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RESEARCH

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Garlic consumption can reduce the risk of dyslipidemia: a meta-analysis of randomized controlled trials

Yanbin Du[1], Hua Zhou[2*] and Wenting Zha[3]

Abstract

Background and purpose Garlic is used as an important medicinal food for treatment of many diseases, however, the association between garlic consumption and dyslipidemia have yielded inconsistent results. So we carried this meta-analysis to explore the blood lipid-lowering effects of garlic.

Methods Databases such as PubMed, Scopus, Web of science, Embase, Cochrane Library were systematically searched until June 2024. Heterogeneity among studies was examined using Q and I^2 statistics. Also subgroup analysis were conducted to explore the potential heterogeneity. Combined weighted mean differences (WMD) with their 95% confidence interval (CI) were calculated using a random-effects model. The GRADE approach was used to evaluate the overall certainty of the evidence in the meta-analyses.

Results A total of 21 RCTs studies involved association between garlic consumption and blood lipids level of dyslipidemia patients were included in the meta-analysis. The pooled results showed that garlic consumption significantly reduced total cholesterol (TC)(WMD = -0.64mmol/L, 95%CI = -0.75 –-0.54, $P<0.001$), triglyceride (TG) (WMD = -0.17mmol/L, 95%CI = -0.26 –-0.09, $P<0.001$), low-density lipoprotein(LDL-C)(WMD = -0.44mmol/L, 95%CI = -0.57 –-0.31, $P<0.001$) while slightly increased high-density lipoprotein (HDL-C)(WMD = 0.04mmol/L, 95%CI = -0.00 – 0.08, $P<0.001$). And subgroup analyses showed that TC, TG and LDL-C significantly decreased in patients aged > 50 years compared to those aged ≤ 50 years. And garlic oil greatly reduced TC and LDL-C compared with garlic power. Finally, sensitivity analysis and publication bias showed that the results were reliable.

Conclusions Evidence from this meta-analysis suggested that garlic consumption could be effective in reducing the risk of dyslipidemia and preventing CVDs. Particularly the older people were more susceptible to the protective effects of garlic.

Keywords Garlic, Dyslipidemia, Blood lipids, Cardiovascular diseases, Meta-analysis

*Correspondence:
Hua Zhou
790024030@qq.com
[1]College of Mathematics and Statistics, Henan University of Science and Technology, Luoyang, Henan Province 471000, China
[2]Endocrinology and Metabolism Center, Henan Key Laboratory of Rare Diseases, The First Affiliated Hospital, and College of Clinical Medicine of Henan University of Science and Technology, Luoyang, Henan Province 471003, China
[3]Key Laboratory of Molecular Epidemiology, Medical College of Hunan Normal University, Changsha, Hunan Province 410013, China

Introduction

Cardiovascular disease (CVDs) is the leading cause of death globally, 17 million people die to CVDs each year and it is estimated to reach 24.8 million deaths in 2030 in the world [1]. Dyslipidemia refers to a number of lipid abnormalities including elevated total cholesterol (TC), triglyceride(TG), low-density lipoprotein-cholesterol (LDL-C), and decreased high-density lipoprotein-cholesterol (HDL-C) [2]. In modern society, due to bad dietary habits, the dyslipidemia has been increasing. It is estimated that prevalent cases of dyslipidemia increased at the rate of 1.76% per year to surpass 500 million in 2022. Furthermore, data from epidemiological studies suggest that dyslipidemia is an important predisposing factor for CVDs, including coronary heart disease(CHD), myocardial infarction, stroke, hypertension and other chronic diseases [3, 4]. LDL-C has always been known to be the main cause of atherosclerosis [5], elevated TC can also increase the risk of ischemic heart disease [6] and other lipid indicators are also proved to play important roles in CVDs development. So it is urgent to take effective measures to improve lipid profiles and prevent the CVDs including the use of effective food products.

