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HERBAL INTERVENTIONS FOR HYPERTENSION: A REVIEW OF TRADITIONAL PLANTS, BIOACTIVE COMPOUNDS, AND NANOTECHNOLOGICAL ADVANCES

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ABSTRACT: Hypertension (HTN), a major global health concern and the primary cause of cardiovascular disease (CVD) death is expected to impact 29% of all adults by 2025. Hypertension (HTN) is a multifactorial condition, arising from the complex interaction of hereditary, environmental, and physiological variables that contribute to elevated systolic and diastolic blood pressure. It is frequently caused by dysregulation of blood pressure control mechanisms, such as over activity of the renin-angiotensin system and increased sympathetic nervous system activity. Traditional hypertension therapies, such as ACE inhibitors and beta-blockers, have drawbacks, including low solubility and absorption. As a result, researchers are increasingly focusing on novel treatment approaches, such as medicinal plants and nanotechnology. Herbal plants such as Ashwagandha, Cat's Claw, Ginger, Ginseng, Murungai, and Touch-Me-Not belonging to different families are renowned for pharmacological activities and have shown potential medicines antihypertensive properties, which are often attributed to their bioactive constituents. Recent breakthroughs in nanotechnology have permitted the manufacture of nanoparticles derived from these plants, improving their stability, bioavailability, and potency. These plant-mediated nanoparticles show potential in controlling hypertension by lowering oxidative stress, increasing endothelial function, and regulating nitric oxide levels. As research progresses, combining nanomedicine with traditional herbal therapy may provide novel and effective methods for hypertension management. Future clinical trials and thorough patient education on herbal medicines will be required to realize their promise while maintaining safety and efficacy fully.

INTRODUCTION: Hypertension (HTN) is the leading risk factor for acute myocardial infarction, accounting for around 16.5% of deaths worldwide each year. The disordered regulation of blood pressure (BP), often known as the silent killer, can result from a combination of hereditary and environmental variables [1-2].

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It is also the primary cause of morbidity and mortality in cardiovascular disease (CVDs) [3]. It is anticipated that by 2025, 29% of the world's adults, a total of 1.56 billion individuals, will suffer from HTN [4]. The threshold for eligibility is systolic blood pressure (SBP) ≥ 140 mm Hg and diastolic blood pressure (DBP) ≥ 90 mm Hg, based on the average of two consecutive BP readings [2].

In nations like India, the prevalence of hypertension among adults stands at 11%, with a notable increase observed particularly in urban areas compared to rural regions [5]. In a study encompassing 8000 subjects in India hypertension emerged as the primary risk factor for CAD in over 50% of both young and elderly participants followed by smoking and diabetes [6, 7]. The estimated annual cardiovascular deaths in India amount to 2.5 millions with projections indicating it may become the leading cause of mortality by 2020 [8]. Hypertension has three subcategories: stage I, stage II, and isolated systolic hypertension (ISH) which is defined by elevated systolic pressure alongside normal diastolic pressure and often occurs in the elderly. Additionally, hypertension is deemed resistant if medications fail to lower blood pressure to normal levels. This condition typically lacks early symptoms but constitutes a significant cardiovascular risk in the long term [9]. The precise mechanisms underlying hypertension (HTN) particularly essential hypertension, remain incompletely understood [10].

HTN is distinguished by dysregulation of blood pressure control mechanisms, in which inadequate sodium secretion by the kidneys causes increased excretion of natriuretic factors such as atrial natriuretic factor. An overactive renin-angiotensin system also causes vasoconstriction, which aids in the retention of salt and water [11]. The accumulation of blood volume is a significant contributor to the development of HTN. Furthermore, heightened activity of the sympathetic nervous system exacerbates stress, further complicating the condition [11-12].

Mechanisms of Hypertension / Hypertensive Mechanisms: Hypertension results from complex interactions between multiple physiological systems and factors. Key mechanisms underlying high blood pressure include: Genetic predispositions, autonomic nervous system dysregulation, renin-angiotensin-aldosterone system (RAAS) activation, vascular structure and function alterations, stimulation of the sympathetic nervous system, vasopressin regulation, disrupted G protein-coupled receptor signaling, inflammatory responses, T-cell mediated immune mechanism, and a wide range of vasoactive peptides secreted by other endothelial and smooth muscle cells [13-14]. Enhanced vasoconstriction may be attributed to a combination of factors, including vascular smooth muscle cell (VSMC) hyperplasia and hypertrophy, leading to increased muscle mass and contractility, elevated basal and activated calcium levels facilitated by altered calcium channel activity, and augmented arterial reactivity resulting from dysregulation of pro-oxidant enzymes and impaired endothelial nitric oxide synthase (eNOS) function [15]. These mechanisms collectively contribute to exaggerated vasoconstriction, potentially exacerbating hypertension [16]. Angiotensin II (Ang II) can promote the advancement of the cell cycle [17].

Antihypertensive medications used to treat HTN include angiotensin-converting enzyme inhibitors, renin blockers, diuretics, sympatholytic drugs, calcium channel blockers, β-adrenergic and α1/β-adrenergic antagonists, and vasodilators [10]. The majority of standard antihypertensive medicines are poorly water-soluble and undergo first-pass metabolism, which contributes to their very low bioavailability, short half-life, and high dosage frequency[1]. To circumvent these limitations, designing new-generation alternative antihypertensive therapeutics and proper delivery systems is the primary focus of research in this field [18].

