CHAPTER 24

Plant-Based Medicines: Unveiling the Biological Mechanism and Therapeutic Action

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SUMMARY

For ages, plant-based medicines have been an essential part of traditional healing methods throughout various cultures. However, current scientific research is still uncovering the complex biological pathways and therapeutic potential of these medicines. The article examines current developments in our knowledge of how chemicals produced by plants interact with biological systems to provide therapeutic effects. It explores the molecular mechanisms by which phytochemicals affect important cellular processes such as antioxidant, antibacterial, and anti-inflammatory responses. The review also emphasizes how these substances affect different biological targets like enzymes, receptors, and signaling cascades, which enhances their therapeutic efficiency. By combining pharmacological research and experimental studies, this chapter seeks to clarify the evidence for the effectiveness of plant-based medications and to pinpoint areas that show promise for further investigation. Through the integration of modern research with traditional wisdom, this review offers a thorough overview of the effective integration of plant-based medicines into current therapeutic procedures.

INTRODUCTION

Numerous plant species that have been identified in ancient prescriptions are still in use today, either by themselves or as a component of herbal mixtures, to treat a wide range of illnesses. Furthermore, natural source-derived organic compounds have been utilized historically and currently to treat a range of diseases; these compounds are used in their natural state as well as act as lead molecules for the creation of synthetic and semisynthetic analogs that have better druggability, with a number of these active ingredients being used in clinical settings (Giannenas et al., 2020). Natural products offer a valuable basis as prospective lead compounds for the development of novel and more potent medications through structural alteration, in addition to the discovery of new chemical entities (NCEs) for therapeutic application. While natural products include a wide range of intricate chemical structures, secondary metabolites found in plants appear to be more drug-like and biologically friendly than those originating from exclusively synthetic sources (Fig 1). Thus, it is believed that compounds derived from natural sources might make better candidates for additional medication development (Chopra & Dhingra, 2021).

With a wide range of pharmaceutical properties, natural products and their related medications are used to treat as well as prevent the majority of common human diseases, such as cancers, peptic ulcers, infectious diseases, and conditions relating to the immune, circulatory, respiratory, and digestive systems. They are also used as antidiabetics and as immunomodulators (Najmi et al., 2022). The main difficulty is in locating medications with negligible or no adverse effects. Even with improvements in technology and understanding of the underlying causes of these illnesses, they continue to be major global killers. Many diseases still lack adequate access to drugs, or they are completely absent. There is a need for creative and novel approaches to drug discovery (Carracedo-Reboredo et al., 2021). Furthermore, the notion of a "wonder drug" a medication that can treat several illnesses in all patients needs to be reevaluated. With a vast number of molecules yet to be identified, nature already offers possibilities when it comes to medication discovery. Nature has already provided several medications (Thomford et al., 2018).

While many diseases are complicated in nature, the majority of the time, medication discovery is based on the analysis of single chemicals. Therefore, research on individual chemicals for some disorders will not provide successful treatments (Zhang et al., 2020). As a result, combinatorial methods are being used in drug development procedures to assess possible molecules. Additionally, scientists can now assess possible compounds' medicinal qualities and molecular

