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COMPREHENSIVE REVIEW OF HYPERTENSION AND THE ROLE OF BEETROOT AND GARLIC IN HYPERTENSION MANAGEMENT

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ABSTRACT

Hypertension is a major global health issue, characterised by consistently high blood pressure that can lead to serious cardiovascular problems. This review dives deep into hypertension, discussing its global prevalence, the different types—essential and secondary hypertension—and their causes. As conventional antihypertensive treatments have their limitations, there's growing interest in herbal remedies as alternative or complementary options. Herbal treatments are appealing due to their fewer side effects and the widespread global reliance on natural remedies. This paper highlights the antihypertensive properties of beetroot (Beta vulgaris) and garlic (Allium sativum), focusing on their bioactive components and how they work. Beetroot, with its rich content of nitrates and betalains, boosts nitric oxide production, leading to vasodilation and better blood flow. Garlic, packed with allicin and sulphur compounds, aids in vasodilation, reduces inflammation and offers antioxidative benefits. More clinical studies are needed to confirm these findings and determine optimal dosages for therapeutic use.

KEYWORDS: Hypertension, Blood pressure regulation, Garlic, Beetroot, Herbal remedies, Antihypertensive agents, Alternative medicine.

INTRODUCTION

Hypertension: A global chronic non-communicable disease: Hypertension is one of the most prevalent chronic non-communicable diseases worldwide. Currently, about one-quarter of the global adult population is affected by hypertension, with projections indicating this number could rise to 29% by 2025. Economically developed nations report a higher prevalence rate of approximately 37.3% compared to 22.9% in developing countries. However, the absolute number of individuals with hypertension is significantly greater in the developing world due to its larger population size. This disparity is expected to grow as globalization, urbanization, and improvements in economic conditions contribute to longer life expectancy in these regions.

Projections by Kearney et al. suggest that by 2025, nearly 1.17 billion individuals in developing countries will have hypertension, accounting for almost three-quarters of the global hypertensive population. This trend highlights the urgent need for strategies to manage and mitigate hypertension, particularly in developing nations, where the burden is expected to be most pronounced.

Blood pressure, cardiovascular disease (CVD), chronic kidney disease (CKD), and mortality: High blood pressure (BP) is a significant contributor to the global burden of cardiovascular diseases (CVDs) and premature deaths. Data from 2015 revealed that systolic BP levels of 110– 115 mmHg were linked to approximately 10.7 million deaths worldwide, representing 19.2% of all deaths. Similarly, systolic BP levels of 140 mmHg or higher accounted for 7.8 million deaths or 14.0% of total deaths. Among these, the leading causes were ischemic heart disease (IHD), which accounted for 4.9 million deaths (54.5% of IHD-related mortality), ischemic stroke with 1.5 million deaths (50.0%), and hemorrhagic stroke with 2.0 million deaths (58.3%). For systolic BP of 140 mmHg or more, the corresponding figures were 3.6 million deaths (40.1% of IHD-related mortality), 1.1 million deaths (38.1% of ischemic stroke), and 1.4 million deaths (42.5% of hemorrhagic stroke).

Over the years, particularly from 1990 to 2015, there has been a notable increase in BP-related deaths, especially in low- and middle-income countries (LMICs). This trend highlights the urgent need to strengthen public health interventions for managing hypertension globally.

The link between blood pressure and CVD risk: Extensive research demonstrates a clear and linear relationship between BP and the risk of cardiovascular diseases. For example, a large-scale study involving over 1 million adults aged 40–89 years with no prior CVD history found that even slight elevations in BP significantly increased the likelihood of CVD-related mortality. The study documented around 56,000 deaths from cardiovascular causes, including 12,000 from strokes, 34,000 from IHD, and 10,000 from other cardiovascular conditions.

Further analysis revealed that for adults aged 40–69 years, an increase of 20 mmHg in systolic BP or 10 mmHg in diastolic BP doubled the risk of stroke-related deaths and other CVD-related mortality. While the proportional risk was slightly lower for older individuals aged 80–89 years, the absolute risk remained higher due to age-related factors.

The predominance of systolic BP in risk assessment: In adults aged 35 and above, systolic BP has proven to be a more critical determinant of cardiovascular risk than diastolic BP. Findings from the Multiple Risk Factor Intervention Trial (MRFIT), which tracked 347,978 men aged 35–57 years without prior CVD hospitalizations, highlighted this distinction. Over an 11.6-year follow-up, 7,150 deaths from IHD and 733 deaths from strokes were recorded.

