WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Chemical Composition of Ayurvedic Herbs: Key Bioactive Compounds and Elements, Their Therapeutic Roles and Modes of Action

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ABSTRACT :

Ayurveda, the age-old Indian medical system has now been used for more than 5,000 years and is still an essential component of healthcare in many parts of the country. The chemical underpinnings of Ayurvedic medicine are examined in this paper, with particular attention paid to the bioactive substances found in metals, mineral, and botanical compositions of ayurvedic formulations. With advancement in modern analytical techniques it is now possible to identifiy numerous phytochemicals, such as alkaloids, flavonoids, terpenoids, flavonoids, polyphenols, terpenoids, essential oils, glycosides, tannins and saponins which contribute to the therapeutic efficacy of these Ayurvedic remedies. Additionally, the paper also discuss the functions of bhasmas (calcined metals and minerals) and their later identified nanoscale properties. Ayurveda, though rich pharmacopeia, is now facing challenges regarding toxicity, standardization, and scientific validation. Integrating traditional knowledge with modern chemistry could enhance drug discovery and global acceptance of Ayurvedic medicine.

Keywords: Ayurveda, chemistry, active principle, antihypertensive, anti-inflammatory, anticancer, antioxidant, antimicrobial, bhasmas.

Introduction

Medicinal plants, many of which contain bioactive substances that give them their therapeutic properties, are a major component of Ayurvedic medicine. Alkaloids, flavonoids, terpenoids, glycosides, and polyphenols are among the types of substances that have been discovered in Ayurvedic herbs by contemporary phytochemical research. Ayurveda "the science of life," is a traditional comprehensive medical approach that places a strong emphasis on maintaining harmony between the body, mind, and spirit. Ayurveda has its roots in ancient Vedic books such as the Charaka Samhita and Sushruta Samhita. This practice uses natural materials, such as plants, minerals, and metals, to heal illnesses. The pharmacological potential of Ayurvedic medicines has been validated by recent scientific investigations that have started to explore its chemical foundation. The chemical components of Ayurvedic medications, their modes of action, and the difficulties in incorporating them into contemporary medicine are reviewed in this paper. More than 6,000 medicinal plants many of which contain bioactive substances with therapeutic qualities, are used in Ayurveda. The class of chemicals that makeup of these Ayurvedic herbs are usually classified into the following categories:

Alkaloids

Alkaloids are a diverse group of naturally occurring organic compounds characterized by their nitrogen content, typically derived from amino acids. They are primarily basic (alkaline) due to the presence of at least one nitrogen atom, often within a heterocyclic ring, though exceptions like ephedrine exist. The term "alkaloid" originates from "alkali-like," reflecting their basic properties. Alkaloids are found to have potent physiological effects. Many Ayurvedic herbs are found to contain alkaloids that influence the nervous, cardiovascular, and digestive systems. They are found in plants like *Sarpagandha (Rauwolfia serpentina)* – containing reserpine as an active principle used as an antihypertensive and sedative agent. Its mechanistic action was later found to be depletion of catecholamines and serotonin in nerve terminals.– *Ashwagandha (Withania somnifera)* containing withanolides as an active principle is used as an adaptogenic, anti-inflammatory, neuroprotective and as a stress relief agent. This active principle was assumed to modulate cortisol levels and enhances GABA receptor activity. *Pippali* (*Piper longum)* containing piperine as active principle is used as bioenhancer (increases drug absorption) and anti-inflammatory drug. This active principle was found to inhibits drug-metabolizing enzymes (CYP3A4, P-glycoprotein).

Polyphenols and Flavonoids

Polyphenols are a broad class of naturally occurring organic compounds characterized by multiple hydroxyl groups (- OH groups). They are a typical kind of secondary metabolites in plants where as flavonoids are a major subclass of polyphenols, distinguished by a 15-carbon skeleton (C_6-C_3-C_6) consisting of two aromatic rings linked by a three-carbon chain. Flavonoids account for roughly 60% of polyphenols found in our diet. The key relationship between the two is that flavonoids are polyphenols, but not all polyphenols are flavonoids. Flavonoids and polyphenols are widely distributed in Ayurvedic herbs and exhibit antioxidant, anti-inflammatory, and anticancer properties. *Turmeric (Curcuma longa)* containing curcumin as an active principle is used as an anti-inflammatory, anticancer, antioxidant and hepatoprotective agent. Curcumin's physiological role is to Inhibits NF-κB, COX-

2, and TNF-α pathways. Onion (*Allium cepa*) and Tulsi (*Ocimum sanctum)* are found to contain quercetin which is widely used as an antioxidant, antiviral and cardioprotective agents. Quercetin is found to scavenge free radicals and modulates inflammatory cytokines. Amla (*Emblica officinalis)* contains ellagic acid and is also used as an antioxidant, anti-aging and radioprotective agents. Ellagic acid forms complex chelate with metal ions and enhances endogenous antioxidant enzymes. Holy Basil (*Ocimum sanctum*) contains eugenol, which has antimicrobial and adaptogenic properties.