In recent years, several alternative approaches including different medicinal plants or dietary approaches with the aim of reducing the risk of cardiometabolic diseases have been investigated, some of which them have also shown promising results [7–10]. Garlic, also known as Allium sativum L.(Liliaceae), is a member of the family Alliaceae. It has been used as an important medicinal ailment in many countries for long history [11, 12]. Ancient Indian and Chinese medicine recommend that garlic can be used to help respiration and digestion, and to treat leprosy and parasitic diseases. Besides, garlic plays important roles in the treatment of many diseases such as infectious diseases, gynecologic diseases, toothache, arthritis and hypertension [13–16]. Because of the widespread effects of garlic in maintaining good health, it has attracted particular attention of modern medicine.

The effect of garlic in anti-hyperlipidemia has been confirmed in some animal studies [17, 18]. However, in human studies, the association between garlic consumption and blood lipids have yielded inconsistent results. Earlier reviews strongly suggested that garlic was effective as a lipid-lowering agent [19, 20]. And some clinical experimental studies have shown that garlic has the ability to inhibit cholesterol biosynthesis, reduce lipids and fibrinogen concentrations [21, 22], decrease LDL oxidation and increase fibrinolitic activity [23]. However, a non-systematic review in 2003 gave contradictory results [24]. And some other studies have concluded that garlic has no significant effects on blood lipids [25–27]. Recent several meta-analysis published in 2014–2023, but they mainly focus on the impact of garlic on coronary heart disease(CAD) and metabolic syndrome(MetS). Hence, in their researches that participants were diagnosed as hypertension, hypercholesterolemia, obesity, CVDs or insulin resistance, and results also showed an inconsistency on TG, LDL-C and HDL-C [28–30].

With the increase of sample size, we carried this meta-analysis to further evaluate the effects of garlic on dyslipidemia. Unlike the previously published meta-analysis, all the enrolled participants in this study were diagnosed with dyslipidemia and not taking any hypolipidemic drugs. Our aim is to explore whether garlic is an effective and safe alternative approach for the treatment of dyslipidemia and prevention of CVDs.

Materials and methods

Literature search strategy

This meta-analysis was planned and conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [31], registration code: CRD42024506637. A systematic search of published articles was conducted in the PubMed, Embase, Scopus, Web of Science and Cochrane Library databases up to June 2024, and the publication language limited to English. Following search terms are used: ("garlic" OR "garlicin" OR "garlic oil" OR "garlic extract" OR "garlic cloves" OR "garlic powder" OR "allicin") AND ("Serum lipids" OR "blood lipids" OR "lipid profile" OR "lipidemia" OR "hypercholesterolemia" OR "hyperlipidemia" OR "dyslipidemia" OR" hyperlipemia" OR "total cholesterol" OR "TC" OR "triglyceride" OR "TG" OR "high density lipoprotein"OR "HDL-C" OR "low density lipoprotein"OR "LDL-C") AND ("randomized controlled trial" OR "RCT" OR "controlled clinical trial" OR "controlled trial" OR "Cross-over" OR "Parallel"). To enhance the comprehensiveness of literature search, we conduced backward and forward snowballing searches to identify additional relevant articles [32].

Inclusion and exclusion criteria

Studies that met the following criteria were included in this meta-analysis: (1) Randomized controlled trial (RCT) in human with either parallel or crossover design; (2) concerning the effects of garlic consumption on blood lipid; (3) outcome is at least one of the lipid parameters (LDL-C, HDL-C, TC, TG); (4) participants with hyperlipidemia and ⩾18 years of age; (5) means and standard deviation (SD) or standard error of the mean (SEM) or 95% confidence intervals(CIs) had been provided.

The exclusion criteria were the following: (1) duplicate studies; (2) reviews, reports, conferences, animal studies; (3) insufficient data; (4) garlic combined with other lipid-lowering drugs or foods; (5) Intervention duration < 2 week; (6) Studies that were not randomized or no placebo control group; (7) Non hyperlipidemia patients. Two of the authors independently searched all references, using a kappa statistic to assess the agreement between the authors [33]. When kappa value > 0.7, we accept the decision, otherwise reject the decision and request a third-party ruling.