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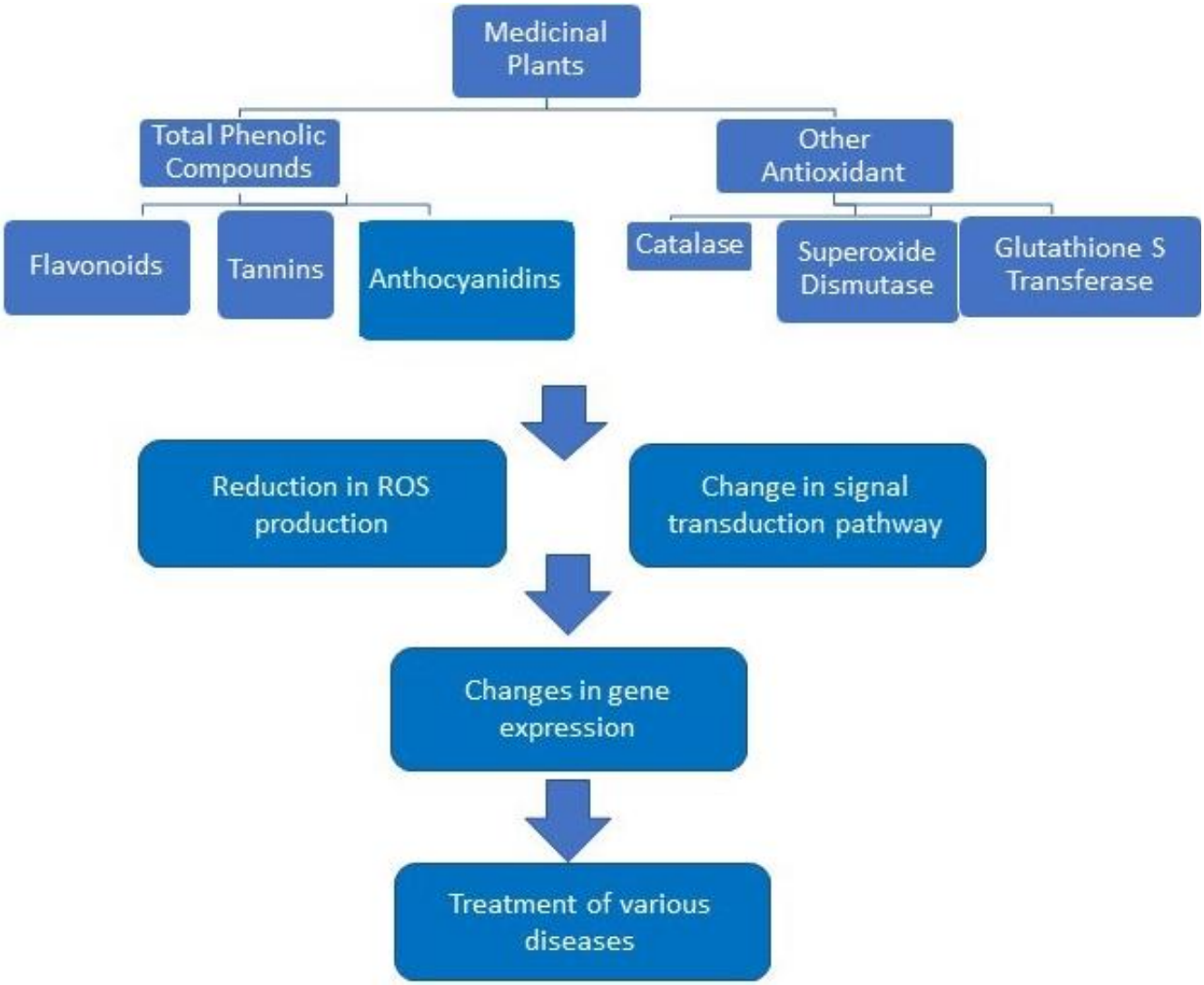

Fig 1. General mechanism of action of plant constituents

impacts in more precise biological systems by using combinatorial methodologies made possible by new technology (Özdemir & Hekim, 2018). Even though the majority of the medications used in conventional medical systems like Ayurveda, Siddha, and Unani are thought to be tried-and-true, when standards of safety, efficacy, and authenticity are considered in the context of modern science, they frequently fall short. According to contemporary biology and medicine, the mechanisms of action of these medications are likewise not entirely understood. Based on experimental data, some medications' expiration dates are not set in stone (Hausman, 2022). China has greatly benefited economically from the global market by bringing traditional medicine up to date with modern pharmaceutical safety and effectiveness standards (Wang et al., 2021). Practical agrotechnology has not been created for nearly any therapeutic plants. Even now, the majority of therapeutic plants are harvested from their natural habitat. This eventually results in the loss of forests, uncontrolled harvesting that wipes off species, difficulty accessing medicinal plants, and combining real plants with fake ones (Ghosh et al., 2020).

PUNICA GRANATUM

The popular name for *Punica (P.) granutam* is pomegranate or Anar in the native language. It is mostly found in Asia and belongs to the Punicaceae family, which has deciduous branches and trees that are generally smaller in size. Certain pomegranate parts, such as the bark, leaves and fruit rind, have therapeutic use (Rahman & Upadhyaya, 2022). Pomegranates have been used in conventional medical treatment for a very long time. The pomegranate is a fruit that is high in phenolic compounds, which have become more and more popular in the last thirty years. The demand for processed pomegranate items has increased globally in the past few years due to the fruit's purported health benefits, which has led to the worldwide pomegranate processing industry's rise. The pomegranate is one of the earliest fruits to be domesticated and grown since ancient times. Originating in Iran and its surrounding nations, it progressively spread over central Asia, reaching the Himalayas, Anatolia, the Middle East, and the Mediterranean region. It has been grown throughout the Mediterranean region, South Asia, and the Middle East;

Kandahar, Afghanistan, is well-known for its premium pomegranates. It also grows in Arizona and California.

