

Phytochemicals and their therapeutic applications in Ayurveda and modern medicine

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Abstract

Medicinal plants such as *Bacopa monnieri* and *Curcuma longa* have long been utilized in Ayurvedic medicine, guided by the principles of the 'tridosha' theory. Their therapeutic value is majorly due to the presence of diverse phytochemicals, including flavonoids, alkaloids and tannins, which exhibit a wide range of pharmacological activities such as antioxidant, antimicrobial, anticancer, anti-inflammatory and wound-healing effects. Recent research has increasingly validated these traditional applications by studying their phytochemistry and molecular mechanisms, including free radical scavenging and modulation of cellular signaling pathways. The ability of phytochemicals to mitigate oxidative stress and tackle challenges such as antibiotic resistance highlights their potential as safe and effective therapeutic agents in clinical settings. This review is in light of phytochemicals contributing as therapeutic agents in both traditional and modern medicine.

Keywords: Ayurveda, antimicrobial activity, anticancer activity, biofilm inhibition, ethnopharmacology, medicinal plants, oxidative stress, wound healing

Introduction

Phytochemicals are naturally occurring compounds in plants. These compounds, especially secondary metabolites are used by plants for defense from predators like insects and animals (Divekar et al., 2022). They are also responsible for the aroma and vibrant color, which makes the plants appealing to pollinators (Xie et al., 2024). Also, they protect the plant parts from intrinsic and extrinsic damage caused due to Ultra-violet (UV) radiation (Njoku and Chidi, 2009). Beyond their ecological roles, phytochemicals pose pharmacological properties. They help human cells to fight against oxidative stress by neutralizing free radicals. They help in efficient absorption of vitamins and minerals in our body. Some of their other functions include anti-inflammatory, antispasmodic, anti-allergic, anti-ageing, antifungal and antibacterial properties, etc (Riaz et al., 2023). Phytochemicals also play a significant role in modulating the immune system, enhancing its ability to combat carcinogens while reducing cellular damage caused by free radical-induced

oxidative stress. (Kumar et al., 2023). Phytochemicals slows down the harmful effects of damaged cells in our body which is responsible for creating cancers and other intense hormonal regulatory responses. Some phytochemicals also help in gene regulation during transcription (Cord et al., 2025).

Role of phytochemicals in Ayurveda

Traditional medicinal practices have their roots in culturally rich nations like China and India, where a diverse range of plants and herbal remedies are employed as therapeutic agents, guided by texts penned by ancient academicians and medical practitioners. Individual physiological and pathological conditions are understood through the three basic principles of vata, pitta and kapha). Because of their natural origin, plants used in the Ayurvedic system are typically regarded as safe, as their medicinal properties are utilized to treat a wide range of illnesses with minimal side effects (Hass et al., 2000). For example, the terpenoid and coumarin-rich roots of *Nardostachys jatamansi* have significant medicinal applications in the treatment of neurological disorders (Chatterjee et al., 2000). *Curcuma longa* (turmeric) is widely used to treat wounds due to its antibacterial and anti-inflammatory properties (Chainani-Wu, 2003). *Centella asiatica* enhances cognitive function, reduces oxidative stress and aids in nerve cell regeneration (Cervenka and Jahodar, 2006). *Bacopa monnieri* is well known for its ability to improve memory (Stough et al., 2008). Furthermore, *Withania somnifera*, also known as ashwagandha, is frequently used to treat respiratory ailments and supports the immunological and neuroendocrine systems (Ven Murthy et al., 2010).

Antioxidant activity

Antioxidants are the stress busters in our body. Due to the functioning of metabolic pathways (anabolism and catabolism), a large number of free radicals are generated through autoxidation, which leads to the degradation of our cells and cellular components. Antioxidants act on these and reduce or eradicate free radicals from the body, thereby preventing further oxidation. Most of the commercial industries also use antioxidants to prevent oxidative damage in food and cosmetics caused by external factors. Antioxidants are known to prevent the oxidation of unsaturated fats as well. Phytochemicals with antioxidant properties are widely used as medicinal agents against such oxidative stress (Nwozo et al., 2023). Most of the whole grains we consume are rich in several types of bioactive compounds, including alkylresorcinols, benzoxazinoids, betaines, flavonoids, lignans, phenolic acids, phytosterols and tocopherols, along with their fatty acid, polyamine and sugar derivatives, which possess antioxidative and modulatory effects on cellular function and gene expression. Consumption of whole grains like barley reduces the risk of cardiovascular diseases, diabetes, cancer and obesity; it also helps lower cancer risk due to the presence of low molecular

weight compounds such as phenolic acids, flavonoids and vitamin E (Lahouar et al., 2014). Antioxidant properties are commonly measured in terms of total flavonoid content, total phenolic content, overall antioxidant activity, as well as metal chelating activity and ABTS scavenging activity (Bangar et al., 2022).