Data extraction

Two authors performed data extraction, again any disagreements were discussed and resolved by consensus. The following information was collected : first author's name, publication year, country, study design, age and gender as well as health status of participants, sample size, daily dose of garlic consumption, intervention duration, blood lipids index(LDL-C, HDL-C, TG, TC). In each trial, the means and standard deviation(SD) of blood lipids at baseline and endpoint were extracted. For studies that had multiple time points measurements, only the last end point was used for analysis. Blood lipid levels were collated in mmol/L. Therefore, blood lipid values reported in mg/dl were converted to mmol/L, where 1 mg/dL = 0.02586 mmol/L for TC, LDL-C, HDL-C, and 1 mg/dL = 0.01129 mmol/L for TG [34].

Quality assessment and quality of evidence

The study quality of RCTs was assessed with the Cochrane Tool, which includes : selection bias, performance and detection bias, attrition bias, reporting bias and other possible sources of bias. Each domain was judged to have a "low risk", "high risk" or "unclear risk". Any disagreements were resolved by consensus. Quality of evidence GRADE (Standards for the Development, Evaluation, and Evaluation Working Group) criteria were used to evaluate the overall certainty of the evidence in the meta-analyses. The quality of the evidence was categorized according to four assessment criteria: high, moderate, low, and very low [35].

Statistical analysis

Weighted mean differences (WMD) with 95% confidence interval (CI) were used to evaluate LDL-C, HDL-C, TG and TC changes levels. Net changes in measurements (change scores) for the trials were calculated using the following formula: (measure at the end of follow-up in the treatment group-measure at baseline in the treatment group) – (measure at the end of follow-up in the control group – measure at baseline in the control group). Change-from-baseline SD was estimated using the equation:

$$\mathrm{SD_{change}} = \sqrt{\mathrm{SD^2_{baseline}} + \mathrm{SD^2_{final}} - 2 \times \mathrm{R} \times \mathrm{SD^2_{baseline}} \times \mathrm{SD^2_{final}}}$$

the R is the correlation coefficient, to be conservative, a minimum correlation coefficient of 0.5 was used. If SDs were not reported directly, we can calculate them from SEM or 95% CI using following formula: (1)$\mathrm{SD} = \mathrm{SEM} \times \sqrt{n}$ (where standard error of the mean (SEM) was only reported); (2) $\mathrm{SD} = (\mathrm{upperlimit} - \mathrm{lowerlimit}) \times \sqrt{n} \div 3.92$ (If the outcome measures were reported in median and range (or 95%CI), where n is the number of subjects [36]. Heterogeneity among the studies was estimated using the I^2 and Q statistic. For the Q statistics, $P < 0.10$ indicated statistically significant heterogeneity. And the I^2 values of 25%, 25–50%, 50–75%, and >75% were classified as indicating no, small, moderate, and significant heterogeneity, respectively. Pooled WMD were obtained using either a fixed-effects model, if $I^2 < 50\%$ or random-effects model if $I^2 > 50\%$ according to Cochrane handbook. In addition, we performed subgroup analysis using sample size (≤60 and >60), age (≤50 years old and >50 years old), types of garlic(garlic powder, garlic tablets, garlic oil) and intervention duration (≤12 weeks and >12 weeks) to explore the potential heterogeneity.

To assess the potential publication bias, we used funnel plots and Egger's linear regression test [37]. Sensitivity analyses were carried out by excluding each studies and reanalyzing the data. All statistical analyses were performed with STATA 12.0 (Stata Corp, Texas, USA). Significance was set at a $P < 0.05$ and all statistical tests were two-sided.