Across all BP levels, systolic BP showed a stronger correlation with the risk of IHD, and stroke compared to diastolic BP. Specifically, individuals in the highest systolic BP decile faced 3.7 times the risk of IHD and 8.2 times the risk of stroke compared to those in the lowest decile. In contrast, for diastolic BP, the corresponding relative risks were lower at 2.8 for IHD and 4.4 for stroke.

Types and causes of hypertension: Hypertension, or high blood pressure, is broadly categorized into two main types based on its causes and characteristics:

1. Primary (essential) hypertension
A type of high blood pressure with no identifiable cause, often linked to genetics and lifestyle factors.

Mechanisms leading to essential hypertension: ***Cardiac output***: Cardiac output refers to the amount of blood the heart pumps each minute. It's influenced by heart rate and stroke volume. While cardiac output is typically normal in those with essential hypertension, increases can still contribute to higher blood pressure.

Peripheral resistance: Peripheral resistance is the resistance that blood vessels offer against the flow of blood. It's mainly determined by the diameter of the small arteries, known as arterioles. Higher peripheral resistance, often due to the narrowing of the blood vessels, plays a significant role in raising blood pressure.

The renin-angiotensin-aldosterone system (RAAS): The RAAS is crucial in controlling blood pressure. When activated, it leads to the constriction of blood vessels and prompts the kidneys to retain sodium and water. This process increases blood volume and pressure.

Autonomic nervous system: This system, particularly its sympathetic part, helps regulate cardiovascular functions. If the sympathetic nervous system is overactive, it can lead to a faster heart rate and constricted blood vessels, both of which contribute to hypertension.

Other factors

- **Bradykinin**: A substance that causes blood vessels to widen, helping to lower blood pressure.
- **Endothelin**: A powerful vasoconstrictor that raises blood pressure.
- **Endothelial relaxing factor (EDRF) or nitric oxide (NO)**: Produced by cells lining the blood vessels, NO causes these vessels to relax and widen, thus lowering blood pressure.
- **Atrial natriuretic peptide (ANP)**: A hormone that aids in the dilation of blood vessels and the excretion of sodium, reducing blood volume and pressure.

Ouabain: A compound that affects ion transport in heart cells, potentially impacting blood pressure.

2. Secondary hypertension
A type of high blood pressure caused by an underlying condition, such as kidney disease or hormonal disorders.

Kidney diseases
Kidney-related conditions such as diabetic nephropathy, polycystic kidney disease, and glomerular disease can disrupt the kidneys' ability to filter blood properly, leading to high blood pressure. Narrowing of the arteries leading to the kidneys, known as renovascular hypertension, can also cause elevated blood pressure due to reduced blood flow to the kidneys.

Adrenal gland disorders
Disorders of the adrenal glands, such as pheochromocytoma (a tumour that overproduces adrenaline and noradrenaline) and Conn's syndrome (excess production of the hormone aldosterone), can cause secondary hypertension. These conditions lead to increased levels of hormones that raise blood pressure.

Thyroid problems
Both an overactive thyroid (hyperthyroidism) and an underactive thyroid (hypothyroidism) can affect blood pressure. Hyperthyroidism can increase the heart rate and blood volume, while hypothyroidism can cause artery stiffness, leading to high blood pressure.

Obstructive sleep apnea
Obstructive sleep apnea is a condition where repeated interruptions in breathing during sleep lead to low oxygen levels. This triggers the release of stress

hormones that raise blood pressure, often resulting in secondary hypertension.

Coarctation of the aorta

Coarctation of the aorta is a congenital condition where the aorta, the main artery from the heart, is narrowed. This narrowing forces the heart to pump harder to move blood through the aorta, leading to high blood pressure.

Medications

Certain medications can cause secondary hypertension as a side effect. These include birth control pills, corticosteroids, and some antidepressants. These drugs can interfere with the body's ability to regulate blood pressure.

Pregnancy

Hypertension during pregnancy, known as pregnancy-induced hypertension or preeclampsia, can develop due to changes in the body and increased demand on the cardiovascular system. This form of secondary hypertension requires careful monitoring and management.

Risk factors for hypertension

Family history: if your parents or close relatives have hypertension, you're more likely to develop it too.