Plants with medicinal properties and their bioactive compounds are used around the world to treat and prevent a wide range of illnesses. According to Pant (2014), around 80% of the world's population relies on herbal medicines to cure, prevent, and manage a variety of medical issues [19].

The potential of the active components of herbal medicine to function as natural therapeutic agents, as well as its availability, accessibility, affordability, and reported reduced or non-toxic effects, may explain why herbal medicines are becoming more popular than conventional treatments [20-19]. In recent decades, various researchers found and classified medicinal plants and their bioactive components for use in the treatment and prevention of life-threatening and chronic illnesses such as cerebrovascular accidents, diabetes, stroke, arthritis, and psychiatric diseases, among others [21]. The initial identification of reserpine approximately five decades prior, derived from the roots of the Indian plant *Rauwolfia serpentina*, demonstrated considerable cardioselectivity [22]. First introduced reserpine for hypertension treatment, with subsequent advancements including its structural elucidation and total synthesis achieved between 1952 and 1958 [23-24]. Polyphenols, naturally occurring plant compounds found in various plant-based foods such as vegetables, fruits, dark chocolate, tea, spices, wine, and herbs, play an important role in neutralizing harmful free radicals that can damage cells and increase the risk of conditions like diabetes, cancer, and cardiovascular disease [25-26]. Regular intake of flavonoids, a type of polyphenol has been shown to mitigate the onset or progression of numerous cardiovascular diseases, particularly hypertension [27]. Carotenoids, which contribute to the red, yellow, and orange hues of fruits and vegetables, are present in smaller quantities but are still vital. They are thought to be responsible for the foods' therapeutic effects in reducing cardiovascular disease and other human disorders [28].

Nanoparticles are sub-ionized colloidal structures made of synthetic or semi-synthetic polymers with sizes ranging from 10 to 100 nanometers (nm). These compounds are commonly employed in the pharmaceutical industry because they play an important role in drug delivery by dissolving, entrapping, encapsulating, or adhering to the matrix. Nanomaterials' unique features, such as their nanoscale size, high surface area to volume ratio, and variable surface chemistry, make them interesting candidates for use in therapeutic applications [29].

Nanoparticle synthesis mediated by "Green chemistry" is currently a major dominant holder. This method is preferred for biomedical and pharmaceutical applications. This approach is not only eco-friendly but also financially affordable. As a result, we can say that green chemistry is an affordable and environmentally benign strategy for plant extract-assisted biogenesis of metal nanoparticles [30].

Herbal Plants used in Treatment of Hypertension:

Ashwagandha (*Withania somnifera*): Ashwagandha has been revered for its extensive benefits, being recognized as a potent rejuvenator, a versatile health tonic, and a remedy for various health issues. Its properties encompass sedative, diuretic, and anti-inflammatory qualities, while also being esteemed for its ability to enhance energy, endurance, and act as an adaptogen, bolstering immune response and mitigating stress. *Withania somnifera,* often referred to as Indian ginseng or Indian Winter Cherry plays a vital role in ancient medical disciplines like Ayurveda and Unani [31]. Its roots are key components of various formulations treating respiratory and reproductive diseases [32-33]. It is rich in alkaloids such as withanine and withasomnin, as well as steroidal lactones and glycosides known as withanoloids and sitoindosides [34-35]. Extracts derived from *Withania somnifera* exhibit analgesic mildly sedative anti-inflammatory, and anabolic properties proving beneficial in managing conditions like stress, fatigue, pain, skin disorders, diabetes, gastrointestinal issues, rheumatoid arthritis, epilepsy, chronic fatigue syndrome, and even during pregnancy without adverse effects [36].

Research has demonstrated influence of this plant on neurological, endocrine, and cardiovascular functions. It is commonly utilized as a general tonic to promote vitality and enhance overall health and longevity. Human studies suggest its potential to faster growth in children, elevate hemoglobin levels, increase red blood cell count, and enhance physical performance in adults [37]. Furthermore, animal studies have corroborated its impact on sex hormone production, demonstrated by its effects on luteinizing hormone, follicle-stimulating hormone, testosterone, and progesterone levels [38].

In recent years, *Withania somnifera* has been investigated for its involvement in the production of nanoparticles, which are gaining importance in medical studies, particularly for the treatment of hypertension. The green synthesis of nanoparticles using plant extracts is a rapidly growing field due to its eco-friendly and sustainable approach. Ashwagandha includes a variety of bioactive chemicals, including alkaloids and flavonoids, that can act as reducing and capping agents in the creation of metal nanoparticles such as silver (AgNPs) and gold (AuNPs).

These biosynthesized nanoparticles have demonstrated significant potential in biomedical applications due to their enhanced stability, biocompatibility, and targeted drug delivery capabilities. Specifically, in the context of hypertension, the antioxidant properties of

Ashwagandha-derived nanoparticles have been studied for their ability to reduce oxidative stress, a major contributor to high blood pressure. These nanoparticles can modulate the levels of nitric oxide (NO), a critical molecule in regulating vascular tone and blood pressure, thereby providing a novel therapeutic avenue for hypertension management [39-40]. Furthermore, Ashwagandha-mediated nanoparticles have shown promise in improving endothelial function and reducing vascular Inflammation, both of which are crucial factors in the pathogenesis of hypertension. These nanoparticles also exhibit minimal side effects, making them a viable option for long-term use in managing chronic conditions such as hypertension [41] **Table 1** and **Fig. 1.**