Terpenoids and Essential Oils

Terpenoids (Isoprenoids) are a vast class of naturally occurring organic compounds derived from terpenes (hydrocarbons). Terpenoids are modified terpenes with oxygen-containing functional groups (e.g., alcohols, ketones). Essential Oils are complex, volatile mixtures of aromatic compounds extracted from plants, primarily composed of monoterpenoids and sesquiterpenoids, along with other compounds like phenylpropanoids. The key relationship between these two sub classes of naturally occurring organic compounds is that essential oils are rich in terpenoids, but not all terpenoids are volatile enough to be part of essential oils. Terpenoids contribute to the aromatic properties of herbs and exhibit diverse pharmacological effects, including antimicrobial, anti-inflammatory, and anxiolytic activities. *Shallaki (Boswellia serrata) a* frankincense contains boswellic acids which is found to be effective against arthritis (Anti-arthritic) and is also used as an anti-inflammatory agent. Study reveals that boswellic acid Inhibits 5-lipoxygenase (5-LOX) and leukotriene synthesis. *Guggul (Commiphora wightii)* is found to yield guggulsterones, which is used as hypolipidemic and thyroid-stimulating agent. It is also employed for lipid metabolism regulation. Guggulsterones antagonizes farnesoid X receptor (FXR), enhancing bile acid excretion. *Tulsi* (*Ocimum sanctum)* contains eugenol and is used as an antimicrobial, analgesic and anti-stress agent. Eugenol is found to modulates serotonin and dopamine levels.

Glycosides

Glycosides are a diverse group of compounds composed of a sugar moiety (glycone) linked to a non-sugar component (aglycone or genin) via a glycosidic bond. Glycosides are reported to have cardiac, laxative, and antimicrobial effects. Ayurvedic plant Senna (*Cassia angustifolia*) is found to contains sennosides, a glycosides which is used as a laxative. Sennosides are found to stimulates colonic peristalsis by irritating the intestinal mucosa. *Kaner (Nerium oleander)* is an ayurvedic plant found to contain digoxin-like compounds which are found to be cardiotonic (but should be administered cautiously due to its toxicity). This active principle found in Kaner is reported to inhibit Na^+/K^+-ATPase, thereby increasing myocardial contractility.

Tannins and Saponins

Tannins and saponins are two distinct classes of plant secondary metabolites with diverse chemical structures, biological roles, and thus applications. Tannins are usually polyphenolic compounds with high molecular weight where as saponins are glycosides with a steroidal or triterpenoid aglycone (sapogenin) linked to one or more sugar chains. Ayurvedic plant *Haritaki* (*Terminalia chebula)* is believed to contain tannins which contributes to its biological activities such as astringent, antidiarrheal and as an antioxidant. Saponins are also found in *Shatavari (Asparagus racemosus*) whose ayurvedic applications include immunomodulatory and adaptogenic agent.

Other important phytochemicals like coumarins are also reported as active principle in *Bael (Aegle marmelos)* plants which are primarily used as an anticoagulant and as an antimicrobial agent. Lignans are also reported to be an active principle in Flaxseed *(Linum usitatissimum)*. This ayurvedic formulation is employed as phytoestrogenic and anticancer agent.

Mineral and Metallic Preparations (Rasa Shastra)

Alchemistry deals with transformation of metals, minerals, and poisonous compounds into medicinal formulations. This is the major emphasis of Rasa Shastra, a specific area of Ayurveda (ancient Indian medicine). With roots in ancient Indian literature, Rasa Shastra blends metallurgy, chemistry, and spirituality to produce remedies that are thought to improve healing, potency, and longevity. When properly cleansed and treated, metals and minerals were thought to transcend their toxic nature and become powerful medicines that renew the body and balance the doshas (Pitta, Kapha, and Vata). Ayurveda uses minerals (sulfur, arsenic) and metals (gold, silver, iron, mercury) in processed forms known as *bhasmas*. To lessen toxicity and increase bioavailability, they go through the processes of shodhana (purification) and marana (calcination). Studies show that *Swarna Bhasma* (gold ash) contains gold nanoparticles with immunomodulatory effects. *Lauha Bhasma* (iron ash) is used for anemia and exhibits nano-iron structures for better absorption.

Safety and Toxicity Concerns

Despite being valued for their all-encompassing advantages, ayurvedic medications have caused serious safety issues because of possible heavy metal toxicity, incorrect processing, herb-drug interactions, and contamination. Heavy metals like lead and mercury, if not prepared properly, can be highly dangerous. Regulatory guidelines laid by government and agencies (like AYUSH and WHO) place a strong emphasis on acceptable limits and quality management.

Scientific Validation and Challenges Pharmacological Studies

A large number of Ayurvedic medicines, such as neem, turmeric, and ashwagandha etc, have been shown to have anti-cancer, anti-diabetic, antioxidant

and other biological properties of pharmacological importance. However, consistency is impacted by standardization problems such as variations in plant sources and preparation techniques, etc. More study on herb-drug interactions and bioavailability is still required to ensure effective integration with modern treatment.

Conclusion

The chemical concepts behind Ayurveda are in line with contemporary pharmacology and provide a wealth of bioactive substances. However, for widespread acceptability, thorough safety evaluations, standardization, and scientific validation are necessary. Equipped with powerful treatments and rich cultural heritage, Rasa Shastra is a singular combination of alchemy, medicine, and spirituality. It highlights the inventiveness of ancient metallurgy and the necessity of thorough scientific proof to connect conventional wisdom with contemporary healthcare, even though its usefulness and safety are still up for debate.

The therapeutic potency and efficacy of Ayurvedic herbs is largely attributed to their diverse phytochemical composition. Current studies continue to support historical assertions by exposing molecular mechanisms of action. To incorporate Ayurveda into evidence-based medicine, standardization, toxicity research, and bioavailability improvement (such as combining piperine and curcumin) are still essential. New therapeutic paths can be opened by cooperative study between contemporary chemistry and traditional wisdom.

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