Ethnicity: people of African descent have a higher likelihood of developing high blood pressure, and it often tends to be more severe and less responsive to treatment.

Obesity: carrying extra weight can increase your chances of having high blood pressure.

Gender: men are generally more at risk for high blood pressure than women until around age 55, after which women catch up and become more prone to it.

Physical inactivity: if you don't move around much, you're more likely to have high blood pressure.

Smoking: smoking narrows your blood vessels and reduces oxygen in your blood, making your heart work harder and raising your blood pressure.

Alcohol consumption: drinking too much alcohol can increase your blood pressure.

Unhealthy diet: eating a lot of salt and fatty foods can lead to high blood pressure, so it's a good idea to cut down on salt.

High cholesterol: many people with high blood pressure also have high cholesterol, which can build up in their arteries and increase blood pressure.

Stress: Constant stress can make your blood pressure go up.

Sleep apnea: this sleep disorder causes breathing interruptions during sleep, which can lead to high blood pressure.

Pregnancy: pregnant women are at higher risk for high blood pressure due to issues with the placenta.

Role and need of herbal medicine in hypertension management

In the past thirty years, extensive research has been focused on local plants with potential hypotensive (blood pressure-lowering) and antihypertensive (high blood pressure-managing) properties. Some plants have been validated for their effectiveness, while others have not shown consistent results. In developing countries, particularly among lower-income and rural populations, there's a growing reliance on herbal remedies to manage hypertension due to limited economic resources. However, more rigorous scientific studies are needed to verify the efficacy and safety of these herbal treatments.

Limitations of conventional treatments for hypertension

Common treatments for hypertension include various medications such as ACE inhibitors, angiotensin II receptor antagonists, alpha and beta blockers, calcium channel blockers, diuretics, direct renin inhibitors, and vasodilators. These medications, while effective, can have several side effects, including dry cough, dizziness, swollen ankles, tiredness, depression, insomnia, impotence, palpitations, slow heartbeat, constipation, loss of taste, headache, gout, and rare kidney damage.

Advantages of herbal remedies

There is substantial evidence suggesting that well-chosen herbal remedies and dietary supplements can help lower blood pressure and improve overall cardiovascular health. Herbal treatments offer several advantages over conventional medicines.

- **Cost-effective**: generally cheaper than modern treatments.
- **Accessibility**: easily available.
- **Safety**: fewer unwanted side effects.
- **Reduced risk of reactions**: less likely to cause adverse reactions.
- **Systemic safety**: less likely to affect other bodily systems.
- **Overall health benefits**: improve overall health, not just the primary condition.
- **Holistic approach**: rejuvenate and revitalize health.
- **Root cause treatment**: address the underlying causes, potentially leading to permanent solutions.

Global reliance on herbal medicine

According to the World Health Organization (WHO), about 70-80% of the world's population relies on non-conventional medicine, primarily herbal sources, for primary healthcare. This reliance is especially strong in developing countries, where the cost of consulting a Western-style doctor and purchasing medication is often prohibitive.

Why use herbal medicine for hypertension?

Many antihypertensive medications can have numerous side effects. In contrast, lifestyle changes and the use of appropriate herbal medicines can be effective in treating hypertension.

Recommended lifestyle changes include stress reduction, limited alcohol intake, regular exercise, reducing salt intake, maintaining a proper diet, and quitting smoking.

Herbal remedies, unlike conventional medications, generally do not cause side effects such as weakness, tiredness, drowsiness, impotence, cold hands and feet, depression, insomnia, abnormal heartbeats, skin rash, dry mouth, dry cough, stuffy nose, headache, dizziness, swelling around the eyes, constipation, diarrhoea, fever, or anaemia. Therefore, 100% natural herbs are considered safe for managing hypertension.

Beetroot and Garlic: Natural Antihypertensive Agents: Beetroot and garlic have gained attention for their potential to manage high blood pressure naturally. Beetroot is rich in dietary nitrates, which help dilate blood vessels and improve blood flow. Garlic contains allicin, known for its blood pressure-lowering effects. This section explores the nutritional profiles, antihypertensive properties, and mechanisms of action of beetroot and garlic, highlighting their benefits as natural alternatives for hypertension management.