Biological Mechanism and Therapeutic Actions

Aqueous-ethanol extraction was used to get pomegranate peel extract (PPE), which had high levels of ellagic acid, punicalin and punicalagin. These substances have a synergistic effect on inflammation and oxidative stress, which is why the effects of PPE were examined in vitro on immune cells and in multiple sclerosis and type 1 diabetic animal models (T1D). PPE decreased the production of interleukin-17 (IL-17) from gut-associated lymphoid tissue (GALT) cells. Additionally, activated T lymphocytes from experimentally autoimmune encephalomyelitis (EAE)-stricken mice produced less IL-17 when exposed to PPE. It successfully decreased the EAE in DA rats and the clinical symptoms of streptozotocin-induced T1D in C57BL/6 mice. PPE reduces the risk of T1D by blocking immune cells from entering pancreatic islets and interacting with GALT's production of IFN-γ and IL-17 (Stojanović et al., 2017).

As a topical antifungal medication, *P. granatum* extract has shown promising outcomes in the management of denture stomatitis-associated candidosis. The main ingredient in pomegranate fruit peel is the tannin punicalagin. This chemical has been obtained from *P. granatum* and showed antifungal activity against *Candida albicans, Candida krusei,* and *Candida parapsilosis.* The growth of *T. rubrum, T. mentagrophytes, M. canis,* and *M. gypseum* was inhibited by pomegranate extract se. The anti dermatophyte testing showed that the crude extract affects conidial and hyphal structures using *Trichophyton rubrum*. In cytotoxicity tests, punicalagin was also shown to be more selective for fungal cells than mammal cells, indicating that therapeutic uses are probably where it will be most helpful. The data, which revealed that both the crude extract and punicalagin had higher antifungal activity against *T. rubrum*, indicated that pomegranate is an ideal topic for research due to its prospective application as a novel therapeutic choice against dermatophytosis (Ismael, 2022).

The *P. granatum's* main ingredients, gallic acid and catechin, are what give it its therapeutic properties. Along with other components, phenolic compounds were found in significant concentration in the methanolic extract of dried pomegranate peels. This extract was created as a water-soluble gel and tested for its ability to repair wounds on Wistar rat skin after an excision. On various days, the group of rats that receive varying concentrations of the prepared gel exhibit healing activity in response to concentration (Karim et al., 2023).

Pomegranate, a popular fruit in folk medicine, has been found to have a positive impact on wound healing in various in vivo studies. Punicalagin contain punicalin, flavon 3-ols, gallotannins, hydroxycinnamic acids, hydroxybenzoic acids, ellagitannins, and gallagyl esters are some of the many phenolic compounds found in pomegranates. These substances are primarily responsible for the anti-atherogenic, anti-angiogenic, anti-hyperglycemic, anticarcinogenic, and wound-healing properties of pomegranate. Pomegranate seed oil has no effect on fibroblast activity; however, it increases keratinocyte proliferation. On the other hand, without affecting keratinocyte proliferation, pomegranate peel extracts enhanced type I procollagen synthesis and reduced fibroblast production of matrix metalloproteinase-1 (MMP-1). The exact mechanism of action is still unknown (Poor et al., 2022).

AZADIRACHTA INDICA

It commonly known as Neem, is a tree that is found in India and many of its states. Because of its various health benefits, it is sometimes referred to as "The Village Pharmacy" or "Divine Tree." This tree mainly grown in southern Asia and Africa, has long been associated with traditional medicine. The aforementioned medical folklore claims that the leaves, bark, fruit, blossoms, oil, and gum of this tree can be used to treat several illnesses, including cancer, cardiovascular disease, diabetes, and hypertension (Islas et al., 2020). Cellular and molecular mechanisms, such as free radical scavenging, detoxification, DNA repair, cell cycle alteration, immune surveillance, the autophagy process and apoptosis, anti-inflammatory, anti-angiogenic, and anti-metastatic actions, and the capacity to regulate different pathways of signaling, are undoubtedly responsible for the possible implications that are observed when utilizing this plant extracts (Ezin & Chabi, 2022).

Mechanism of Action and Therapeutic Actions

Numerous substances present in *A. indica* possess medicinal potential. When it comes to medical applications, triterpenes are the most advantageous of these compounds. Research has specifically shown that nimbin, or triterpene, possesses antipyretic, fungicidal, antihistamine, and antiseptic properties. Nimbin also possesses anti-inflammatory and antioxidant qualities that reduce damage by reducing the production of reactive oxygen species (Naik et al., 2014). Neem also includes flavonoids, which inhibit the synthesis of prostaglandins, endoperoxides, and enzymes linked to inflammation, such as protein kinases and phosphodiesterases (Batista et al., 2018).

Studies have shown that neem plants have an anti-inflammatory impact. Nimbidin from neem trees was used orally in an investigation utilizing rat models to assess its anti-inflammatory activity. It was established that phagocytosis was inhibited and that, in response to inflammatory stimuli, the spread of macrophages to intraperitoneal cavities was severely inhibited. Furthermore, nimbidin also prevented phagocytosis in vitro when rat peritoneal macrophages were exposed to it, and phorbol myristate acetate induced a respiratory burst in these cells. Following an *in vitro* interaction with lipopolysaccharide-stimulated macrophages, nimbidin reduced the synthesis of prostaglandin E2 and nitric oxide (Rahmani et al., 2018).

