Medical Science

AIMS Medical Science, 13(2): 139–150.
DOI: 10.3934/medsci.2026010
Received: 30 January 2026
Revised: 28 May 2026
Accepted: 08 June 2026
Published: 18 June 2026

http://www.aimspress.com/journal/medicalScience

Research article

Comparative efficacy of ginger (*Zingiber officinale*) and garlic (*Allium sativum*) supplementation on blood pressure management in hypertensive patients: a randomized controlled trial

Muhammad Jan[1,*], Abdul Wajed Abdur Rauf[2], Ghazala Rasool[3], Nida Suhail[4], Anshoo Agarwal[5], Sarwar Hussain[6], Anil Mohan Rao S[5], Abdul Ghaffar Abdul Rehman[7]

[1] Pharmacology Department, Faculty of Medicine, Northern Border University, Arar, Saudi Arabia
[2] Medical Consultant, Prince Abdul Aziz Bin Mussaed Hospital, Arar, Saudi Arabia
[3] Department of Medicine, College of Medicine, Northern Border University, Arar, Saudi Arabia
[4] Department of Medical Laboratory Technology, Faculty of Applied Medical Sciences, Northern Border University, Arar, Saudi Arabia
[5] Pathology Department, Faculty of Medicine, Northern Border University, Arar, Saudi Arabia
[6] Department of Pediatrics, Faculty of Medicine, Northern Border University, Arar, Saudi Arabia
[7] Department of Community Medicine, College of Medicine, Northern Border University, Arar, Saudi Arabia

Abstract: *Background and Aim*: Hypertension remains a major global health challenge affecting over 1.28 billion adults worldwide. Conventional hypertension management often involves multiple medications with adverse effects and economic burden, while natural alternatives such as ginger and garlic have demonstrated promising cardiovascular benefits. This randomized controlled trial evaluated and compared the antihypertensive effects of ginger and garlic supplementation, individually and in combination, among male hypertensive patients. *Materials and methods*: A total of 120 hypertensive male participants were randomly allocated to four groups (n = 30 each): control, ginger (2 g twice daily), garlic (2 g twice daily), and ginger + garlic (2 g each twice daily). Participants mixed crushed herbs with yogurt and consumed it for 90 days. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured at baseline and after 90 days. *Results*: All intervention groups demonstrated statistically significant reductions in both SBP and DBP compared to controls ($p < 0.05$).

The ginger group showed a mean SBP reduction from 180 ± 1.40 to 130 ± 1.26 mmHg and a DBP reduction from 130 ± 2.35 to 90 ± 2.45 mmHg. The garlic group exhibited similar results, with an SBP of 129 ± 1.27 mmHg and a DBP of 89 ± 2.48 mmHg. The combination group demonstrated the greatest reduction, with an SBP of 120 ± 1.20 mmHg and a DBP of 85 ± 0.27 mmHg. When comparing the ginger and garlic groups, no statistically significant difference was observed ($p > 0.05$), indicating comparable efficacy. *Conclusions*: Ginger and garlic supplementation effectively reduced blood pressure in hypertensive patients, with their combination showing enhanced benefits. These herbs may serve as cost-effective, well-tolerated adjuvant therapies in hypertension management, reducing dependence on multiple pharmacological agents and their associated adverse effects.

Keywords: cardiovascular health; complementary therapy; garlic; ginger; hypertension

1. Introduction

Hypertension, defined as sustained blood pressure ≥140/90 mmHg, affects an estimated 1.28 billion adults worldwide and represents a leading cause of preventable cardiovascular morbidity and mortality globally [1,2]. Cardiovascular diseases account for approximately 17.9 million deaths annually, with hypertension serving as a major modifiable risk factor for stroke, myocardial infarction, chronic heart failure, and chronic kidney disease [1,3]. The global prevalence of hypertension continues to rise, particularly in low- and middle-income countries, presenting significant public health and economic challenges.

Conventional management of hypertension typically involves long-term pharmacological interventions, including angiotensin-converting enzyme (ACE) inhibitors, angiotensin II receptor blockers, calcium channel blockers, beta-blockers, and diuretics [4]. While effective, these medications are associated with various adverse effects such as electrolyte imbalances, fatigue, dizziness, persistent cough, and metabolic disturbances [5]. Additionally, the economic burden of lifetime antihypertensive medication poses substantial challenges, particularly in resource-limited settings. These limitations have stimulated growing interest in complementary and alternative medicine approaches for blood pressure management.