Antimicrobial properties

There are many different types of microbes on our planet, some of which are harmful, some are not and some are beneficial. However, there are many pathogens that can lead to infections such as cholera, leprosy, pneumonia and many more (Prasad et al., 2007). In addition to causing serious infections, pathogenic microorganisms can sometimes be fatal. We employ a variety of antibiotics to either kill or inhibit these bacteria, but nowadays these drugs are not functioning effectively, as bacteria have acquired resistance to various antibiotics. Nowadays, phytochemicals are considered a major substitute for pharmaceuticals because they are derived from plants, are less damaging to our bodies and show effectiveness against resistant bacteria (Doughari et al., 2009). Phytochemicals act not only against bacteria but also against fungi, viruses and various other microbes. Antimicrobial compounds such as phenols, aldehydes, coumarins, flavonoids and polyphenols exhibit such activities and also help shield plants from various stresses, including UV radiation (Andre et al., 2010). The increase in antibacterial action is attributed to coumarins that contain ester groups in their structure (Patra, Amlan Kumar, 2012). However, the phytochemicals present in plants can be degraded when vegetables are cooked, fried, grilled, or boiled. Among these compounds, polyphenols are considered the most potent; they are present in almost all edible fruits and vegetables and possess strong antibacterial properties (Hochma et al., 2021). Quorum sensing (QS) is a unique communication system used by microbes to interact with one another and it is closely associated with antibiotic resistance, where drugs become ineffective and microbes proliferate unchecked. This issue can be addressed using certain bioactive compounds that act as quorum sensing quenchers (Bouyahya et al., 2022). Malaria and certain types of wounds are traditionally treated using *Acanthus polystachyus*. Its potent antibacterial properties are influenced by various environmental factors, including soil temperature, sunlight, watering and others (Getahun et al., 2023).

Anticancer properties

Nowadays, a large part of the population is affected by cancer. Various treatments, such as hormone replacement therapy and immunotherapies, are used, although they are not entirely beneficial. Cranberry fruit have showed to reduce the expression of matrix metalloproteinases and induces apoptosis in cancer cells, both of which help to reduce the spread of prostate tumours

(Neto, 2007). Plant-derived phytoestrogens possess oestrogen-like characteristics and can bind to oestrogen receptors and are currently being employed as anticancer agents in some countries (Dwevedi et al., 2015). Because of their high phytoestrogen content, soybeans are utilised to lower the risk of breast cancer (Jiang et al., 2016). When taken in appropriate amounts, curcumin has the ability to significantly reduce colon cancer, as it inhibits the transcription and translation of COX-2 (Khan et al., 2019). Capsaicin, a compound found in chillies, works effectively as a chemopreventive agent when applied to the affected area; it also induces apoptosis and acts as a tumour-suppressive compound (Ranjan et al., 2019). Similar to auronones, flavonoids are also known to aid in the treatment of cancer by targeting microtubules and telomeres. Lupeol and betulinic acid-type triterpenes are found in *Anthocephalus cadamba* and they exhibit antineoplastic properties. According to Ullah et al. (2020), methanolic extracts show better activity. The ethanol leaf extract of *A. cadamba* can arrest cancer cells in the G0 and G1 phases and induce apoptosis within 72 hours, thereby affecting MCF-7 breast cancer cells. Similarly, valepotriate is a potent phytochemical found in *Nardostachys jatamansi*, which shows activity against tumours of hepatoma and ovarian cancer cells (Razali et al., 2021).