A. indica is a popular anticancer herb. O6-methylguanine-DNA methyl transferase (MGMT), an enzyme that detoxifies O6-alkylguanines after it was found that they cause cancer, helps to maintain the cellular structure of cells. The MGMT enzyme is more active in neem ethanol-based and aqueous extracts. Azadirachtin, nimbolide, and nimbidin are other

molecules found in neem that have anticancer qualities. Human breast and cervical cells (MCF-7) as well as HeLa cancer cells have antiproliferative properties when exposed to ethanolic neem leaf extract (Shukla et al., 2020).

Research indicates that while consuming *A. indica* does not negatively impact the reproductive system as a whole, it does have a contraceptive effect on reproductive cells and their surroundings. As a more secure and efficient substitute for chemical contraceptives, which permanently affect the reproductive system, *A. indica* has the potential to be a ground-breaking herbal remedy. Increasing the Bax protein level through potential amplification of the Bax/bcl-2-caspase-3 pathway is indicative of its effect on oocyte degeneration. *A. indica* also induced cytochrome c release from oocyte mitochondria, which triggered caspase-3 and -9 apoptotic activities and caused ROS-mediated oocyte degeneration. Additionally, *A. indica* stimulates the immune system through the production of TNF-α and interleukin-β (IL-β), which destroy spermatozoa (Patil et al., 2021). In mice stimulated with or without α-melanocyte-stimulating hormone, many substances from *A. indica* have demonstrated inhibitory efficacy against melanogenesis in B16 4A5. The coloring of skin and hair is a reaction to α-MSH stimulation. Some of these substances, such as 4 azadiradione-type limonoids, 5 nimbin-type limonoids, and 2 salannin-type limonoids, shown greater suppression of melanogenesis than arbutin, which was utilized in the cosmetic industry as a depigmentation substitute for lightening the skin (Baby et al., 2022).

The anticancer properties of neem have been studied in the past and these include its ability to modulate the tumor environment, increase the cytotoxic ability of host monocytes and suppress the proliferation of tumor cells. Glycoproteins, liminoids from neem leaf extracts have been the focus of much investigation due to their potential anticancer effects. By controlling the enzymatic degradation of glutathione, the neem leaf extract has a chemopreventive impact on the oral mucosa. Extracts from neem seeds and leaves have been tested for their enhanced apoptotic effects in a range of human malignancies. Clinical trials are required to know more about the potential of this plant to prevent and manage cancer (Agrawal et al., 2020).

ASIATICA CENTELLA Linn.

It is often called Indian Pennywort. *Linn.* is a member of the Apiaceae family and formerly known as Umbelliferae. *C. asiatica* is commonly referred to as "Brain food" in India since it is the most effective herbal medicine for healing wounds, treating skin conditions, and reviving nerves and brain cells (Hoque et al., 2023). Since *C. asiatica* offers so many positive health effects, like being an antioxidant, an anti-inflammatory, a wound healer, a memory enhancer, and more, its use in food and drink has grown throughout time. *C. asiatica* promise as a plant-based alternative antioxidant and its ability to guard against aging-related alterations in the brain's antioxidant defense system have grown significantly in recent years (Shoaib et al., 2023).

Biological Mechanism and Therapeutic Actions

Since the physiologically active ingredients of *C. asiatica* include triterpenes and saponins, it is thought that the chemical contents of the plant play a significant role in medical and nutraceutical uses. The triterpenes found in Centella include a variety of compounds, including asiatic acid, madecassic acid, asiaticosside, madecassoside, brahmoside, brahminoside, thankiniside, isothankunisode, centelloside, madasiatic acid, centic acid, and cenellicacid. These triterpenes' primary physiologically active constituents are madecassic acid, asiatic acid, madecassoside, and asiaticosside (Mandal et al., 2023).

Aqueous extract of *C. asiatica* dramatically reduced brain levels of norepinephrine, dopamine, and 5-HT as well as their metabolites and demonstrated a significant impact on improving learning and memory. The plant's aqueous extract showed antioxidant and cognitive-enhancing qualities in rats, and streptozotocin caused oxidative damage and mental retardation (Kumar and Gupta, 2002). The administration of *C. asiatica* aqueous extract during the neonatal developing stage had an impact on the morphology of neurons and enhanced the cognitive performance of newly born and mature mice (Abbas et al., 2021).