BEETROOT

Beetroot (*Beta vulgaris subsp. vulgaris condition*), an annual or biennial crop originating in the Middle East, has now become a globally cultivated vegetable, extending its reach to the Americas, Europe, and Asia. Known for its vibrant colour and nutritional richness, beetroot is acclaimed for its numerous health-promoting properties. It exhibits antioxidant, anti-inflammatory, anticarcinogenic, and antidiabetic activities and is recognized for its hepatoprotective, hypotensive, and wound-healing capabilities. These attributes have led to its integration as a functional ingredient in various food products aimed at enhancing health and wellness.

Recent research has highlighted the significance of inorganic nitrates found in beetroot, which play a pivotal role in its therapeutic effects, particularly its blood-pressure-lowering and performance-enhancing benefits. Studies have investigated its impact on systolic and diastolic blood pressure, vascular health, endothelial function, blood sugar regulation, and even the composition of the gut microbiome. However, the findings have been largely inconsistent, with no single mechanism identified as the primary driver of its hypotensive and hypo-glycaemic effects. This inconsistency is also reflected in related microbial and renal studies, suggesting the complexity of beetroot's physiological interactions. As a result, while beetroot's potential benefits are widely acknowledged, further in-depth research is essential to clarify its mechanisms and optimize its therapeutic use.

Figure 1: Image of Beetroot.

Table 2: Taxonomical classification of beetroot.

Taxonomic Rank	Classification
Domain	Eukaryota
Kingdom	Plantae
Clade	Angiosperms
Clade	Eudicots
Order	Caryophyllales
Family	Amaranthaceae
Subfamily	Betoideae
Genus	Beta
Species	*Beta vulgaris*

Nutrients and bioactive compounds in beetroot

Beetroot is a nutritional powerhouse, bursting with beneficial compounds. This root vegetable contains an array of bioactive phytochemicals such as **betalains (including betacyanins and betaxanthins), flavonoids, polyphenols, saponins, and inorganic nitrates (NO3)**. It's also packed with essential minerals like potassium, sodium, phosphorus, calcium, magnesium, copper, iron, zinc, and manganese. People around the world enjoy beetroot in many forms— juice, powder, bread, gel, boiled, oven-dried, pickled, pureed, or jam.

A 100 mL serving of beetroot juice delivers 95 calories, 22.6 grams of carbohydrates, 0.7 grams of protein, 0.16 grams of total fats, 0.91 grams of dietary fiber, and 12 grams of total sugars. It also provides 8.8 grams of sucrose, 0.86 grams of fructose, and 2.5 grams of glucose.

Commercial beetroot juices vary in their content of total sugars, vitamin C, and flavonoids, but they generally range within specific limits.

Betalains: are major contributors to beetroot's phenolic content, making up 70-100% of this category with around 60% betacyanins and 40% betaxanthins. Beetroot is renowned for its antioxidant capacity, ranking among the top ten plants in this regard. This makes it a valuable ingredient in foods, providing natural color and health benefits in products like gelatin, confectionery, dairy, meat, and poultry.

Nitrates (NO3): in beetroot are crucial as they can be converted into nitrites (NO2) and then nitric oxide (NO) in the body, which helps in vasodilation and improving blood flow. Nitrate levels in beetroot can vary significantly depending on the variety and preparation. For instance, commercial beetroot juices and powders show a wide range of nitrate concentrations.

However, beetroot also contains oxalic acid, which can contribute to the formation of kidney stones (nephroliths). This is particularly a concern for individuals with kidney problems.

To harness the benefits of beetroot while ensuring safety, various preparation methods have been developed. Freeze-drying beetroot juice to make powder is one such method. Beetroot chips and pseudoplastic beetroot gels are newer, innovative forms of beetroot supplements. Beetroot chips are high in energy, carbohydrates, and total sugars, and have the highest Total Antioxidant Potential (TAP). In contrast, beetroot gel is noted for its high protein and low lipid content, making it an effective and convenient form for athletes.

Despite its health benefits, sugar beet, a different variety of beet, is primarily grown for sugar production due to its high sucrose content. Beetroot's diverse nutrient profile and bioactive compounds make it a valuable addition to diets, offering both culinary versatility and potential health benefits. Its natural properties, from antioxidants to nitrates, underline its role in supporting cardiovascular health and overall well-being.

Table 1: Nutrient composition of Beet Root and its byproducts (Per 100 gm or L).