Results

Literature search

An electronic literature search identified 8623 studies concerning effects of garlic consumption on blood lipids level, 8602 of which were excluded based on the a series of reasons (firstly, exclusion of 1711 duplicated articles, then 6912 articles were screened by title and abstract, leading to exclusion of 3634 irrelevant studies, 2164 reports, reviews or meta-analysis, or letters, 972 non-human studies. Finally, leaving 142 articles for full-text review, where 46 articles do not provide available data, 21 articles are not RCT, 19 articles are healthy individuals, 31 articles garlic combined with other lipid-lowering food and 4 articles intervention duration < 2 week), resulting in inclusion of a total of 21 studies in the meta-analysis. The details of literature search are shown in Fig. 1.

Study characteristics

The characteristics of included studies are shown in Table 1. A total of 21 RCT (20 parallel design, 1 cross-over design) [38–58] that met the inclusion criteria for our meta-analysis were published between 1981 and 2021. Of these studies, twelve were carried out in Asian countries, including Korea(n=2), India(n=2), Iran(n=2), Nepal(n=1), Iraq(n=1), Pakistan(n=2), Thailand(n=1) and Turkey (n=1); Five in American countries, including

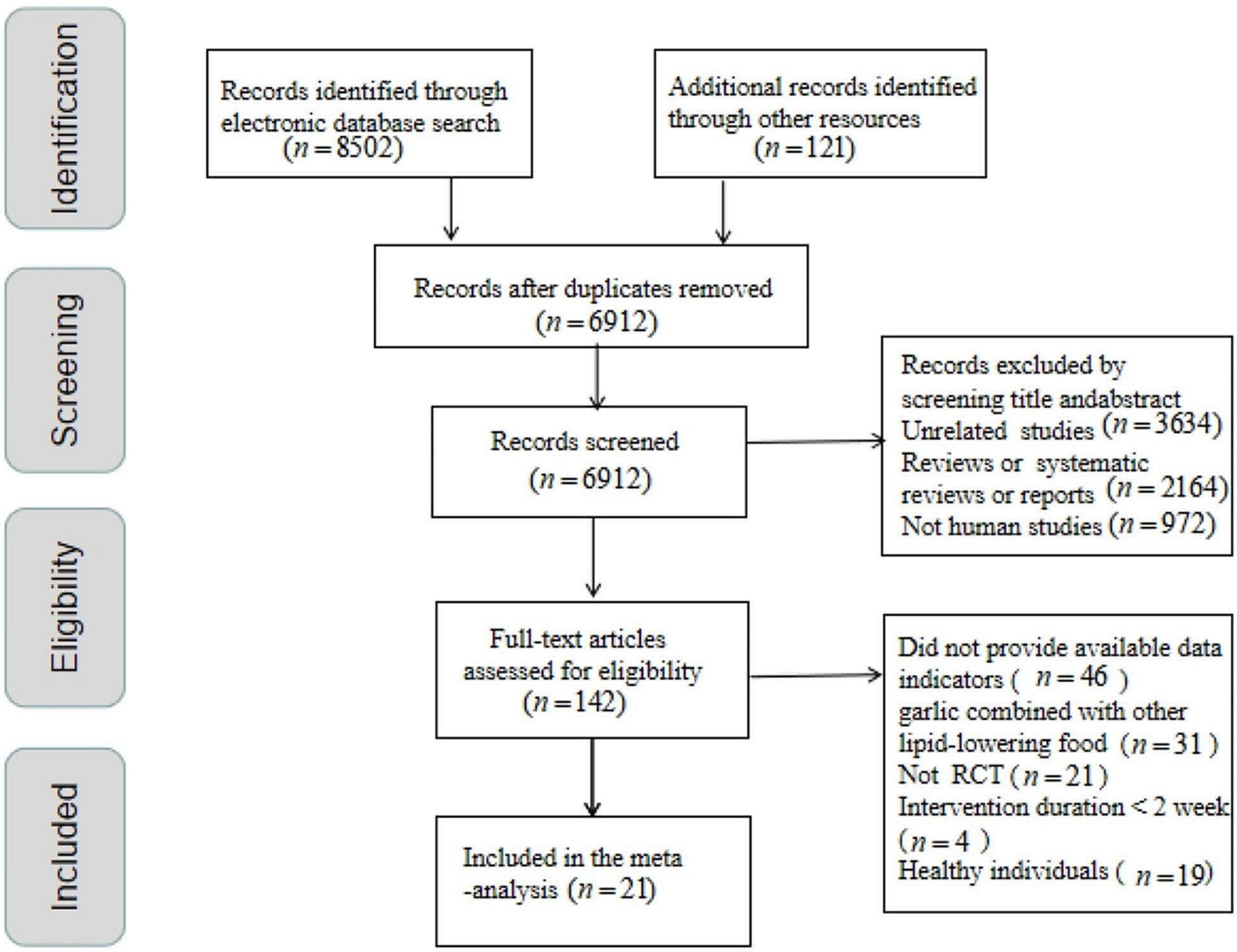

Fig. 1 Flowchart of study procedure

USA (n=4), Canada (n=1); Others including Australia (n=2), and Russia (n=2). In total, 1603 subjects included in this meta-analysis. Mean ages of participants ranged from 25 to 70 years. Except two studies [44, 46] were done on male, one study in female [38], others all were conducted on both sexes. Sample size ranged from 23 to 258, the intervention period ranged