Cat's Claw (*Uncaria rhynchophylla*): Uncaria species are primarily utilized to treat ulcers and wounds, asthma, hyperpyrexia, hypertension, gastrointestinal disease, headaches, fever, rheumatism, and bacterial/fungal infections [42]. It is prepared from the dried stem of the plant, along with a segment featuring five curled, hook-shaped structures. The medicinal components of this remedy come from *U. rhynchophylla* and *U. sinensis*. In recent years, extensive studies on *Uncaria* species have led to the successful identification of several metabolites, including alkaloids, triterpenes, and flavonoids. Notably, monoterpenoid indole alkaloids such as hirsutanine, rhynchophylline units, and uncarialins have been recognized as key components of this herb. These compounds exhibit a range of pharmacological effects, including antidepressant, anticancer, and antihypertensive properties [43]. *U. rhynchophylla*, native to tropical regions, contains phenolic compounds (such as hyperin, caffeic acid, procyanidin B2, epicatechin, chlorogenic acid, rutin, and hyperoside), pentacyclic triterpene esters, and indole alkaloids (including rhynchophylline and isorhynchophylline). Passive targeting is a significant advantage since it allows nanoparticles to enter and aggregate in tumors, which contain blood arteries with greater fenestrations due to angiogenesis and inefficient lymphatic drainage [44] **Table 1 a**nd **Fig. 1.**

Ginger (*Zingiber officinale*): *Zingiber officinale* commonly known as ginger has been widely incorporated into everyday diets and utilized for various therapeutic intentions. It is comprised of potassium, which helps regulate the heart rate and blood pressure activities [45]. It contains a variety of cations and anions, including calcium, magnesium, and phosphorus, which are essential for bone growth, muscular contraction, and nerve conduction [45]. The root nodules assists by inhibiting the electrical current of calcium channels. These channels typically stimulate the contraction of smooth muscle tissue found in organs and arterial walls thus facilitating smoother blood flow and consequently lowering blood pressure. It also aids in reducing hypertension by decreasing the body's requirement for dietary salt[46]. *Z. officinale* is considered as one of the interests for the treatment of many cardiovascular diseases. The studies suggest that *Z. officinale* has anti-inflammatory, antioxidant, anti-platelet, hypotensive and hypolipidemic effects in *in-vitro* and animal studies [47]. Studies on silver nanoparticles produced using ginger extract have shown that these particles are quite persistent in solution. The use of biologically generated nanoparticles, which reduce aspects like toxicity and cost and are observed to be highly stable, could be an effective way to use silver nanoparticles in biomedical applications [48] **Table 1** and **Fig. 1.**

Ginseng (*Panax spp.*): Ginseng stands out as one of the most popular medicinal herbs [49], often purported to have efficacy across a wide array of conditions, including cancer [50], erectile dysfunction [51] and postmenopausal symptoms [52]. Extensive research has delved into the cardiovascular effects of ginseng or its individual ginsenosides. While a particular study indicated that ginseng is unlikely to effectively reduce blood pressure, other researchers have proposed its potential in addressing hypertension [53]. Several *in-vivo* studies have suggested that ginseng might lower blood pressure in a manner not dependent on dosage. Ginseng is available in many forms such as capsules, tablets, extracts, dried roots, oil, or tea, and it has hypotensive properties. Minimal dosages of ginseng can raise blood pressure, whereas increased doses have a hypotensive impact. Ginseng is likely to regulate blood pressure levels in hypotensive patients by altering vascular function, influencing the autonomic nervous system, or adjusting the arterial baroreflex [54].

In recent decades, there has been an increasing interest in using nanotechnology to improve the medicinal potential of ginseng, particularly in the treatment of hypertension. The bioactive compounds in ginseng, especially ginsenosides, have been used in the green synthesis of nanoparticles, which are recognized for their potential to treat hypertension effectively. The phytochemicals in ginseng act as reducing and stabilizing agents during the nanoparticle synthesis process, resulting in nanoparticles that are biocompatible and effective for medical applications. These ginseng-mediated nanoparticles, particularly gold (AuNPs) and silver nanoparticles (AgNPs), have shown promising results in preclinical studies.

The nanoparticles exhibit strong antioxidant properties, which are crucial in managing oxidative stress a key factor contributing to hypertension. By scavenging reactive oxygen species (ROS), these nanoparticles help protect the cardiovascular system from oxidative damage, thereby supporting the maintenance of normal blood pressure levels [55]. Moreover, these nanoparticles have been found to enhance the bioavailability and efficacy of ginsenosides, allowing for more efficient modulation of vascular function and blood pressure. The nanoparticles also improve endothelial function and nitric oxide (NO) production, both of which are critical in the regulation of blood pressure. These findings suggest that ginseng-based nanoparticles could offer a novel and more effective approach to hypertension treatment, combining traditional herbal medicine with cutting-edge nanotechnology [56] **Table 1** and **Fig. 1.**

Murungai (*Moringa oleifera*): Murungai, which is part of the Moringaceae family is a herbal plant that has been researched for its effects on blood pressure in sedated rats. Moringa leaf phytochemicals, including flavonoids, quercetin, and phenolic acid, are thought to ameliorate non-alcoholic fatty liver disease (NAFLD) [57]. The crude leaf extract of *M. oleifera* caused a dose-dependent decrease in systolic, diastolic, and mean blood pressure. However, this antihypertensive effect was short-lived, with blood pressure returning to normal within two minutes. Heart rate was not significantly impacted, except at higher doses, which caused a slight bradycardia. The crude extract's thiocarbamate and isothiocyanate fractions were also revealed to be responsible for its antihypertensive effect [58]. In addition to the conventional antihypertensive properties of *Moringa oleifera*, recent research has delved into its potential in the synthesis of nanoparticles for therapeutic applications, including the treatment of hypertension.