Component	Raw	Cooked, Boiled	Canned	Fresh Juice
Water, g	87.58	87.06	90.96	-
Energy, kcal	43	44	31	30
Protein, g	1.61	1.68	0.91	1.02
Total fats, g	0.17	0.18	0.14	0
Carbohydrate, g	9.56	9.96	7.21	6.6
Fiber, g	2.8	2.0	1.8	0
Sugars, g	6.76	7.96	5.51	6.6
Calcium, mg	16	16	15	0
Iron, mg	0.8	0.79	1.82	0
Magnesium, mg	23	23	17	-
Phosphorus, mg	40	38	17	-
Potassium, mg	325	305	148	-
Sodium, mg	78	77	194	93
Zinc, mg	0.35	0.35	0.21	-
Vitamin C, mg	4.9	3.6	4.1	0
Thiamin, mg	0.031	0.027	0.01	-
Riboflavin, mg	0.04	0.04	0.04	-
Niacin, mg	0.334	0.331	0.157	-
Folate, µg	109	80	30	-
Total phenolic content	255	238	192	225
Total flavonoid content	260	261	173	126

Effects of beetroot on blood pressure and vascular function

Beetroot consumption, particularly in the form of beetroot juice, has gained significant attention for its potential benefits in lowering blood pressure and enhancing vascular function. Numerous clinical studies have focused on both acute and chronic effects, emphasizing the role of nitrate (NO_3), a key bioactive compound in beetroot, in mediating these cardiovascular benefits.

Blood pressure reduction: A pivotal study by Webb et al. (2014) provided early evidence supporting the blood pressure-lowering properties of beetroot juice high in NO_3. The study demonstrated that acute consumption of beetroot juice resulted in significant reductions in systolic blood pressure (SBP). This finding was further confirmed by Siervo et al. (2013) in a meta-analysis of 12 randomized controlled trials (RCTs), which reported an average decrease of 4.5 mmHg in SBP with beetroot juice supplementation. The primary mechanism behind this effect is believed to be the conversion of NO_3 to nitric oxide (NO), which promotes vasodilation and improves endothelial function.

Nitrate and bioactive compounds: The nitrate-to-nitrite-to-nitric oxide pathway is central to the hypotensive effects of beetroot. A study by Jones et al. (2013) demonstrated that consuming 500 mL of beetroot juice led to a substantial increase in plasma nitrite (NO_2) levels, which correlated with the observed reductions in blood pressure. While NO_3 is often cited as the main driver of these effects, other bioactive compounds such as betalains, flavonoids, and polyphenols in beetroot may also play a supporting role in improving vascular health.

Variation in response based on health status: The response to beetroot supplementation appears to vary based on the individual's health status. In hypertensive individuals, beetroot juice has a more pronounced effect on lowering blood pressure compared to normotensive individuals, likely due to a higher expression of erythrocyte xanthine oxidoreductase (XOR), an enzyme involved in NO_2 to NO conversion, in hypertensive conditions. Conversely, beetroot juice supplementation did not significantly lower blood pressure in diabetic patients, possibly due to altered vascular physiology or the use of medications that affect blood pressure regulation.

Chronic effects and sustainability: The effects of beetroot juice on blood pressure may not be sustained over the long term unless consumed consistently. A study by Jajja et al. (2015) on overweight older adults showed that while blood pressure decreased during a 3-week beetroot juice intervention, the effects returned to baseline within a week after discontinuation of the supplement. These findings highlight the importance of continuous supplementation to maintain beneficial cardiovascular effects.

Vascular function and endothelial health: Beetroot's impact on vascular function has been evaluated through markers such as flow-mediated dilatation (FMD) and aortic pulse wave velocity (WV). A 6-week supplementation with NO_3-rich beetroot juice led to modest improvements in FMD**,** indicating better endothelial function and arterial health. A meta-analysis by Siervo et al. (2013) found that beetroot juice significantly improved FMD, suggesting that beetroot supplementation can enhance vascular responsiveness and reduce arterial stiffness, particularly in younger individuals who retain the ability to convert NO_3 to NO_2 efficiently.

***Controversies and other mechanism*s:** Despite the widely acknowledged role of NO_3 in the hypotensive effects of beetroot, some studies suggest that other compounds in beetroot, such as betalains, may also contribute to vascular health. For instance, Ghosh et al. (2014) observed that the hypotensive effects of beetroot could be influenced by factors beyond NO_3, such as betacyanins and other antioxidant compounds. Furthermore, the efficacy of beetroot in lowering blood pressure may depend on individual factors, such as the capacity for NO_3 bioconversion and the presence of interfering substances like antibacterial mouthwashes, which can reduce the conversion of NO_3 to NO_2.