from 8 weeks to 36 weeks. Five different garlic preparations were tested in the trials, including garlic powder [40, 44, 45, 52, 53, 57], raw garlic [46, 54], garlic tablets [47, 48, 51], aged garlic [43, 56], garlic oil [42, 58], six studies did not provide detailed information about the garlic [38, 39, 41, 49, 50, 55]. All studies surveyed subjects with dyslipidemia.

Methodological quality of included trials

Documents quality evaluation were done based on standard methods recommended by Cochrane Collaboration. All of the included studies were randomized, placebo-controlled trials, including thirteen double-blind trials [38, 39, 42–45, 48, 50–53, 56, 57] and two single-blind trial [40, 47]. Thus they were considered as low risk of bias and others as unclear risk. Although randomization was declared in all studies, none of the trials reported how the randomization was conducted. Therefore, they were regarded as unclear risk of bias. None of the trials provided incomplete outcomes and selective reporting, and were assessed as low risk; In addition, none of the trials provided a clear description of allocations concealment, so they all were assessed as "unclear" risk(Table 2).

Effect of garlic consumption on blood lipids

TC

Effect of garlic consumption on TC levels was explored from 20 studies (Intervention group=661, control group=668). Heterogeneity test results found significant heterogeneity in these.

studies (Q=136.98, P<0.001, I2=86.1%). And a random-effects model was applied, the summary WMD for 20 studies showed that garlic consumption significantly reduced TC levels(WMD = -0.64mmol/L, 95%CI = -0.75 – -0.54, P<0.001). (Fig. 2) Subgroup analyses indicated that there was no significant difference in TC