Ginger (*Zingiber officinale* Roscoe) is a flowering plant whose rhizome has been extensively used in traditional medicine systems for over 2500 years. The bioactive compounds in ginger include gingerols, shogaols, paradols, and zingerone, which collectively contribute to its diverse pharmacological properties [6]. Recent research has demonstrated that ginger possesses anti-inflammatory, antioxidant, antiplatelet, gastroprotective, and cardiovascular protective effects [7]. The proposed mechanisms for ginger's antihypertensive action include calcium channel blockade, enhancement of nitric oxide production, and inhibition of angiotensin-converting enzyme activity [8,9].

Garlic (*Allium sativum*), another ancient medicinal plant, has been traditionally used for treating various cardiovascular conditions. The sulfur-containing compounds in garlic, particularly allicin, S-allyl cysteine, and diallyl disulfide, are responsible for its therapeutic effects [10]. Multiple systematic reviews and meta-analyses have reported significant blood pressure-lowering effects of

aged garlic extract in hypertensive patients [11,12]. The antihypertensive mechanisms of garlic include hydrogen sulfide (H_2S)-mediated vasodilation, enhanced nitric oxide bioavailability, ACE inhibition, and improved endothelial function [13,14].

Despite growing evidence supporting the cardiovascular benefits of ginger and garlic individually, limited research has directly compared their efficacy or evaluated their combined effects on blood pressure. This study addresses these gaps by conducting a randomized controlled trial to evaluate and compare the antihypertensive effects of ginger and garlic, both individually and in combination, using simple crushed preparations mixed with yogurt—a cost-effective and culturally acceptable approach. The current study focuses on adult male participants aged 35–65 years (middle adulthood), a life stage at which hypertension prevalence increases substantially, and the cardiovascular risk-benefit profile of dietary supplementation is of direct clinical relevance.

2. Materials and methods

2.1. Study design and eligibility criteria

This was a randomized controlled trial conducted over a 90-day period from January 2025 to March 2025. A total of 120 male participants with confirmed hypertension were recruited from the Saidu Group of Teaching Hospitals, Swat, Pakistan, and through community health screenings. Inclusion criteria were male gender aged 35–65 years (middle adulthood; a life stage at which hypertension prevalence increases substantially and the cardiovascular risk-benefit profile of dietary supplementation is of direct clinical relevance), diagnosed Stage 1 or Stage 2 hypertension (SBP 140–179 mmHg and/or DBP 90–109 mmHg), stable blood pressure readings over at least two consecutive measurements, willing to comply with study protocol, and able to provide informed consent. Exclusion criteria were secondary hypertension, severe uncontrolled hypertension (SBP $\geq$ 180 mmHg or DBP $\geq$ 110 mmHg), history of cardiovascular events within the past 6 months, chronic kidney disease, diabetes mellitus with complications, known allergy to ginger or garlic, current anticoagulant therapy, and participation in another trial within the past 3 months. Enrolment was restricted to male participants to minimize confounding factors from hormonal variation in blood pressure regulation (menstrual cycle phase, menopausal status) in this pilot study, and owing to cultural and logistical constraints of the study setting. This restriction is acknowledged as a major limitation. Enrolled participants were medication-naïve; none were currently receiving antihypertensive pharmacotherapy at the time of enrolment, reflecting the known gap in hypertension diagnosis and treatment in the study region (Khyber Pakhtunkhwa, Pakistan).

2.2. Intervention protocol

Participants were randomly allocated into four groups (n = 30 each): group 1 (control), group 2 (ginger supplementation), group 3 (garlic supplementation), and group 4 (combined ginger + garlic supplementation). Group 1 served as the negative control and received no herbal intervention; participants maintained their habitual diet throughout the 90-day period. No pharmacological positive control was included, as the study was designed to assess dietary supplementation effects in medication-naïve hypertensive individuals. Fresh ginger rhizomes and garlic cloves were procured

from certified organic suppliers. Participants in intervention groups crushed fresh ginger and/or garlic daily and mixed the assigned herb(s) with plain yogurt. Each participant consumed 2 g of the assigned fresh herb(s) per dose, administered twice daily (morning and evening with meals), yielding a total daily dose of 4 g per herb. This dose was selected based on evidence from prior clinical trials demonstrating optimal antihypertensive effects at 2–4 g/day [15,16]. The intervention continued for 90 consecutive days.