The bioactive compounds present in *M. oleifera*, such as flavonoids, phenolics, and glucosinolates, have been effectively utilized in the green synthesis of nanoparticles, particularly silver nanoparticles (AgNPs). These *Moringa oleifera*-mediated nanoparticles exhibit remarkable antioxidant properties, which are crucial in counteracting oxidative stress, a major factor in the development of hypertension. The nanoparticles enhance the bioavailability of nitric oxide (NO), a vasodilator that plays a vital role in regulating blood pressure by relaxing blood vessels. The increase in NO availability facilitated by these nanoparticles helps in reducing vascular resistance, thereby lowering blood pressure [59]. Furthermore, studies have shown that these biosynthesized nanoparticles can improve endothelial function, reduce inflammation, and prevent the progression of hypertension-related vascular damage. Their biocompatibility and minimal side effects make them promising candidates for long-term use in managing hypertension [60] **Table 1** and **Fig. 1.**

Touch-Me-Not (*Mimosa pudica*): *Mimosa pudica L*. is a perennial herb from the Mimosaceae family. Phytochemical studies have identified several compounds in *M. pudica*, including terpenoids, tannins, alkaloids, sterols, and fatty acids. The medicinal properties of *Mimosa pudica* reported to date primarily encompass antidepressant, anticonvulsant, hyperglycemic, and anti-implantation effects [61]. Among the plant groups with potential biological effects, the genus Mimosa stands out, as several of its species have been scientifically investigated for their impact on the cardiovascular and renal systems. Notably, *M. pigra* has been shown to mitigate the progression of experimental pulmonary hypertension [62]. Green silver nanoparticles derived from *M. pudica* flower extract had strong antibacterial and antibiofilm properties against *E. coli* [63].

Recent research has expanded the exploration of *M. pudica* to include its potential in the green synthesis of nanoparticles, particularly in the context of hypertension treatment. Nanoparticles synthesized from plant extracts have gained attention for their biocompatibility and eco-friendly production processes. Mimosa pudica's phytochemicals, such as flavonoids and tannins, play a significant part in the reduction and stability of metal ions during nanoparticle synthesis, which leads to stable and effective nanoparticles. Specifically, Mimosa pudica has been used in the biosynthesis of silver nanoparticles (AgNPs), which have indicated potential in a variety of biological applications. These nanoparticles have significant antioxidant activities, which are important in the control of oxidative stress, a major contributor in the development and progression of hypertension. The antioxidant activity of *Mimosa pudica*-mediated AgNPs can help reduce oxidative damage in the vascular system, thereby potentially lowering blood pressure and preventing further cardiovascular complications [64]. Moreover, studies have suggested that these nanoparticles can enhance nitric oxide (NO) availability, leading to vasodilation and improved endothelial function, both of which are important in the management of hypertension. The use of *Mimosa pudica* in nanoparticle synthesis thus represents a novel and promising approach to the treatment of hypertension, combining the traditional medicinal properties of the plant with innovative nanotechnology [65]. The exploration of *Mimosa pudica* in the field of nanomedicine underscores the potential of this plant not only in antibacterial and antiparasitic treatments but also in addressing complex conditions such as hypertension, offering a natural and sustainable alternative to conventional therapies **Table 1** and **Fig. 1.**

TABLE 1: HERBAL PLANTS AND ITS SECONDARY METABOLITES IN THE MANAGEMENT OF HYPERTENSION

Sl. no.	Common Name	Botanical Name	Family	Secondary Metabolites	Reference
1	Ashwagandha	*Withania somnifera*	Solanaceae	Withanolides, Withanosides, Alkaloids (e.g., somniferine, anaferine), Flavonoids and Sitoindosides.	66
2	Cat's Claw	*Uncaria rhynchophylla*	Rubiaceae	Isorhynchophylline, Rhynchophylline, Hirsutine, Corynoxeine and Corynantheine.	67
3	Ginger	*Zingiber officinale*	Zingiberaceae	Gingerol, Shogaol, Zingerone, Paradols and Flavonoids.	68
4	Ginseng	*Panax spp.*	Araliaceae	Ginsenosides, Polyacetylenes, Polysaccharides and Flavonoids.	69
5	Moringa	*Moringa oleifera*	Moringaceae	Glucosinolates, Quercetin, Chlorogenic Acid and β-Sitosterol.	70
6	Touch-me-not	*Mimosa pudica*	Fabaceae	Flavonoids, Tannins, Saponins and Alkaloids.	71