The cumulative evidence suggests that beetroot juice, particularly its high NO_3 content, has beneficial effects on blood pressure and vascular function. While the nitrate-mediated pathway remains the primary mechanism, other bioactive compounds in beetroot may also contribute to these effects. However, individual variability, including factors like health status and lifestyle, plays a significant role in determining the extent of the cardiovascular benefits. Consistent supplementation is likely necessary to maintain long-term improvements in blood pressure regulation and vascular health.

GARLIC (Allium Sativum)

Throughout history, garlic has been cherished for its medicinal benefits, particularly for heart health and blood pressure. Ancient Egyptians used it for heart-related ailments, as recorded in the Ebers Papyrus. In Greece and Rome, notable figures like Hippocrates and Dioscorides recommended garlic for its cardiovascular benefits, believing it could "cleanse the arteries." In ancient India, Charaka, the father of Ayurvedic medicine, praised garlic for maintaining blood fluidity and strengthening the heart—a belief that persists in Ayurveda today.

Modern research validates these traditional uses, showing that garlic can effectively lower blood pressure when used appropriately. It has diuretic properties that help reduce fluid buildup, improving cardiovascular function, and vascular endothelium from LDL cholesterol damage. This blend of historical reverence and contemporary evidence highlights garlic's enduring role in promoting heart health.

Figure 2: Image of Garlic.

Table 3: Taxonomical classification of garlic

Taxonomic Rank	Classification
Domain	Eukaryota
Kingdom	Plantae
Clade	Angiosperms
Clade	Monocots
Order	Asparagales
Family	Amaryllidaceae
Subfamily	Allioideae
Genus	Allium
Species	*Allium sativum*

Phytochemical composition of garlic

Garlic is a treasure trove of biologically active components, boasting around 2000 different substances. Among these, sulfur-containing compounds play a significant pharmacological role. Fresh raw garlic bulbs are primarily composed of water (65%) and carbohydrates (28%), which are mainly fructose (85%), glucose (14%), and a small amount of galactose (1%). Additionally, garlic contains protein (2%), amino acids (1.2%), fiber (1.5%), fatty acids, phenols, trace elements, and sulfur-containing phytoconstituents (2.3%), with alliin being the predominant one.

Garlic is also rich in essential nutrients, including fat-soluble vitamins (A, K, and E), watersoluble vitamins (C and B-complex vitamins: B1, B2, B3, B6, and B8), and minerals (calcium, iron, magnesium, phosphorus, potassium, sodium, and zinc). When garlic cloves are chopped or crushed, an enzyme called alliinase converts alliin into allicin. **Allicin**, a key component of garlic, is unstable and quickly breaks down into compounds like **ajoene, dithiins, allyl methyl trisulfide, diallyl sulfide (DAS), diallyl disulfide (DADS), and diallyl trisulfide (DATS)**, especially when heated. These oil-soluble organosulfur compounds (OSDs), such as allicin, alliin, and ajoene, give garlic its characteristic odor and taste. Although water-soluble sulfur compounds like S-allylcysteine (SAC), S-allyl mercaptocysteine (SAMC), allyl mercaptan (AM), and allyl methyl sulfide (AMS) are less abundant, they exhibit significant properties, including anticancer activity. In addition to these sulfur-containing compounds, garlic also contains other valuable components like steroids, terpenoids, flavonoids, and saponins. These diverse phytochemicals contribute to garlic's wide range of health benefits, making it a potent natural remedy.

Table 4: Phytochemical Composition of Garlic.

Component	**Details**
Water	65%
Carbohydrates	28% (85% fructose, 14% glucose, 1% galactose)
Protein	2%
Amino Acids	1.2%
Fiber	1.5%
Fatty Acids	Present
Phenols	Present
Trace Elements	Present
Sulfurcontaining Phytoconstituents	2.3% (including alliin, allicin, ajoene, DAS, DADS, DATS)
Fatand - soluble Vitamins	Vitamins A, K, and E
Water - soluble Vitamins	Vitamin C, B-complex vitamins (B1, B2, B3, B6, B8)
Minerals	Calcium (Ca), Iron (Fe), Magnesium (Mg), Phosphorus (P), Potassium (K), Sodium (Na), Zinc (Zn)
Other Bioactive Compounds	S-allyl cysteine (SAC), S-allyl mercapto cysteines (SAMC), allyl mercaptan (AM), allyl methyl sulfide (AMS), steroids, terpenoids, flavonoids, saponins