The immunomodulatory impact of *C. asiatica* triterpenoid saponins was demonstrated. Methanol extracts demonstrated early immunomodulatory activity, and pectin extracted from *C. asiatica* showed immunostimulating activity. The neutrophil phagocytic activity of *C. asiatica* ethanol extract is increased, stimulating the cell-mediated immune system. *C. asiatica* methanol extract that had been partially purified stopped tumor cells from growing while having no harmful effects on lymphocytes. Colon tumorigenesis is chemoprevented by water extract. It has been discovered that Asiatic acid has an anticancer impact on skin cancer. Asiatic acid decreased viability and induced apoptosis in human melanoma SK-MEL-2 cells in a manner that was dose- and time-dependent. Furthermore, Asiatic acid enhanced the activity of the protein Bax in the cells and markedly increased the amount of intracellular reactive oxygen species (ROS), but not Bcl-2. Moreover, Asiatic acid-induced caspase-3 activity activation is dose-dependent. Activation of caspase-3, alterations in the Bax/Bcl-2 ratio, and the generation of ROS can all contribute to Asiatic acid-induced apoptosis, even if p53 is not necessary (Zhang et al., 2022)

The percentage of collagen in cell layer fibrnectin was enhanced by the whole triterpenoid fraction derived from *C. asiatica*, suggesting that it may aid in the promotion of wound healing. Peptide hydroxyproline levels have been shown to rise in Asiatic acid and Medacassic acid derived from *C. asistica*, indicating heightened collagen production remodeling in wounds. An alcoholic extract applied topically and orally induced cellular proliferation and collagen synthesis, as demonstrated by the increased DNA, protein, and collagen content in the granulation tissues of rats with superficial wounds. Asiaticosides may contribute significantly to this substance's ability to heal by enhancing the induction of antioxidant levels in the initial phases of healing. The main active component of *C. asiatica* is called asticoside, and it has

significant wound-healing activity in both normal and delayed healing models (Diniz et al., 2023)

The plant *C. asiatica*, a strong antioxidant, has a notable neuroprotective effect and was effective in safeguarding the rat brain from oxidative damage caused by aging. Asiatic acid enhanced the cellular oxidative defense system, which had a major neuroprotective effect on cultured cortical cells. When colchicine is administered, the hippocampus granule cells and septohippocampal pathways are severely destroyed. This leads to the death of cholinergic neurons and a reduction in the activity of acetylcholinesterase and choline acetyltransferase. Rats' decreased AChE activity caused by colchicine could be improved by *C. asiatica*. So avoiding the oxidative damage and cognitive impairment caused by colchicine. It appears that oxidative stress plays a part early in Alzheimer's disease genesis (Abbas et al., 2021).

It has been established that asiatic acid affects metabolic pathways that are essential for carcinogenesis, proliferation, and metastasis and are controlled by molecular targets such as TNF-α, NF-κB, PI3K/Akt, VEGF, and others. Asiatic acid can cause apoptosis, lower phosphorylation, and limit gene transcription in cancer cells. According to the information acquired, asiatic acid merits more research as a possible adjuvant therapy or anticancer medication. By affecting key signaling pathways such as PI3K, Akt, mTOR, p70S6K, and STAT3 in cancer cells, asiatic acid has been shown to contribute to phosphorylation inhibition, cell death, and decreased tumor growth and metastasis. The significant role that asiatic acid plays in lowering the expression of markers like vimentin, β-catenin, claudin-1, and N-cadherin should also be mentioned. According to certain research, asiatic acid may cause cancer cells to undergo autophagy by altering the amounts of particular proteins including p62 and LC3 (Wiciński et al., 2024).

CINNAMOMUM CAMPHORA

The Lauraceae family includes the camphor tree [*Cinnamomum (C.) camphora*], which is found in South Korea, China, and India. It is currently found around the world, including Australia and the Himalayas. The commercial cultivation of this tree has been established in China and Korea, and it has been declared and protected as a cultural property. This tree is one of the plant species that is highly regarded in Asia concerning its economy and culture. There is a lot of pressure and concern on *C. camphora*. There is a growing interest in its worth, which is causing excessive usage and a significant population decline. If proper protection measures are not adopted, this may result in extinction (Lee et al., 2022).

The long-standing use of *C. camphora* in traditional medicine has a theoretical foundation as a result of the advancement of current pharmaceutical technologies. According to the primary research findings to date, *C. camphora's* essential oils are primarily responsible for its pharmacological effects. Technology advancements have made it possible to extract essential oil from different parts of *C. camphora* to treat inflammation-related illnesses like rheumatism, bruises, bronchitis, and muscle aches. Additionally, components of essential oils that show pharmacological effects can be isolated and purified. Distillation is mostly used to extract essential oils (Zhang et al., 2023).