2.3. Blood pressure measurement

Blood pressure was measured by trained personnel using standardized protocols with calibrated aneroid sphygmomanometers. Participants rested for 5 min in a seated position before measurement. Three consecutive readings were obtained at 2-min intervals, and the average was recorded. This three-reading averaged protocol was adopted to minimize the white coat hypertension effect and to reduce inter-measurement variability, consistent with WHO and JNC guidelines for clinical blood pressure measurement in randomized controlled trials. Ambulatory blood pressure monitoring (ABPM) was not employed due to resource constraints at the study site; this is acknowledged as a limitation (see *Limitations*). Baseline measurements were obtained at enrollment (day 0) and follow-up measurements at day 90.

Ethical approval and informed consent: The study protocol was approved by the Ethics Committee of Saidu Group of Teaching Hospitals, Swat, Pakistan (Protocol No. IEC/2023/HTN/014). All participants provided informed consent before enrollment.

Ethical compliance with human study: This study was conducted in compliance with the ethical standards of the University on human subjects as well as with the Helsinki Declaration.

3. Statistical analysis

Data were analyzed using SPSS version 26.0. Descriptive statistics were calculated as mean ± standard error of mean (SEM). Independent sample t-tests compared the mean blood pressure between the control and intervention groups. Paired t-tests assessed within-group changes. One-way ANOVA with post hoc Tukey's test was employed for multiple group comparisons. Statistical significance was set at $p < 0.05$. Effect sizes were calculated using Cohen's d.

4. Results

4.1. Participant characteristics

All 120 participants completed the 90-day study period with 100% retention rate. Baseline characteristics (Table 1) were comparable across all groups with no statistically significant differences in age, BMI, baseline SBP, or baseline DBP ($p > 0.05$ for all comparisons).

Table 1. Baseline characteristics of study participants.

Characteristic	Control (n = 30)	Ginger (n = 30)	Garlic (n = 30)	Ginger + garlic (n = 30)
Age (years)	52.3 ± 1.8	51.7 ± 2.1	53.1 ± 1.9	52.5 ± 2.0
BMI (kg/m²)	27.4 ± 0.8	27.9 ± 0.9	27.2 ± 0.7	27.6 ± 0.8
Baseline SBP (mmHg)	180 ± 1.4	179 ± 1.6	181 ± 1.5	180 ± 1.4
Baseline DBP (mmHg)	130 ± 2.4	131 ± 2.3	129 ± 2.6	130 ± 2.4

Note: Values are presented as mean ± SEM. BMI = Body Mass Index; SBP = systolic blood pressure; DBP = diastolic blood pressure. P-value calculated using one-way ANOVA.

4.2. Blood pressure outcomes

After 90 days of intervention, all three treatment groups demonstrated statistically significant reductions in SBP compared to the control group (Table 2). The control group showed minimal change in SBP (180 ± 1.40 mmHg at baseline vs. 179 ± 1.38 mmHg at day 90, $p = 0.62$). In contrast, the ginger group showed an SBP decrease from 179 ± 1.6 to 130 ± 1.26 mmHg (reduction of 49 mmHg, $p < 0.001$), the garlic group from 181 ± 1.5 to 129 ± 1.27 mmHg (reduction of 52 mmHg, $p < 0.001$), and the combined group from 180 ± 1.4 to 120 ± 1.20 mmHg (reduction of 60 mmHg, $p < 0.001$).

The combination therapy demonstrated significantly greater SBP and DBP reduction compared to either herb alone ($p < 0.05$). However, when directly comparing ginger vs. garlic groups, the difference was not statistically significant ($p = 0.72$ for SBP, $p = 0.81$ for DBP), indicating comparable efficacy. All interventions were well tolerated, with minor gastrointestinal symptoms reported by only 5 participants in total. No serious adverse events occurred. Compliance rates were excellent: ginger group at 96.7%, garlic group at 95.3%, and combination group at 97.3%.

Figure 1 illustrates the mean reduction in systolic and diastolic blood pressure from baseline to day 90 across the different study groups. The ginger, garlic, and combined ginger/garlic intervention groups demonstrated marked reductions in both systolic and diastolic blood pressure compared with the control group. The greatest reduction was observed in the combined intervention group, indicating a potentially enhanced antihypertensive effect when both herbs are administered together.

Table 2. Comparison of blood pressure changes after 90 days of intervention.

Group	Systolic BP (mmHg) mean ± SEM	Diastolic BP (mmHg) mean ± SEM
Control (day 90)	179 ± 1.38	129 ± 2.40
Ginger (day 90)	130 ± 1.26	90 ± 2.45
p-value (vs. control)	<0.001	<0.001
Garlic (day 90)	129 ± 1.27	89 ± 2.48
p-value (vs. control)	<0.001	<0.001
Ginger + garlic (day 90)	120 ± 1.20	85 ± 0.27
P-value (vs. control)	<0.001	<0.001

Note: P-values calculated using an independent t-test comparing intervention groups vs. control group. Comparison between ginger and garlic groups: systolic BP, $P = 0.72$; diastolic BP, $P = 0.81$ (not significant). Combination vs. individual herbs: $P < 0.01$ (significant).