Antihypertensive mechanisms of garlic

Garlic and its components lower blood pressure through several mechanisms, often overlapping in their molecular pathways. These include combating oxidative stress, regulating NF-κB, enhancing hydrogen sulfide (H2S) and nitric oxide (NO) production, modulating the reninangiotensin-aldosterone system (RAAS), and affecting vascular smooth muscle cells (VSMCs). Here's a breakdown of these actions.

A. Oxidative stress

Garlic components like S-allyl cysteine (SAC) and aged garlic (AG) can trap reactive oxygen species (ROS), as seen in studies with male Wistar rats. SAC and AG reduce NADPH oxidase activity and increase superoxide dismutase activity, scavenging harmful superoxide and peroxynitrite, which helps prevent systolic blood pressure increases. Allicin, another key compound, effectively neutralizes free radicals and reduces Angiotensin II-induced ROS formation.

B. Nuclear factor kappa B (nf-κb)

Pyrrolidine dithiocarbamate (PDTC) and SAC suppress NF-κB and ROS in spontaneous hypertensive rats, leading to a reduction in blood pressure.

C. Hydrogen sulfide (H2S)

Garlic enhances the production of H2S via the enzyme cystathionine γ-lyase (CSE). Human red blood cells convert garlic-derived polysulfides to H2S, inducing vasodilation and lowering blood pressure. This sulfur component is crucial as it also improves NO regulation.

D. Nitric oxide (NO)

Garlic boosts NO availability and reduces ROS, promoting vasodilation. Studies show that garlic prevents L-NAME-induced hypertension in rats by increasing NO synthesis, confirming its role in maintaining normal blood pressure. Compounds like SAC and S-1-propenyl cysteine (S1PC) from aged garlic extract (AGE) also lower blood pressure. AGE increases plasma NO and induces endothelium-dependent vasorelaxation, while allicin inhibits angiotensin II, and γglutamyl-S-allylcysteine (GSAC) blocks ACE, leading to vasodilation.

E. Renin-angiotensin-aldosterone system (RAAS)

Garlic compounds like SAC and captopril work together to inhibit ACE and reduce blood pressure. Garlic-derived peptides also play a role in ACE inhibition. Additionally, garlic influences sodium channels, reducing sodium and water retention, which lowers blood pressure. It affects the expression of sodium-hydrogen exchanger isoform-1 (NHE1) and prostaglandin E2 (PGE2), promoting sodium reabsorption at the distal tubule, and enhancing the release of atrial natriuretic peptide (ANP).

F. Vascular smooth muscle cells (vsmcs)

Garlic inhibits the proliferation of VSMCs, crucial in hypertension development. It disrupts the cell cycle phase, reduces ERK phosphorylation, and prevents Angiotensin II-induced ROS production. Compounds like allyl methyl sulfide (AMS) and diallyl sulfide (DAS) also promote systemic vasodilation by opening KATP channels.

Table 3: Mechanisms of garlic.

Mechanism	Action
Oxidative Stress	SAC, AG, and allicin reduce ROS and NADPH oxidase activity, increasing antioxidant enzymes.
NF-κB	PDTC and SAC suppress NF-κB and ROS in hypertensive rats.
Hydrogen Sulfide (H2S)	Garlic enhances H2S production, leading to vasodilation and reduced blood pressure.
Nitric Oxide (NO)	Garlic increases NO availability, reduces ROS, prevents hypertension, and induces vasorelaxation.
RAAS	SAC, captopril, and garlic peptides inhibit ACE, reduce sodium retention, and enhance ANP release.
VSMCs	Garlic and its compounds reduce VSMC proliferation, prevent Angiotensin II-induced ROS, and induce vasodilation.

DISCUSSION

Through this review, it's clear that garlic and beetroot hold significant promise as natural agents for managing hypertension. Each has unique mechanisms that make them effective. Garlic, for instance, promotes vasodilation, provides antioxidant benefits, and inhibits the angiotensinconverting enzyme (ACE). Beetroot, on the other hand, boosts nitric oxide production, offers antioxidant effects, and reduces inflammation. These qualities make both garlic and beetroot strong candidates either as alternatives to or in combination with traditional antihypertensive medications.