Biological Mechanism and Therapeutic Actions

Chromatograms of *C. camphora* tissues showing the leaves, branches, wood, and roots revealed 74 different chemicals. The bioactive component of *C. camphora* oil detects the analgesic effects of β-caryophyllene, α-caryophyllene, bicyclogermacrene, germacrene D, unidentified, nerolidol, spathulenol, and unidentified (E)-α-atlantone. Another study found that the essential oils contained a wide range of compounds, including methyl isobutyl ketone, pinene (α and β), α-thujene, camphene, sabinene, α-phellandrene, hexanal, 3-hexanal-1-ol, 1-hexaol, and sabinene. *C. camphora* contains the following primary bioactive compounds: cineole, safrole, linalool, and camphor (Poudel et al., 2021).

The leaves of *C. camphora* are used to treat atrophic dermatitis, an allergic inflammatory disease. The vital mediator of inflammation and immunity, IFN-γ, initiates the signal pathway known as Janus tyrosine kinases-signal transducer and activator of transcription (JAK-STAT). *C. camphora* leaves prevented the phosphorylation of Janus kinase signal transducer and transcription activator. Furthermore, extracellular signal-regulated kinase 1/2, a crucial signaling molecule implicated in the inflammatory process, was not phosphorylated when *C. camphora* leaves were present. By downregulating the STAT 1 and extracellular signal-regulated kinase 1/2 (ERK1/2) pathways, the researchers discovered that leaf extract decreased the synthesis of macrophage-derived chemokines (MDC/CCL22) in skin inflammatory lesions. Many symptoms, such as lymph node enlargement, ear edema, blood parameter abnormalities, including serum IgE, and histological changes in mice with allergic dermatitis, improved as a result (Kang et al., 2019).

There were notable anti-anxiety and antidepressant effects demonstrated by *C. camphora* oil (CCO). Phytochemical investigations validate the presence of many monoterpenoid components in the essential oil. Monoterpenoids β-thujone, β-pinene, linalool, and limonene have been shown to have antidepressant properties. Moreover, recent studies have suggested that β-pinene, which raises dopamine levels and decreases monoamine Oxidase activity in rabbits, has antidepressant properties. Furthermore, investigations revealed that a wide range of physiologically active substances, such as monoterpenoids, are strong MAO-A and MAO-B inhibitors (Sharma, 2021).

The compound1,8-cineole is one of the ingredients in *C. camphora* oil (CC0), which has anti-inflammatory properties by reducing the concentration of pro-inflammatory factors and the number of inflammatory cells. Furthermore, relevant research have demonstrated that *C. camphora* and *C. subavenium* extracts modulate several inflammatory responses at the transcriptional level. There is conjecture that the effects could be attributed to blocking the production of genes associated with proinflammatory processes, such cytokines,

and enzymes that produce cytotoxic molecules, including cyclooxygenase and nitric oxide synthase, via influencing the nuclear factor kappa B pathway. Furthermore, CCO extracted from seeds has been shown to decrease inflammatory markers like P65, interleukin-6, and tumor necrosis factor-α, most likely through upregulating peroxisome proliferator-activated receptor. Additionally, a different study found that an 80% ethanol-based-extraction of *C. camphora* leaves possesses anti-inflammatory activities via phosphorylating signal transducer, activator of transcription 1, and extracellular signal-regulated kinase 1/2 (Du et al., 2022). α-atlantone and nerolidol are the main ingredients in the essential oils. By inhibiting the nuclear factor, the essential oil extracted from camphor leaves considerably lessens migraine pain.-Nitric oxide pathway: kappa B/inducible nitric oxide synthase (Fan et al., 2020).

Following a phytochemical analysis of the *C. camphora* extract, 37 secondary metabolites were isolated and identified. A novel phenylpropanoid glycoside was compound 1, also known as camphodiol A. Compounds 2–10, 12, 13, 16–25, 27, and 29–37 were the first to be identified in this plant. According to the molecular docking research, chemical 22 may bind via hydrogen bonding and π-π interactions inside the α-glucosidase. This finding not only advances our understanding of the chemical components found in *C. camphora* and establishes a basis for using this botanical resource to treat diabetic mellitus, but it also yields lead compounds for the creation of medications that treat hypoglycemia (Jiang et al., 2023).

C. camphora contains camphor, a bicyclic monoterpenoids with antifungal properties against *Fusarium*. According to the mechanism's initial investigation, camphor may both contribute to and prevent the phytopathogens' cell wall and cytomembrane production. When camphor is involved, fungus release internal ions, proteins, and nucleic acids that are essential for regular cell function, which eventually stops the fungi from growing. A possible substitute fungicide for preventing *Fusarium* disease in crops and horticulture plants is camphor (Kong et al., 2022).

SANTALUM ALBUM L.