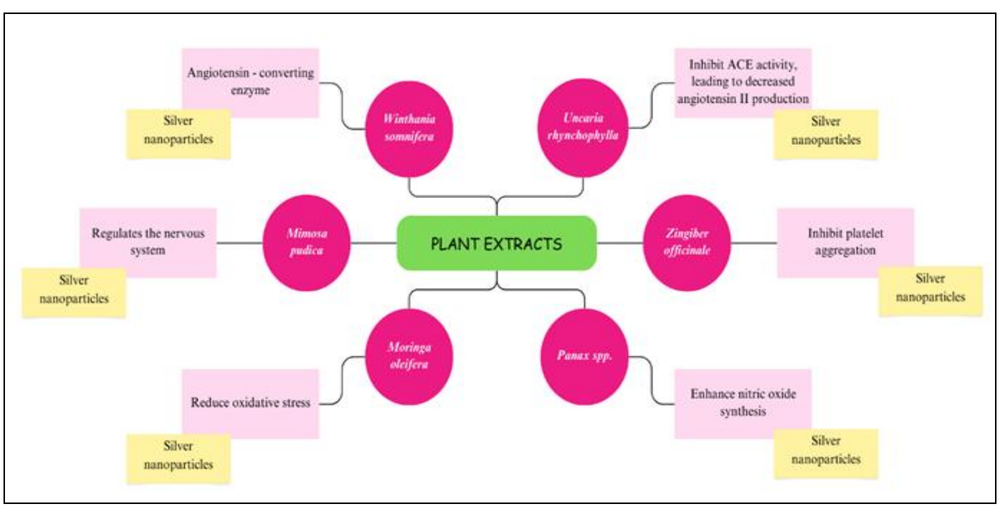

FIG. 1: SCHEMATIC REPRESENTATION OF PLANT EXTRACTS AND IT'S ON THE MANAGEMENT OF HYPERTENSION

CONCLUSION: In recent years, developing more effective treatments for hypertension and cardiovascular disease (CVD), the leading cause of death worldwide, has become critical. Nature has historically served as an inspiration for the development of new small-molecule drugs, which may explain why many patients prefer herbal therapy to allopathic treatments for CVD management. This article examines the most often used plants for treating hypertension, as well as their modes of action. These natural plants and their compounds have pharmacological effects on the pathogenesis of hypertension by modulating endothelial function, reactive oxygen species (ROS) production, pro-inflammatory signaling, platelet activation, ion channel regulation, ACE inhibition, and gene expression.

Nano-formulations are a new tool in biology and medicine that provide distinct physicochemical and biological features due to their size, shape, and surface characteristics. These characteristics make them an attractive platform for creating novel, non-conventional medicines. To effectively convert research findings into clinical practice, it is critical to take use of all advances in nanomedicine to gain a more precise grasp of the subject. This necessitates collecting precise data on existing nanotherapeutics and thoroughly examining their intrinsic features and biological impacts. Such an approach will make it possible to create smart nano-formulations that are suited to specific diseases and personalize nano-therapies. Herbal medicines are anticipated to receive more attention in the future due to their broad range of efficacy, assuming that relevant clinical and experimental research are done. It is also critical to educate patients on the safe use of herbs such as black cumin, coriander, garlic, Chinese sage, ginger, and ginseng, particularly because some ingredients can elevate blood pressure and be hazardous if not chosen appropriately.

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REFERENCES:

1. Wang C, Yuan Y and Zheng M: Association of age of onset of hypertension with cardiovascular diseases and mortality. Journal of the American College of Cardiology. 2020; 75(23): 2921-2930. doi:10.1016/j.jacc.2020.04.038
2. Kamyab R, Namdar H, Torbati M, Ghojazadeh M, Araj-Khodaei M and Fazljou SMB: Medicinal Plants in the Treatment of Hypertension: A Review. Adv Pharm Bull 2021; 11(4): 601-617. doi:10.34172/apb.2021.090
3. Anwar MA, Al Disi SS and Eid AH: Anti-Hypertensive Herbs and Their Mechanisms of Action: Part II. Front Pharmacol 2016; 7. doi:10.3389/fphar.2016.00050
4. Hashemi V, Dolati S, Hosseini A, Gharibi T, Danaii S and Yousefi M: Natural killer T cells in Preeclampsia: An updated review. Biomedicine & Pharmacotherapy. 2017; 95: 412-418. doi:10.1016/j.biopha.2017.08.077
5. Al Disi SS, Anwar MA and Eid AH: Anti-hypertensive Herbs and their Mechanisms of Action: Part I. Front Pharmacol 2016; 6. doi:10.3389/fphar.2015.00323
6. Mucalo I, Jovanovski E, Rahelić D, Božikov V, Romić Ž and Vuksan V: Effect of American ginseng (*Panax quinquefolius* L.) on arterial stiffness in subjects with type-2 diabetes and concomitant hypertension. Journal of Ethnopharmacology 2013; 150(1): 148-153. doi:10.1016/j.jep.2013.08.015
7. Forouzanfar MH, Liu P and Roth GA: Global Burden of Hypertension and Systolic Blood Pressure of at Least 110 to 115 mm Hg, 1990-2015. JAMA 2017; 317(2): 165-182. doi:10.1001/jama.2016.19043
8. Prabhakaran D, Singh K, Roth GA, Banerjee A, Pagidipati NJ and Huffman MD: Cardiovascular Diseases in India Compared With the United States. J Am Coll Cardiol 2018; 72(1): 79-95. doi:10.1016/j.jacc.2018.04.042
9. Costa GFD, Ognibene DT and Costa CAD: *Vitis vinifera* L. Grape skin extract prevents development of hypertension and altered lipid profile in spontaneously hypertensive rats: Role of Oxidative Stress. PNF 2020; 25(1): 25-31. doi:10.3746/pnf.2020.25.1.25
10. Iqbal AM and Jamal SF: Essential Hypertension. In: StatPearls. StatPearls Publishing; 2024. Accessed August 22, 2024. http://www.ncbi.nlm.nih.gov/books/NBK539859/
11. Ames MK, Atkins CE and Pitt B: The renin-angiotensin-aldosterone system and its suppression. J Vet Intern Med 2019; 33(2): 363-382. doi:10.1111/jvim.15454
12. Efremov A: Psychosomatics: communication of the central nervous system through connection to tissues, organs, and cells. Clin Psychopharmacol Neurosci 2024; 22(4): 565-577. doi:10.9758/cpn.24.1197
13. Rawat P, Singh PK and Kumar V: Anti-hypertensive medicinal plants and their mode of action. Journal of Herbal Medicine 2016; 6(3): 107-118. doi:10.1016/j.hermed.2016.06.001
14. Luo Y, Yang J and Wang Y: Quantitative proteomics assay reveals G protein-coupled receptor kinase 4-induced HepG2 cell growth inhibition. Heliyon 2024; 10(8). doi:10.1016/j.heliyon.2024.e29514
15. Francis GA: The greatly under-represented role of smooth muscle cells in atherosclerosis. Curr Atheroscler Rep 2023; 25(10): 741-749. doi:10.1007/s11883-023-01145-8
16. Hao X, Wang Y and Liu R: Developing engineering technologies for the treatment of systemic lupus erythematosus. Biomedical Technology 2023; 4: 1-10. doi:10.1016/j.bmt.2023.02.002
17. Flores K, Siques P, Brito J and Arribas SM: AMPK and the Challenge of Treating Hypoxic Pulmonary