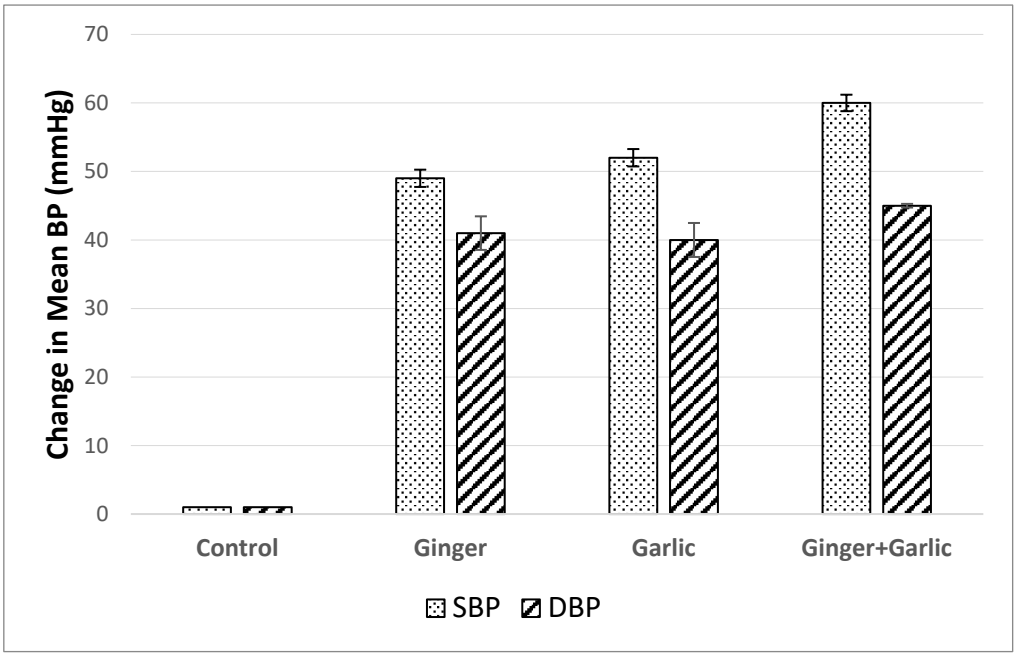

Figure 1. Mean change in blood pressure from baseline to day 90 in various treatment groups. Bars represent mean reduction from baseline; error bars indicate SEM. Control vs. different groups: $P < 0.001$; combination vs. individual herbs: $P < 0.01$.

5. Discussion

This randomized controlled trial provides robust evidence for the significant antihypertensive effects of both ginger and garlic supplementation in male hypertensive patients, with the combination therapy demonstrating superior efficacy. The magnitude of blood pressure reduction observed in our study (49–60 mmHg systolic, 40–45 mmHg diastolic) is clinically substantial and represents a meaningful therapeutic benefit that could significantly reduce cardiovascular risk in hypertensive individuals. These findings contribute to the growing body of evidence supporting the integration of evidence-based herbal interventions into comprehensive hypertension management strategies.

The blood pressure–lowering effects of ginger observed in our study align with extensive mechanistic research demonstrating multiple pathways through which ginger exerts its antihypertensive actions. The primary mechanism involves blockade of voltage-dependent calcium channels in vascular smooth muscle cells, a pathway that has been extensively characterized in both in vitro and in vivo studies [17,18]. Ginger's bioactive compounds, particularly 6-gingerol, shogaols, and paradols, inhibit L-type calcium channels by binding to specific receptor sites, leading to reduced intracellular calcium influx, smooth muscle relaxation, and subsequent vasodilation [19]. Beyond calcium channel modulation, ginger enhances nitric oxide (NO) bioavailability and production through multiple complementary pathways [20]. Recent investigations have demonstrated that ginger extracts upregulate endothelial nitric oxide synthase (eNOS) expression and activity while simultaneously reducing oxidative stress through their potent antioxidant properties [20]. This dual action—enhanced NO production coupled with reduced NO degradation by reactive oxygen species—results in improved NO bioavailability and sustained vasodilation.