One of the rarest and most valuable natural smell sources, Indian sandalwood (*Santalum album L.,* Santalaceae) has substantial therapeutic and industrial utility. Due to its abundance of phytochemicals, especially sesquiterpeness, sandalwood is valuable for a variety of medical applications. Numerous pharmacological properties, from antibacterial to anticancer, have been shown through recent pharmacological investigations. Concerns over Sandalwood's conservation and productivity development using current methods and techniques have grown due to the plant's low productivity and rising commercial exploitation. The primary constituents of sandalwood oil are sesquiterpene alcohols, such as bergamotols and α- and β-santalols. Other insignificant components consist of sesquiterpene hydrocarbons such as α-, β-, and γ-curcumenes, β-bisabolene, and phenylpropanoids, in addition to lanceol, nuciferol, and bisabolol. Typically, there are more α-santalols than β-santalols (Madhuvanthi et al., 2023).

It has been shown that trans-mammary exposure to sandalwood oil alters the newborn hepatic xenobiotic metabolizing enzymes in nursing mouse pups. Additionally, it is noted that the components of sandalwood oil and their passage through milk changed the way the liver metabolized xenobiotics, increasing the activities of the liver's glutathione-S-transferase, glutathione reductase, and glutathione peroxidase. As a result, the liver's levels of cytochrome B5 and acid-soluble sulfhydryl increased and cytochrome P 450 decreased (Boruah et al., 2023). Numerous physiological processes and sensory stimulation have been discovered to be impacted by sandalwood oil and its main ingredient, santalol. While the oil was found to increase systolic blood pressure, skin conductance level, and pulse rate, α-santalol was found to increase mood and attention ratings more than the oil (Heuberger, 2020).

It has been observed that inhaling sandalwood oil improves hearing. Recently, it was shown that sandalwood tea considerably increased the cardiac rate and contractility of the myocardium of frogs. Furthermore, it demonstrated effective anti-fatigue characteristics in terms of contracting the rabbit aortic strips' smooth muscle. Although occasional reports of discomfort or hypersensitivity reactions in humans have been made, sandalwood oil did not exhibit any phototoxic effects (Zhang et al., 2021).

One of the ingredients in sandalwood oil, α-santalol, delayed the growth of papillomas. When treated with alphasantalol, human epidermal carcinoma A431 cells have been demonstrated to undergo apoptosis as a result of cytochrome release, loss of mitochondrial potential, and caspase activation. In a related study, topical application of α-santalol was shown to have chemo preventive effects in female hairless mice strain SKH-1, as demonstrated by lower tumor incidence, multiplicity, and ornithine decarboxylase activity. Additionally, it has been demonstrated that santalol suppressed in vitro lipid peroxidation in skin and liver microsomes, delayed the formation of skin tumors, decreased tumor multiplicity, and, perhaps through an antiperoxidative effect, prevented the development of skin tumors. Through an extrinsic mechanism, α-santalol has been shown to dramatically raise the levels of caspases 3 and 8, which are connected to apoptosis, and the tumor suppressor protein p53. α-santalol activated caspases-3, which in turn caused apoptosis in human prostate cancer cells (Blankenhorn et al., 2022).

Sandalwood oil and aqueous extract have already been shown to have sedative properties. Sandalwood oil is said to alleviate agitated emotional states that lead to stress, migraines, and sleepiness. It also relaxes the nerves. Santalols are a bioactive component that has been demonstrated to have depressing effects on the central nervous system; hence, they may be useful for individuals who have trouble sleeping (Murugesh et al., 2023).

In a novel investigation, it was discovered that synthesized sandalwood chemicals and oil selectively activated certain olfactory receptor neurons. Additionally, it was demonstrated

that heartwood solvent extracts have neuroleptic properties in mice. α-santalols significantly increased the amounts of homovanillic acid, 3, 4-dihydroxyphenylacetic acid, and/or 5-hydroxyindoleacetic acid in the brains of mice when given intragastrically and intracerebroventricularly. It has been demonstrated that α-santalol is a potent antagonist of serotonine 5 HT2A and dopamine D2 receptor binding. Furthermore, α-santalol's antipsychotic impact was identical to that of chlorpromazine. Significant physiological alterations, including soothing and comforting effects, were brought on by α-santalol, while topical absorption of sandalwood oil resulted in physiological deactivation followed by behavioural activation (Banerjee et al., 2024).

Sandal wood oil's warm, rich scent produces calming, sensual, relaxing, and calming qualities. It is mostly used in conjunction with other oils to improve fixation capacity. All skin types—dry, sensitive, and oily—can use it. It lowers anxiety while promoting sound sleep. It has a calming effect. Research demonstrates that sandalwood oil helps to relax veins, muscles, and nerves by lessening compressions and fits. Because sandal wood oil has calming properties, it can be used to treat tense emotional states that cause headaches, sleeplessness, and restlessness. Sandalwood is very important because of its wide range of pharmacological activities (Aftab et al., 2023).