Table 1 Characteristics of 21 RCT studies included in the meta-analysis

Author and Publication Year	Country	Study Design	Age and Sex	Sample size	Experiment group	Intervention duration	Data indicators	Health status
Roya Zadhoush 2021 [38]	Iran	Parallel	18–45 F	80	800 mg/d garlic supplemen	8 weeks	TC, TG, LDL-C, HDL-C	dyslipidemia
Alisha Limbu 2019 [39]	Nepal	Parallel	Age no description Both sex	112	250 mg/d garlic	12 weeks	TC, TG, LDL-C, HDL-C	dyslipidemia
Zeb et al., 2018 [40]	Pakistan	Parallel	53.57 ± 8.5 both	80	2 g/d garlic powder	8 weeks	TC, TG, LDL-C, HDL-C	hyperlipid-emia
Aslani et al., 2016 [41]	Iran	Parallel	30–60 both	112	20 g/d garlic	8 weeks	TC, TG, LDL-C, HDL-C	Hyperlipi-daemia
Alobaidi et al., 2014 [42]	Iraq	Parallel	24–57 both	258	250 mg/d garlic oil	8 weeks	TC, TG, LDL-C, HDL-C	hyperlipid-emia
Jung et al., 2014 [43]	Korea	Parallel	50.48 ± 8.58 both	60	6 g/d aged black garlic(ABG)	12 weeks	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Sobenin et al., 2010 [44]	Russia	Parallel	40–65 both	63	150 mg/d garlic powder	12 months	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Sobenin et al., 2008 [45]	Russia	Parallel	35–70 M	42	600 mg/d garlic powder	12 weeks	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Gardner et al., 2007 [46]	USA	Parallel	30–65 both	192	4 g/d raw garlic	6 months	TG, LDL-C, HDL-C	hypercho-lesterolemic
RizwanShifa et al.,2005 [47]	Pakistan	Parallel	25–70 both	70	300 mg/d tablet garlic	12 weeks	TC, TG, LDL-C, HDL-C	dyslipidemia
Tanamai et al., 2004 [48]	Thailand	crossover	47.03 ± 6.7 M	100	garlic tablets	9 months	TC, TG, LDL-C, HDL-C	Hyperlipid-emia
Durak et al., 2004 [49]	Turkey	Parallel	24–68 both	23	10 g/d garlic	4 months	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Gardner et al., 2001 [50]	USA	Parallel	51.8 ± 8.3 both	51	1000 mg/d garlic preparation	12 weeks	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Kannar et al., 2001 [51]	Australia	Parallel	52.6 ± 10.4 both	46	9.6 mg/d garlic powder or tablets	12 weeks	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Superko et al., 2000 [52]	USA	Parallel	53 ± 10 both	50	900 mg/d garlic powder	3 months	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Isaacsohn et al.,1998 [53]	USA	Parallel	58 ± 14 both	28	900 mg/d garlic powder	12 weeks	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Bordia et al., 1998 [54]	India	Parallel	No description	60	4 g/d raw garlic	3 months	TC, TG, HDL-C	dyslipidemia
Adler et al., 1997 [55]	Canada	Parallel	45.9 ± 12.6 both	50	900 mg/d garlic	12 weeks	TC, TG, HDL-C	hypercho-lesterolemic
Yeh et al., 1997 [56]	USA	Parallel	35–55 both	36	800 mg/d aged garlic	5 months	TC LDL-C	hypercho-lesterolemic
Simons et al., 1995 [57]	Australia	Parallel	53.6 ± 10.4 both	28	900 mg/d garlic powder	12 weeks	TC, TG, LDL-C, HDL-C	hypercho-lesterolemic
Bordia et al., 1981 [58]	India	Parallel	44–62 both	62	15 mg/d garlic oil	8 months	TC, HDL-C	dyslipidemia

Abbreviations: F: female; M: male; Both: female and male; TC: total cholesterol; TG: triglyceride; LDL-C: low density lipoprotein; HDL-C: high density lipoprotein;

decrease between sample size and intervention duration. However, TC significantly decreased in patients age > 50 years(WMD = -0.66mmol/L, 95%CI = -0.73 – -0.59) compared to age ≤ 50 years(WMD = -0.45mmol/L, 95%CI = -0.69 – -0.20). For different types of garlic, a greater reduction in garlic oil group(WMD = -0.73mmol/L, 95%CI = -0.91 – -0.56) compared to garlic powder(WMD = -0.51mmol/L, 95%CI = -0.80 – -0.23). The quality of evidence related to TC was downgraded to moderate due to serious limitations in indirectness (Table 3).