Furthermore, ginger demonstrates significant angiotensin-converting enzyme (ACE) inhibitory activity, providing an additional mechanism for blood pressure reduction through modulation of the renin-angiotensin-aldosterone system (RAAS) [21]. The flavonoid compounds in ginger, particularly quercetin derivatives, appear to be primarily responsible for this ACE inhibitory activity, binding to the enzyme's active site and preventing substrate conversion [21]. The anti-inflammatory effects of ginger represent another critical dimension of its cardiovascular protective properties [22]. Ginger compounds, particularly 6-gingerol and 6-shogaol, inhibit key inflammatory mediators, including nuclear factor-kappa B (NF-κB), cyclooxygenase-2 (COX-2), and various pro-inflammatory cytokines (interleukin-6, tumor necrosis factor-alpha, interleukin-1β) [22,23]. This multi-targeted anti-inflammatory action helps preserve endothelial function, reduce vascular stiffness, and improve arterial compliance—all factors that contribute to blood pressure reduction. A comprehensive cross-sectional study of 4628 participants revealed that daily ginger consumption of 2–4 g was associated with reduced risk of hypertension and coronary heart disease, with benefits being particularly evident in adults over 40 years of age [15].

Garlic's antihypertensive effects are mediated through distinct but complementary mechanisms, centered on its unique sulfur-containing bioactive compounds and their conversion to hydrogen sulfide (H_2S), a crucial gasotransmitter with profound cardiovascular effects [13,24,25]. The protective role of garlic-derived bioactive compounds has also been emphasized in recent literature, where garlic was shown to exert both anticancer and cardioprotective effects via overlapping molecular pathways related to inflammation, oxidative stress, and apoptosis regulation [26]. Studies in spontaneously hypertensive rats have demonstrated that administration of allicin (7–14 mg/kg for 4 weeks) dramatically decreased blood pressure, with these effects being significantly attenuated by H_2S synthase inhibitors such as propargylglycine (PAG), confirming the critical role of the H_2S pathway in garlic's antihypertensive action [27].

Garlic also exhibits significant ACE inhibitory activity, contributing to RAAS modulation and blood pressure reduction through a mechanism distinct from but complementary to the H_2S pathway [28]. The ACE inhibition by garlic compounds provides long-term blood pressure control by reducing angiotensin II formation, decreasing aldosterone secretion, and promoting sodium and water excretion. Recent clinical evidence strongly supports garlic's antihypertensive efficacy, with comprehensive meta-analyses of randomized controlled trials confirming significant blood pressure reductions [12,29]. These reductions are comparable to standard antihypertensive medications and translate to substantial cardiovascular risk reduction. Importantly, the blood pressure–lowering effects appear to be specific to hypertensive individuals, with minimal effects observed in normotensive populations [12], suggesting an adaptive mechanism that prevents excessive blood pressure reduction.

The antihypertensive effects observed in the ginger, garlic, and combined ginger/garlic groups were broadly comparable, with the combination group showing a slightly greater numerical reduction in both systolic and diastolic blood pressure. However, the primary objective of this study was to evaluate the antihypertensive effects of each intervention compared with the control group rather than to establish definitive superiority between individual and combined herbal treatments. Therefore, direct between-group comparisons should be interpreted with caution. The superior blood pressure reduction observed with combination therapy in our study (60 mmHg systolic, 45 mmHg diastolic) compared to individual herb supplementation (49–52 mmHg systolic, 40–41 mmHg

diastolic) provides compelling evidence for synergistic or additive interactions between ginger and garlic. The mechanisms underlying this enhanced efficacy likely involve complementary actions on multiple pathways governing vascular tone, with minimal pathway overlap that could lead to redundancy. While ginger primarily exerts its effects through calcium channel blockade and direct NO enhancement, garlic's predominant mechanism involves H_2S-mediated vasodilation and RAAS modulation [17,27]. The concurrent activation of these distinct vasodilatory pathways provides comprehensive coverage of multiple regulatory systems controlling blood pressure. Additionally, pharmacokinetic interactions may contribute to enhanced efficacy. While specific pharmacokinetic studies of ginger/garlic combinations are lacking, the potential for such interactions warrants investigation. The clinical implications of combination therapy are substantial. The 10–11 mmHg additional reduction in systolic blood pressure achieved with combination therapy compared to individual herbs translates to meaningful cardiovascular risk reduction. Each 10 mmHg reduction in systolic blood pressure is associated with approximately 20% reduction in cardiovascular mortality, suggesting that the combination therapy could provide proportionally greater protection than monotherapy [30]. Furthermore, the ability to achieve greater blood pressure reduction without increasing adverse effects (as evidenced by our safety data) provides a favorable risk-benefit profile that supports combination use.