Additionally, sandalwood has been demonstrated to possess virucidal qualities. The capacity of sandalwood oil to prevent the growth of herpes simplex viruses (HSV)-1 and 2 further revealed that this oil helps protect cells by modifying the amounts of the acid-soluble enzyme glutathione S-transferase and sulfhydryl in the liver. Sandalwood oil only had an impact on the virus prior to its adsorption into the cells by preventing the virus and host cells from interacting in an unknown way. Alpha and beta santalols, which are components of sandalwood oil, have been associated with the treatment of human warts, specifically those caused by the pox virus and human papillomavirus (Das & Khan, 2022).

CONCLUSION

Medicinal plants have long been utilized to treat a wide range of infectious and non-infectious disorders, and they continue to be a valuable source of novel lead compounds and significant medicinal products. Many effective medicinal substances have been created from naturally occurring lead compounds or directly acquired from plant sources. Plant-derived natural product medication discovery and development is gaining scientific attention again, and research trends suggest that this area will potentially provide new therapeutic molecules in the future as shown (Fig 2). Plant metabolites are being developed in the field of plant-based medication development and discovery research in order to

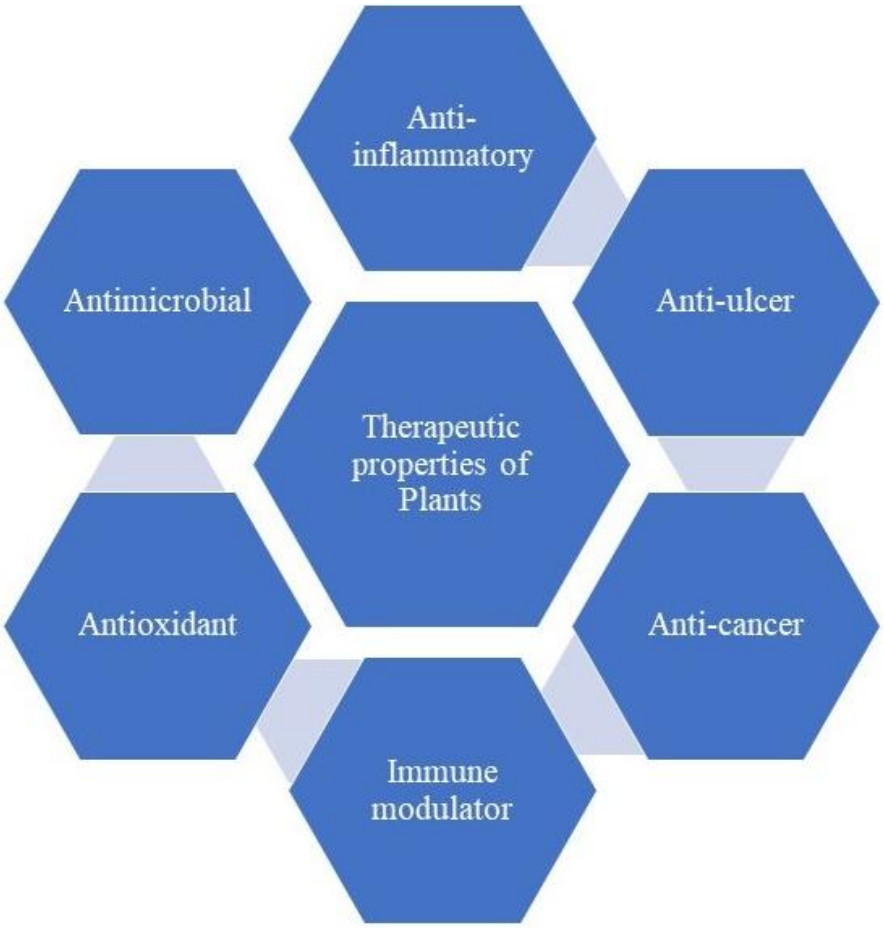

Fig 2. Therapeutic actions of medicinal plants

create prospective analogs that have the necessary safety and effectiveness. Many new techniques for the selection, identification, isolation, characterization, and biological screening of natural products have been created, along with technology advancements, as a result of the revived interest of medicinal chemists in natural product drug development. For this kind of work, it is especially crucial to use an interdisciplinary strategy that incorporates knowledge of traditional and ethnopharmacology, phytochemistry, botany, analytical chemistry, appropriate biological screening techniques, and contemporary drug development technologies. Future approaches to the production of drugs from natural products will reduce difficulties and raise success rates; novel compounds derived from plants and chemical databases based on natural products are going to be used more frequently in the drug discovery process. It might significantly aid in the discovery of novel drugs and address issues related to global health.

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