Hypertension. International Journal of Molecular Sciences 2022; 23(11): 6205. doi:10.3390/ijms23116205

18. Adepu S and Ramakrishna S: Controlled drug delivery systems: current status and future directions. Molecules. 2021; 26(19): 5905. doi:10.3390/molecules26195905
19. Ugbogu OC, Emmanuel O and Agi GO: A review on the traditional uses, phytochemistry, and pharmacological activities of clove basil (*Ocimum gratissimum* L.). Heliyon 2021; 7(11): 08404. doi:10.1016/j.heliyon.2021.e08404
20. Adurosakin OE, Iweala EJ and Otike JO: Ethnomedicinal uses, phytochemistry, pharmacological activities and toxicological effects of *Mimosa pudica*- A review. Pharmacological Research - Modern Chinese Medicine 2023; 7: 100241. doi:10.1016/j.prmcm.2023.100241
21. Raghavendra VB, Sagar N and Kusha LM: Recent advances on *Nigella sativa* – A promising herb: Antihypertensive properties, thimoquinone nanoformulations, and health applications. Pharmacological Research - Natural Products 2024; 3: 100052. doi:10.1016/j.prenap.2024.100052
22. López-Muñoz F, Bhatara VS, Alamo C and Cuenca E: [Historical approach to reserpine discovery and its introduction in psychiatry]. Actas Esp Psiquiatr 2004; 32(6): 387-395.
23. Zabludovich S, Schaposnik F and De Falco JC: [*Rauwolfia serpentina* in the treatment of hypertension]. Prensa Med Argent 1955; 42(51): 3830-3834.
24. Sinha D, Odoh UE and Ganguly S: Chapter 1 - Phytochemistry, history, and progress in drug discovery. In: Egbuna C, Rudrapal M, Tijjani H, eds. Phytochemistry, Computational Tools and Databases in Drug Discovery. Drug Discovery Update. Elsevier 2023; 1-26. doi:10.1016/B978-0-323-90593-0.00001-0
25. Lobay D: Rauwolfia in the Treatment of Hypertension. Integr Med (Encinitas) 2015; 14(3): 40-46.
26. Iqbal I, Wilairatana P and Saqib F: Plant Polyphenols and their potential benefits on cardiovascular health: a review. Molecules 2023; 28(17): 6403.
27. Shah SMA, Naqvi SAR, Munir N, Zafar S, Akram M and Nisar J: Antihypertensive and Antihyperlipidemic Activity of Aqueous Methanolic Extract of *Rauwolfia serpentina* in Albino Rats. Dose Response. 2020; 18(3): 1559325820942077. doi:10.1177/1559325820942077
28. Alshahrani MY, Rafi Z and Alabdallah NM: A comparative antibacterial, antioxidant, and antineoplastic potential of *Rauwolfia serpentina* (L.) Leaf Extract with Its Biologically Synthesized Gold Nanoparticles (R-AuNPs). Plants 2021; 10(11): 2278. doi:10.3390/plants10112278
29. Nosrati H, Heydari M and Khodaei M: Cerium oxide nanoparticles: Synthesis methods and applications in wound healing. Materials Today Bio 2023; 23: 100823. doi:10.1016/j.mtbio.2023.100823
30. Sharmila G, Thirumarimurugan M and Muthukumaran C: Green synthesis of ZnO nanoparticles using *Tecoma castanifolia* leaf extract: Characterization and evaluation of its antioxidant, bactericidal and anticancer activities. Microchemical Journal 2019; 145: 578-587. doi:10.1016/j.microc.2018.11.022
31. Kayesth S, Gupta KK, Tyagi K, Mohan RR, Arora J and Nissapatorn V: Natural products and human health— A special focus on Indian Ginseng *Withania somnifera* (L.) Dunal. Indian Journal of Natural Products and Resources (IJNPR) [Formerly Natural Product Radiance (NPR)] 2024; 15(2): 244-259. doi:10.56042/ijnpr.v15i2.11665