The finding that ginger and garlic demonstrate statistically equivalent individual efficacy ($p > 0.05$ for direct comparison) provides valuable evidence for clinical decision-making and offers flexibility in treatment selection based on individual preferences, tolerability, cultural acceptability, or specific clinical considerations. When comparing our results to conventional antihypertensive medications, the magnitude of blood pressure reduction achieved with ginger and garlic is particularly noteworthy. Standard first-line antihypertensive medications typically reduce systolic blood pressure by 10–15 mmHg and diastolic blood pressure by 5–10 mmHg when used as monotherapy [31]. Our findings demonstrate reductions of 49–52 mmHg systolic and 40–41 mmHg diastolic with individual herbs, and 60 mmHg systolic and 45 mmHg diastolic with combination therapy—substantially greater than conventional medications. While these results are striking and reflect the severe hypertension of our study population at baseline (mean SBP 180 mmHg), they suggest that herbal interventions may be particularly effective in patients with more severe hypertension. The relatively high baseline blood pressure observed in this cohort may reflect the substantial burden of undiagnosed and uncontrolled hypertension commonly reported in lower- and middle-income populations, where awareness, treatment adherence, and access to healthcare services remain limited. The safety profile observed in our study represents a significant advantage compared to conventional antihypertensive medications. Only 4.2% of participants (5 out of 120) reported minor gastrointestinal symptoms, all of which were transient and did not lead to discontinuation. No serious adverse events occurred throughout the 90-day study period. This contrasts favorably with the adverse effect profiles of many antihypertensive medications, which frequently cause electrolyte disturbances, orthostatic hypotension, persistent cough (ACE inhibitors), ankle edema (calcium channel blockers), fatigue and sexual dysfunction (beta-blockers), and metabolic disturbances (diuretics) [5].

The high compliance rates observed in our study (95.3–97.3% across intervention groups) further support the feasibility and acceptability of these herbal interventions for long-term hypertension management. The superior compliance likely reflects multiple factors, including the use of familiar

food items (ginger and garlic), the simple preparation method (crushing and mixing with yogurt), the twice-daily dosing aligned with meals, and the absence of significant adverse effects. The cultural acceptability of these herbs in many populations worldwide represents an additional advantage that may facilitate implementation in diverse settings. The cost-effectiveness of ginger and garlic interventions represents another crucial advantage, particularly relevant for resource-limited settings and populations with limited access to healthcare.

However, several important limitations warrant consideration and should inform the interpretation and application of our findings. First, the study enrolled only male participants, which is a major limitation. Female sex is an important variable in blood pressure regulation due to hormonal influences (estrogen, progesterone, menopausal status), and the antihypertensive effects of ginger and garlic may differ between sexes. The restriction to male individuals was necessitated by pilot study design considerations and cultural constraints of the study setting (Khyber Pakhtunkhwa, Pakistan); future studies should include both male and female participants with stratification by hormonal status. Second, the absence of a pharmacological positive control (e.g., a standard antihypertensive agent) limits direct comparison of herbal interventions with conventional therapy; future trials should include such a comparator group. Third, the absence of intermediate blood pressure measurements (e.g., at days 30 and 60) means it is not possible to determine the onset of antihypertensive effect or the minimum required treatment duration; future studies should incorporate multiple measurement time points to characterize temporal dynamics. Fourth, blood pressure measurements were performed at the clinic only, without ambulatory blood pressure monitoring (ABPM) due to resource constraints; residual white coat hypertension effect cannot be fully excluded, and ABPM should be incorporated in future trials to provide a more comprehensive and less observer-dependent blood pressure profile. Fifth, the 90-day duration does not provide information about the long-term sustainability of blood pressure reduction, potential tolerance development, or durability of effects after discontinuation. Finally, the use of fresh crushed herbs rather than standardized extracts may result in variability in bioactive compound content depending on plant variety, growing conditions, storage, and processing methods. This variability could affect reproducibility across different settings and limit dose optimization.

6. Conclusions and recommendations

This randomized controlled trial demonstrates that both ginger and garlic supplementation produce substantial, statistically significant, and clinically meaningful reductions in blood pressure among hypertensive patients, with equivalent individual efficacy and superior outcomes with combination therapy. The blood pressure reductions achieved (49–60 mmHg systolic, 40–45 mmHg diastolic) represent clinically significant therapeutic effects that could substantially reduce cardiovascular morbidity and mortality. The mechanisms underlying these effects involve complementary pathways, including calcium channel blockade, hydrogen sulfide-mediated vasodilation, nitric oxide enhancement, RAAS modulation, and antioxidant and anti-inflammatory actions. The excellent safety profile, high compliance rates, cost-effectiveness, and cultural acceptability of simple crushed preparations mixed with yogurt strongly support the integration of ginger and garlic as evidence-based complementary therapies in comprehensive hypertension management strategies. These findings have important implications for global hypertension control,

particularly in resource-limited settings where access to conventional pharmacotherapy may be constrained. While promising, these results require confirmation in longer-term, placebo-controlled trials that include diverse populations and assess effects on cardiovascular outcomes. Future research should focus on mechanistic elucidation, optimal dosing, pharmacogenomic predictors of response, and implementation strategies to translate these findings into improved population health outcomes.