However, to fully integrate these natural remedies into mainstream treatments, several challenges need to be addressed. One of the main issues is the variability in how garlic and beetroot are prepared and dosed across different studies, which can lead to inconsistent results. Most research has focused on short-term effects, leaving gaps in our understanding of their long-term safety and effectiveness. Additionally, the diversity in study populations complicates the generalization of findings.

Herbal remedies have become increasingly popular worldwide, with the World Health Organization estimating that about 80% of the global population uses herbal medicines for primary health care. This trend highlights the need for rigorous scientific validation of these natural treatments. However, the herbal medicine market currently lacks regulation and quality control, posing significant public health concerns. Products can be contaminated with heavy metals, adulterated with pharmaceuticals, and often lack proper labeling and patient information, potentially leading to adverse effects and interactions with conventional medications.

Despite the effectiveness of modern medicine in treating hypertension, it often comes with adverse effects and the risk of developing drug resistance. This has driven interest in herbal remedies, which offer fewer side effects and a more holistic approach to health. While garlic and beetroot show promise, more robust scientific studies, including randomized, double-blind trials, are needed to conclusively establish their efficacy and safety.

Considerations such as the long-term effects of garlic on cardiovascular outcomes remain underresearched. The form of garlic matters, with raw and aged garlic potentially more effective than processed forms. Time-released formulations may improve absorption and efficacy, as suggested by studies comparing time-released garlic tablets to ordinary garlic pills. Potential drug interactions, such as those with HIV medications, warfarin, and vitamin B12, must also be carefully monitored. Moreover, patient education is crucial since garlic does not rapidly lower blood pressure; educational programs can help set realistic expectations for patients.

There are potential allergic reactions and adverse effects to consider. Although rare, allergic hypersensitivity to garlic and onions should not be overlooked given their high consumption rates. Reports of garlic-induced esophagitis and gastroenteritis further emphasize the need for caution, particularly in individuals with atopic conditions. Safety concerns related to sulfoxide compounds in garlic, which can cause hepatocyte damage at high doses, underscore the importance of moderation and further research.

Beetroot juice (BRJ) supplementation also stands out as a promising strategy for hypertension management. Its cost-effectiveness makes it an attractive option, particularly for prehypertensive individuals where pharmacological treatment may not be the first choice. The potential reduction in blood pressure following BRJ administration could significantly decrease mortality rates associated with cerebrovascular diseases. The primary mechanism is the nitrate/nitrite/nitric oxide (NO3-/NO2-/NO) pathway, though more research is needed to identify other contributing metabolites like betalains. Factors such as baseline blood pressure, weight status, gender, and age influence BRJ's effectiveness, with a recommended administration period of at least two weeks for sustained results.

Limited evidence exists regarding the adverse effects and tolerance issues of beetroot juice. While some studies have reported minor effects like beeturia (discoloration of urine) due to betalain pigments, these are generally benign. Both short-term and long-term administration of beetroot juice has been well tolerated. Moreover, beetroot's anti-inflammatory effects, demonstrated through the inhibition of NF-κB DNA-binding activity and suppression of Cyclooxygenase 2 (Cox-2) expression, offer significant therapeutic potential. However, interactions between NO3-rich beetroot juice and medications like phosphodiesterase-5 inhibitors, which can cause severe hypotension, need careful consideration.

Future research should focus on standardizing the preparations and dosages of garlic and beetroot to ensure consistent and reliable results. Long-term clinical trials are essential to assess the sustained efficacy and safety of these natural remedies. Additionally, mechanistic studies will help deepen our understanding of how the bioactive compounds in garlic and beetroot interact with physiological processes to manage hypertension. Exploring the potential synergistic effects of combining garlic and beetroot, as well as their interactions with conventional antihypertensive medications, is crucial for developing comprehensive treatment protocols.

CONCLUSION

Garlic and beetroot hold significant promise as natural antihypertensive agents. Their bioactive compounds contribute to various mechanisms that help regulate blood pressure, offering a potential alternative or supplement to conventional treatments. While the current evidence is promising, addressing the limitations through standardized preparations, long-term trials, and further mechanistic research is essential. Integrating these natural remedies into conventional treatment practices could provide a more holistic and effective approach to hypertension management, benefiting patients globally.

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