32. Manivannan U, Rajeswari R and Rahale S: The Pharma Innovation Traditional and Medicinal Uses of *Withania somnifera*. Pharm Innov 2012; 1.
33. Mechanisms of Neuroprotection by Combined Formulation of Water-Soluble CoQ10 and Ashwagandha Root Extract - ProQuest. Accessed December 30, 2024. https://www.proquest.com/openview/c6a29563f6fc28aede5f33061d17447d/1?pq-origsite=gscholar&cbl=18750&diss=y
34. Mishra LC, Singh BB and Dagenais S: Scientific Basis for the Therapeutic Use of *Withania somnifera* (Ashwagandha): A Review. Alternative Medicine Review 2000; 5(4).
35. Gaurav H, Yadav D and Maurya A: Biodiversity, Biochemical Profiling, and Pharmaco-Commercial Applications of *Withania somnifera*: A Review. Molecules 2023; 28(3): 1208. doi:10.3390/molecules28031208
36. Ali HM: Ashwagandha (*Withania somnifera*) and Their Effects on the Reproductive Hormones of Male Rats Published online 2021.
37. Vaidya VG, Gothwad A, Ganu G, Girme A, Modi SJ and Hingorani L: Clinical safety and tolerability evaluation of *Withania somnifera* (L.) Dunal (Ashwagandha) root extract in healthy human volunteers. Journal of Ayurveda and Integrative Medicine 2024; 15(1): 100859. doi:10.1016/j.jaim.2023.100859
38. John J: Therapeutic Potential of *Withania somnifera*: A Report on Phytopharmacological Properties. Published online 2014.
39. Koliyote S and Shaji J: A Recent Review on Synthesis, Characterization and Activities of Gold Nanoparticles Using Plant Extracts. Indian Journal of Pharmaceutical Education and Research 2023; 57(2).
40. Gupta SD: Eco-sustainable synthesis and biological evaluation of 2-phenyl 1,3-benzodioxole derivatives as anticancer, DNA binding and antibacterial agents. Published online 2014.
41. Sharma VK, Yngard RA and Lin Y: Silver nanoparticles: Green synthesis and their antimicrobial activities. Advances in Colloid and Interface Science. 2009; 145(1): 83-96. doi:10.1016/j.cis.2008.09.002
42. Abdul R, Wang MR, Zhong CJ, Liu YY, Hou W and Xiong HR: An updated review on the antimicrobial and pharmacological properties of Uncaria (Rubiaceae). Journal of Herbal Medicine 2022; 34: 100573. doi:10.1016/j.hermed.2022.100573
43. Zhou JY and Zhou SW: Isorhynchophylline: A plant alkaloid with therapeutic potential for cardiovascular and central nervous system diseases. Fitoterapia 2012; 83(4): 617-626. doi:10.1016/j.fitote.2012.02.010
44. Ribeiro AF, Santos JF and Mattos RR: Characterization and *in-vitro* antitumor activity of polymeric nanoparticles loaded with *Uncaria tomentosa* extract. An Acad Bras Ciênc 2020; 92(1): 20190336. doi:10.1590/0001-3765202020190336
45. Akinyemi AJ, Ademiluyi AO and Oboh G: Inhibition of angiotensin-1-converting enzyme activity by two varieties of ginger (*Zingiber officinale*) in Rats Fed a High Cholesterol Diet. Journal of Medicinal Food 2014; 17(3): 317-323. doi:10.1089/jmf.2012.0264
46. Raj R, Garg M and Kaur A: Targeting Hypertension: A Review on Pathophysiological Factors and Treatment Strategies. Current Hypertension Reviews 2024; 20(2): 70-79. doi:10.2174/0115734021293403240309165336
47. Rajendra Nath. An experimental study to evaluate the preventive effect of *Zingiber officinale* (ginger) on hypertension and hyperlipidaemia and its comparison with *Allium sativum* (garlic) in rats. J Med Plants Res 2011; 6(25). doi:10.5897/JMPR12.323