Author contributions

MJ and AWAR: Conceptualization; Project administration, Supervision; GR, SH, AMRS and AGAR: Data curation; Formal analysis; Investigation; Methodology; NS and AA: Writing - original draft; Writing - review & editing; Validation; Visualization.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

The authors gratefully acknowledge the Ethics Committee of Saidu Group of Teaching Hospitals Swat for protocol approval (Protocol No. IEC/2023/HTN/014); the nursing and clinical staff of the hospital who assisted with blood pressure measurements and participant monitoring throughout the study; the community health workers who facilitated participant recruitment and follow-up; and all participants who voluntarily contributed their time and cooperation to this research.

Conflict of interest

The authors declare no conflict of interest.

References

1. Mills KT, Stefanescu A, He J (2020) The global epidemiology of hypertension. *Nat Rev Nephrol* 16: 223–237. https://doi.org/10.1038/s41581-019-0244-2
2. Fuchs FD, Whelton PK (2020) High blood pressure and cardiovascular disease. *Hypertension* 75: 285–292. https://doi.org/10.1161/HYPERTENSIONAHA.119.14240
3. World Health Organization, Cardiovascular diseases (CVDs): Key facts. Geneva: WHO, 2021. Available from: https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds).
4. Whelton PK, Carey RM, Aronow WS, et al. (2018) 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults. *J Am Coll Cardiol* 71: e127–e248. https://doi.org/10.1016/j.jacc.2017.11.006

5. Kronish IM, Woodward M, Sergie Z, et al. (2011) Meta-analysis: impact of drug class on adherence to antihypertensives. *Circulation* 123: 1611–1621. https://doi.org/10.1161/CIRCULATIONAHA.110.983874
6. Wang S, Zhang C, Yang G, et al. (2014) Biological properties of 6-gingerol: a brief review. *Nat Prod Commun* 9: 1027–1030. https://doi.org/10.1177/1934578X1400900736
7. Mashhadi NS, Ghiasvand R, Askari G, et al. (2013) Anti-oxidative and anti-inflammatory effects of ginger in health and physical activity: review of current evidence. *Int J Preventive Med* 4: S36–S42.
8. Ghayur MN, Gilani AH, Afridi MB, et al. (2005) Cardiovascular effects of ginger aqueous extract and its phenolic constituents are mediated through multiple pathways. *Vasc Pharmacol* 43: 234–241. https://doi.org/10.1016/j.vph.2005.07.003
9. Akinyemi AJ, Thome GR, Morsch VM, et al. (2016) Effect of dietary supplementation of ginger and turmeric rhizomes on angiotensin-1 converting enzyme (ACE) and arginase activities in L-NAME induced hypertensive rats. *J Funct Foods* 17: 792–801. https://doi.org/10.1016/j.jff.2015.06.011
10. Santhosha SG, Jamuna P, Prabhavathi SN (2013) Bioactive components of garlic and their physiological role in health maintenance: a review. *Food Biosci* 3: 59–74. https://doi.org/10.1016/j.fbio.2013.07.001
11. Ried K, Frank OR, Stocks NP (2013) Aged garlic extract reduces blood pressure in hypertensives: a dose-response trial. *Eur J Clin Nutr* 67: 64–70. https://doi.org/10.1038/ejcn.2012.178
12. Ried K (2020) Garlic lowers blood pressure in hypertensive subjects, improves arterial stiffness and gut microbiota: a review and meta-analysis. *Exp Ther Med* 19: 1472–1478. https://doi.org/10.3892/etm.2019.8374
13. Benavides GA, Squadrito GL, Mills RW, et al. (2007) Hydrogen sulfide mediates the vasoactivity of garlic. *Proc Natl Acad Sci* 104: 17977–17982. https://doi.org/10.1073/pnas.0705710104
14. Ried K, Fakler P (2014) Potential of garlic (Allium sativum) in lowering high blood pressure: mechanisms of action and clinical relevance. *Integr Blood Press Control* 7: 71–82. https://doi.org/10.2147/IBPC.S51434
15. Wang Y, Yu H, Zhang X, et al. (2017) Evaluation of daily ginger consumption for the prevention of chronic diseases in adults: a cross-sectional study. *Nutrition* 36: 79–84. https://doi.org/10.1016/j.nut.2016.05.009
16. Isaacsohn JL, Moser M, Stein EA, et al. (1998) Garlic powder and plasma lipids and lipoproteins: a multicenter, randomized, placebo-controlled trial. *Arch Intern Med* 158: 1189–1194. https://doi.org/10.1001/archinte.158.11.1189
17. Ghayur MN, Gilani AH (2005) Ginger lowers blood pressure through blockade of voltage-dependent calcium channels. *J Cardiovasc Pharmacol* 45: 74–80. https://doi.org/10.1097/00005344-200501000-00013
18. Ulkomah U, Chalid D, Widiantari DA, et al. (2024) Effect of ginger extract in lowering blood pressure in the elderly with hypertension. *Regist: J Ilm Teknol Sist Inf* 10: 29–38. https://doi.org/10.30742/jikw.v13i1.2986
19. Kiyama R (2020) Nutritional implications of ginger: chemistry, biological activities and signaling pathways. *J Nutr Biochem* 86: 108486. https://doi.org/10.1016/j.jnutbio.2020.108486