Anti-inflammatory properties

Immune systems of animals use the anti-inflammatory response as a crucial defence mechanism against infections and harmful organisms. Inflammation is often initiated by neutrophil activation, which releases lysosomal enzymes during phagocytosis. Although these enzymes help in breaking down pathogens, they can also lead to inflammation and tissue damage. Medicinal plants can here be employed for preventing inflammation. For instance, *Nardostachys jatamansi* exhibits anti-inflammatory properties, particularly during endotoxin shock and lipopolysaccharide-induced inflammation (Arora, 1965). Lysosomal membrane destabilisation and protein denaturation are two important mechanisms underlying inflammation, both of which intensify inflammatory responses and may result in long-term conditions such as arthritis. These inflammatory pathways are significantly modulated by phytochemicals obtained from medicinal plants (Brown and Mackey, 1968). Similarly, extracts from *Neolamarckia cadamba*, especially methanolic extracts of its bark and leaves, demonstrate notable analgesic and anti-inflammatory properties (Chatterjee and Das, 1996; Hass et al., 2010). These extracts have been shown to stabilise lysosomal membranes, thereby inhibiting the release of inflammatory mediators and reducing neutrophil-induced damage. Through a range of pharmacological activities, other medicinal plants also contribute to anti-inflammatory responses and wound healing. One of the earliest known medicinal plants, *Achillea millefolium* (yarrow), has been widely used for treating wounds, inflammation and spasmodic disorders due to its bioactive compounds that influence pharmacokinetic and pharmacodynamic

pathways (Dorjsembe et al., 2017). In a similar manner, *Artemisia absinthium* (common wormwood) is well known for its effectiveness in healing inflammatory conditions and skin wounds (Benkhalel et al., 2020). Furthermore, *Aloe vera* offers multiple therapeutic benefits, including enhanced collagen production, wound contraction and epithelialisation, while also reducing scar formation (Vitale et al., 2022).

Biofilm dislocation by phytochemicals

As biofilms shield microbial communities from traditional antimicrobial treatments, they have become more difficult to control with the growing problem of antibiotic resistance. In this context, phytochemicals have emerged as viable substitutes, as they can interfere with the stability and growth of biofilms without inducing resistance (Magma, 2000). Certain compounds can enhance the antibacterial and antibiofilm properties of plant extracts. For instance, phenolic compounds present in phytochemicals exhibit anti-adhesive properties that prevent bacteria such as *Streptococcus mutans* from attaching, thereby reducing biofilm formation (Daglia et al., 2002). Plant-based essential oils, owing to their high terpene content, are particularly potent. These oils are considered relatively safe, have fewer adverse effects and have long been used to treat illnesses in many countries (Burt, 2004). Similarly, essential oils with aromatic ring structures, found in methanolic extracts of *Cuminum cyminum*, inhibit bacterial growth and prevent biofilm formation in pathogens such as *Proteus mirabilis* and *Pseudomonas aeruginosa* (Packiavathy et al., 2012). Benzoic acid derivatives such as gallic acid play a crucial role in inhibiting biofilms by targeting quorum sensing (QS), a key regulatory mechanism in bacterial communication. By interfering with QS, these compounds effectively prevent biofilm formation in organisms such as *Escherichia coli*, *Pseudomonas aeruginosa* and *Streptococcus* species (Ta et al., 2017). Furthermore, plant extracts derived from *Diospyros kaki* leaves have shown strong inhibitory effects against a variety of pathogens, including *Salmonella typhimurium*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Streptococcus mutans* and *Streptococcus sanguinis*. Notably, *Diospyros kaki* leaves contain a bioactive compound, deoxynojirimycin, which exhibits antibacterial and antibiofilm activity against *S. mutans* that is nearly eight times stronger than the crude extract (Ham and Kim, 2018).

Conclusion

In both contemporary biological research and traditional Ayurvedic medicine, phytochemicals represent a broad class of bioactive substances with substantial therapeutic potential. Their relevance in preserving health and preventing disease is shown by their wide spectrum of pharmacological activities, including antioxidant, antibacterial, anticancer, anti-inflammatory and wound-healing properties. Plant-based remedies, grounded in holistic concepts such as the

tridosha hypothesis, have long been practiced in Ayurveda and contemporary studies are increasingly providing scientific evidence to support these traditional approaches. Phytochemicals serve as viable substitutes for conventional medications due to their ability to regulate key biological processes, including oxidative stress, inflammation, microbial growth, quorum sensing and apoptosis, especially in the context of rising antibiotic resistance and chronic diseases. Their clinical significance is further emphasized by their role in disrupting biofilms and promoting tissue healing. Despite their immense potential, challenges such as low bioavailability, variability in plant composition, lack of standardisation and insufficient clinical trials remain significant barriers to their widespread medicinal application. To ensure safety, efficacy and consistency, future research should focus on advanced extraction techniques, improved formulation strategies, detailed investigations of molecular mechanisms and well-designed clinical studies.

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