48. Biological Synthesis of Silver Nanoparticles using Ginger (*Zingiber officinale*) Extract. J Environ Nanotechnol 2014; 3(4): 32-40. doi:10.13074/jent.2014.12.143106
49. Cho IH: Volatile compounds of ginseng (Panax sp.): a review. J Korean Soc Appl Biol Chem 2015; 58(1): 67-75. doi:10.1007/s13765-015-0007-0
50. Ahuja A, Kim JH, Kim JH, Yi YS and Cho JY: Functional role of ginseng-derived compounds in cancer. Journal of Ginseng Research 2018; 42(3): 248-254. doi:10.1016/j.jgr.2017.04.009
51. Nair R, Sellaturay S and Sriprasad S: The history of ginseng in the management of erectile dysfunction in ancient China (3500-2600 BCE). Indian J Urol 2012; 28(1): 15. doi:10.4103/0970-1591.94946
52. Ghorbani Z, Mirghafourvand M, Farshbaf Khalili A, Javadzadeh Y, Shakouri SK and Dastranj Tabrizi A: The Effect of panax ginseng on genitourinary syndrome in postmenopausal women: a randomized, double-blind, placebo-controlled clinical trial. Complementary Medicine Research 2021; 28(5): 419-426. doi:10.1159/000514944
53. Verma T, Sinha M, Bansal N, Yadav SR, Shah K and Chauhan NS: Plants used as antihypertensive. Nat Prod Bioprospect 2021; 11(2): 155-184. doi:10.1007/s13659-020-00281-x
54. Hur MH, Lee MS, Yang HJ, Kim C, Bae IL and Ernst E: Ginseng for Reducing the Blood Pressure in Patients with Hypertension: A Systematic Review and Meta-Analysis. Journal of Ginseng Research 2010; 34(4): 342-347. doi:10.5142/jgr.2010.34.4.342
55. Ni J, Negm S, El-kott AF, Ghamry HI and Karmakar B: *Panax ginseng* leaf aqueous extract mediated green synthesis of AgNPs under ultrasound condition and investigation of its anti-lung adenocarcinoma effects. Open Chemistry 2023; 21(1). doi:10.1515/chem-2023-0103
56. El-Semary MS, Belal F, El-Emam AA, Rabie Shehab El-Din EM and El-Masry AA: Ginseng root extract-mediated synthesis of monodisperse silver nanoparticles as a fluorescent probe for the spectrofluorometric determination of nilvadipine; Evaluation of remarkable anti-bacterial, anti-fungal and *in-vitro* cytotoxic activities. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 2024; 311: 124017. doi:10.1016/j.saa.2024.124017
57. Nurhayati T, Ridho MF, Santoso PTR, Setiawan S, Goenawan H and Tarawan VM: Effects of *Moringa oleifera* Leaf Extract on Liver Histopathology: A Systematic Review. Journal of Nutrition and Metabolism 2024; 2024(1): 6815993. doi:10.1155/2024/6815993
58. Xu Y, Chen G, Muema FW, Xiao J and Guo M: Most Recent Research Progress in *Moringa oleifera*: Bioactive Phytochemicals and Their Correlated Health Promoting Effects. Food Reviews International 2024; 40(2): 740-770. doi:10.1080/87559129.2023.2195189
59. Mohammed GM and Hawar SN: Green Biosynthesis of silver nanoparticles from *Moringa oleifera* Leaves and its antimicrobial and cytotoxicity activities. International Journal of Biomaterials 2022; 2022(1): 4136641.
60. Suh Song Y, Kim H, Yu J and Lee J: Improvement in self-heating characteristic by utilizing sapphire substrate in omega-gate-shaped nanowire field effect transistor for wearable, military, and aerospace application. Journal of Nanoscience and Nanotechnology 2021; 21(5): 3092-3098. doi:10.1166/jnn.2021.19149
61. Hanumanthappa SK, Harris JH, Sudhakar NP, Ashoka P and Hanumanthappa M: Antihypertensive and Cardioprotective property of *Mimosa pudica* Using Zebra Fish. PR 2022; 14(3): 333-337. doi:10.5530/pres.14.3.49
62. Jasemi SV, Khazaei H, Aneva IY, Farzaei MH and Echeverría J: Medicinal plants and phytochemicals for the treatment of pulmonary hypertension. Front Pharmacol 2020; 11. doi:10.3389/fphar.2020.00145
63. Bukhari SNA, Ali A and Hussain MA: Extraction optimization of mucilage from seeds of *Mimosa pudica* by response surface methodology. Polymers 2022; 14(9): 1904. doi:10.3390/polym14091904
64. Pilaquinga F, Amaguaña D and Morey J: Synthesis of Silver Nanoparticles Using Aqueous Leaf Extract of *Mimosa albida* (Mimosoideae): Characterization and Antioxidant Activity. Materials 2020; 13(3): 503. doi:10.3390/ma13030503
65. Sangu V, Yamuna T, Preethi GA and Sineha A: Green synthesis and characterization of silver nanoparticles using ethanolic extract of mimosa *Ppudica linn* leaves. Journal of Advanced Scientific Research 2021; 12(2): 91-97. doi:10.55218/JASR.s2202112212
66. Ellinger S, Müller N, Stehle P and Ulrich-Merzenich G: Consumption of green tea or green tea products: is there an evidence for antioxidant effects from controlled interventional studies? Phytomedicine 2011; 18(11): 903-915. doi:10.1016/j.phymed.2011.06.006
67. Liang JH, Wang C and Huo XK: The genus Uncaria: A review on phytochemical metabolites and biological aspects. Fitoterapia 2020; 147: 104772. doi:10.1016/j.fitote.2020.104772
68. Ali BH, Blunden G, Tanira MO and Nemmar A: Some phytochemical, pharmacological and toxicological properties of ginger (*Zingiber officinale* Roscoe): A review of recent research. Food and Chemical Toxicology Published online 2008.
69. Park BJ, Lee YJ and Lee HR: Effects of korean red ginseng on cardiovascular risks in subjects with metabolic syndrome: a double-blind randomized controlled study. Korean J Fam Med 2012; 33(4): 190-196. doi:10.4082/kjfm.2012.33.4.190
70. Alia F, Putri M and Anggraeni N: The Potency of *Moringa oleifera* Lam. as Protective Agent in Cardiac Damage and Vascular Dysfunction. Frontiers in Pharmacology 2022; 12.
71. Hl K, Sl S, Ps V, Vh P, Am S and Sibgatullah M: Diuretic activity of ethanolic root extract of *Mimosa pudica* in albino rats. J Clin Diagn Res 2015; 9(12): 05-07. doi:10.7860/JCDR/2015/14662.6877

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