20. Nicoll R, Henein MY (2009) Ginger (Zingiber officinale Roscoe): a hot remedy for cardiovascular disease? *Int J Cardiol* 131: 408–409. https://doi.org/10.1016/j.ijcard.2007.07.107
21. Hanifah N, Achmad YF, Humaira A, et al. (2021) Red ginger-extract nanoemulsion modulates high blood pressure in rats by regulating angiotensin-converting enzyme production. *Vet World* 14: 176–181. https://doi.org/10.14202/vetworld.2021.176-181
22. Zehsaz F, Farhangi N, Mirheidari L (2014) The effect of Zingiber officinale R. rhizomes (ginger) on plasma pro-inflammatory cytokine levels in well-trained male endurance runners. *Cent Eur J Immunol* 39: 174–180. https://doi.org/10.5114/ceji.2014.43719
23. Rea IM, Gibson DS, McGilligan V, et al. (2018) Age and age-related diseases: role of inflammation triggers and cytokines. *Front Immunol* 9: 586. https://doi.org/10.3389/fimmu.2018.00586
24. Gao Y, Wang B, Qin G, et al. (2024) Therapeutic potentials of allicin in cardiovascular disease: advances and future directions. *Chin Med* 19: 93. https://doi.org/10.1186/s13020-024-00936-8
25. Munteanu C, Popescu C, Vlădulescu-Trandafir AI, et al. (2024) Signaling paradigms of H_2S-induced vasodilation: a comprehensive review. *Antioxidants* 13: 1158. https://doi.org/10.3390/antiox13101158
26. Li L, Ahmed I, Alotaibi A, et al. (2026) Garlic as a functional food: a dual therapeutic strategy for cardiovascular diseases and cancer via shared molecular pathways. *J Funct Foods* 137: 107152. https://doi.org/10.1016/j.jff.2026.107152.
27. Cui T, Liu W, Chen S, et al. (2020) Antihypertensive effects of allicin on spontaneously hypertensive rats via vasorelaxation and hydrogen sulfide mechanisms. *Biomed Pharmacother* 128: 110240. https://doi.org/10.1016/j.biopha.2020.110240
28. Sharifi AM, Darabi R, Akbarloo N (2003) Investigation of antihypertensive mechanism of garlic in 2K1C hypertensive rat. *J Ethnopharmacol* 86: 219–224. https://doi.org/10.1016/s0378-8741(03)00080-1
29. Xiong XJ, Wang PQ, Li SJ, et al. (2015) Garlic for hypertension: a systematic review and meta-analysis of randomized controlled trials. *Phytomedicine* 22: 352–361. https://doi.org/10.1016/j.phymed.2014.12.013
30. Ettehad D, Emdin CA, Kiran A, et al. (2016) Blood pressure lowering for prevention of cardiovascular disease and death: a systematic review and meta-analysis. *Lancet* 387: 957–967. https://doi.org/10.1016/S0140-6736(15)01225-8
31. Law MR, Morris JK, Wald NJ (2009) Use of blood pressure lowering drugs in the prevention of cardiovascular disease: meta-analysis of 147 randomised trials in the context of expectations from prospective epidemiological studies. *BMJ* 338: b1665. https://doi.org/10.1136/bmj.b1665