidemic effects. Thus, the aqueous extract has the potential to serve as a substitute drug for the treatment of diabetes mellitus [57].

Larvicidal activity

Mathew et al. [58] discovered that extracts from the flowers of *N. arbor-tristis*, specifically methanol and chloroform extracts, exhibited larvicidal efficacy against *Anopheles stephensi* larvae. The LC₅₀ values for methanol and chloroform extracts were 244.4 ppm and 747.7 ppm, respectively. This work has significant implications for managing the *Anopheles stephensi* population and the potential decrease in the spread of filarial diseases. Naturally derived larvicidal chemicals provide the possibility of environmentally sustainable alternatives to manufactured pesticides for vector management. Nevertheless, this study requires rigorous experimentation techniques, such as positive and negative control measures and specific dosages. Hence, it is imperative for forthcoming research to conduct experiments more methodically to validate the larvicidal activity of *N. arbor-tristis*. In addition, Table 3 also provides a summary of the additional

pharmacological potential of *N. arbor-tristis* and its active chemical components.

Conclusion

This paper provides a concise overview of the botanical characteristics, techniques for extracting essential oil, the amount of oil obtained, the chemical composition, and the pharmacological and biological effects of *N. arbor-tristis* extracts and essential oil. The plant's essential oil production and chemical compositions primarily concentrate on leaves and flowers, whereas the analysis of barks needs to be addressed or given more consideration. Hydrodistillation is the primary process of extracting essential oils among the several available extraction methods. Chromatographic techniques are employed to identify chemical components present in essential oils. The main chemical components of NAEO and extracts were phytol, methyl palmitate, *cis*-9-tricosene, geranylgeraniol, nonadecane, n-pentacosane, phytone, methyl myristate, eucarvone, and linalool. The chemical components found in *N. arbor-tristis* have the potential to be a new and natural source for the food, fragrance, and pharmaceutical industries. Our literature review revealed that *N. arbor-tristis* possesses biological solid activity that can effectively safeguard individuals against various ailments. Research studies have verified that *N. arbor-tristis* possesses antioxidant, antimicrobial, anti-inflammatory, analgesic, anticancer, antidiabetic, hepatoprotective, anti-arthritis, and larvicidal properties.

Our comprehensive review indicates that the primary bioactive compounds in *N. arbor-tristis* can exhibit significant variability based on species, geographical location, growth conditions, and harvest time. This inconsistency poses challenges in standardizing herbal medicines and ensuring their consistent therapeutic effects. *N. arbor-tristis* has been utilized in traditional medicines for centuries, yet there is often a lack of rigorous clinical trials. Solid clinical evidence makes it easier to ascertain these herbal medicines' safety, efficacy, and optimal dosage. Many previous biological and pharmacological studies still need to provide specific details regarding positive and negative controls, as shown in Table 3. Consequently, future research should undertake meticulous investigations using cellular and animal models. The current state of pharmacological research on *N. arbor-tristis* needs to be improved. Some studies that explored biological activity employed extremely high dosage concentrations. Furthermore, several of these studies did not include comparisons with standard positive and negative controls, and some lacked determination of minimum inhibitory concentration (MIC) values, potentially leading to false positive results. Also, previous research has predominantly concentrated on crude

extracts, and organic fractions, with the aqueous extracts receiving minimal focus. It is imperative to pay attention to its conventional usage. Furthermore, to assess the efficacy and safety, there is a need for extensive placebo-controlled and double-blind clinical trials.

Nevertheless, the clinical research was conducted exclusively on cell lines and animals, with no human clinical trials. Therefore, future studies should investigate the pharmacological activity of *N. arbor-tristis* and its active components in humans. Subsequent investigations should focus on examining the bioavailability, and pharmacokinetics of *N. arbor-tristis* to identify the specific chemical constituents responsible for its effects and broaden the current medical uses of *N. arbor-tristis*. The information discussed here will enhance public knowledge of *N. arbor-tristis* extracts and essential oils and prove valuable for future study.

Abbreviations

ABTS	2,2-Azinobis-(3-ethylbenzothiazoline-6-sulfonate)
DPPH	2,2-Diphenyl-1-picrylhydrazyl
IC ₅₀	Inhibitory concentration
LC ₅₀	Lethal concentration
MBC	Minimum bactericide concentration
MFC	Minimum fungicidal concentration
MIC	Minimum inhibition concentration
NAEO	<i>N. arbor-tristis</i> Essential oil
OGTT	Oral glucose tolerance test
ROS	Reactive oxygen species

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Declarations

Ethics approval and consent to participate

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Consent for publication

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Competing interests

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