TG

Effect of garlic consumption on TG levels was explored from 19 studies (Intervention group = 658, control group = 670). Combined results through the random-effects model revealed that garlic consumption

Table 2 Quality assessment of included RCT studies based on the Cochrane guidelines

Study	Random sequence generation	Allocations concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective outcome reporting	Other potential sources of bias
Roya Zadhoush 2021	U	U	L	L	L	L	U
Alisha Limbu 2019	U	U	L	L	L	L	U
Zeb et al. 2018	U	U	L	U	L	L	U
Aslani et al. 2016	U	U	U	U	L	L	U
Alobaidi et al. 2014	U	U	L	L	L	L	U
Jung et al. 2014	U	U	L	L	L	L	U
Sobenin et al. 2010	U	U	L	L	L	L	U
Sobenin et al. 2008	U	U	L	L	L	L	U
Gardner et al. 2007	U	U	U	U	L	L	U
RizwanShifa et al. 2005	U	U	L	U	L	L	U
Tanamai et al. 2004	U	U	L	L	L	L	U
Durak et al. 2004	U	U	U	U	L	L	U
Gardner et al. 2001	U	U	L	L	L	L	U
Kannar et al. 2001	U	U	L	L	L	L	U
Superko et al. 2000	U	U	L	L	L	L	U
Isaacsohn et al. 1998	U	U	L	L	L	L	U
Bordia et al. 1998	U	U	U	U	L	L	U
Adler et al. 1997	U	U	U	U	L	L	U
Yeh et al. 1997	U	U	L	L	L	L	U
Simons et al. 1995	U	U	L	L	L	L	U
Bordia et al1981	U	U	U	U	L	L	U

L: low risk of bias; H: high risk of bias; U: unclear risk of bias

significantly reduced TG levels(WMD = -0.17mmol/L, 95%CI = -0.26 – -0.09, P=0.000) with moderate heterogeneity in these studies (Q=88.64, P<0.001, I^2=79.7%). (Fig. 3) Subgroup analyses showed that a significant reduction in people age > 50 years(WMD = -0.19mmol/L, 95%CI = -0.28 – -0.04) compared to age ≤ 50 years(WMD = -0.07mmol/L, 95%CI = -0.14 – -0.01). However, there was no significant effect on TG in male patients, sample size > 60 and > 12 weeks intervention duration. According to the GRADE approach, TG was considered to have a moderate quality of evidence (Table 3).

LDL-C

Effect of garlic consumption on LDL-C levels was explored from 18 studies (625 cases and 637 controls). We observed significant heterogeneity in these studies (Q=133.59, P<0.001, I^2=88.9%). And a random-effects model was applied, the summary WMD for 18 studies showed that garlic consumption significantly reduced LDL-C levels (WMD = -0.44mmol/L, 95%CI = -0.57 – -0.31, P<0.001). (Fig. 4) Subgroup analyses indicated that garlic oil group resulted in a greater reduction in LDL-C levels(WMD = -0.66mmol/L, 95%CI = -0.86 – -0.46). However, there was no significant difference in LDL-C decrease between age, sex and sample size (WMD ranged between −0.41 and −0.48). The LDL-C quality of evidence was rated as moderate using the GRADE approach (Table 3).

HDL-C

Effect of garlic consumption on HDL-C levels was explored from 20 studies (690 cases and 699 controls). Combined results through the random-effects model revealed that garlic consumption had significant effects on HDL-C (WMD=0.04mmol/L, 95%CI = -0.00−0.08, P<0.001) with significant heterogeneity across these studies (Q=146.27, P<0.001, I^2=87.7%). (Fig. 5) However, all subgroup analysis results are consistent, they indicated that garlic consumption has no significant effect on HDL-C. The quality of evidence related to HDL-C was downgraded to low due to serious limitations in indirectness and imprecision (Table 3).

Sensitivity analysis and publication bias

Sensitivity analysis results showed that removed each studies did not significantly alter the overall effect of garlic consumption on TC (WMD altered between −0.7 and −0.49), LDL-C (WMD altered between −0.61 and −0.27) and TG (WMD altered between −0.21 and −0.06). No publication bias was detected in current meta-analysis, although slight asymmetries were observed in the funnel plots, Egger's linear regression test were not statistically

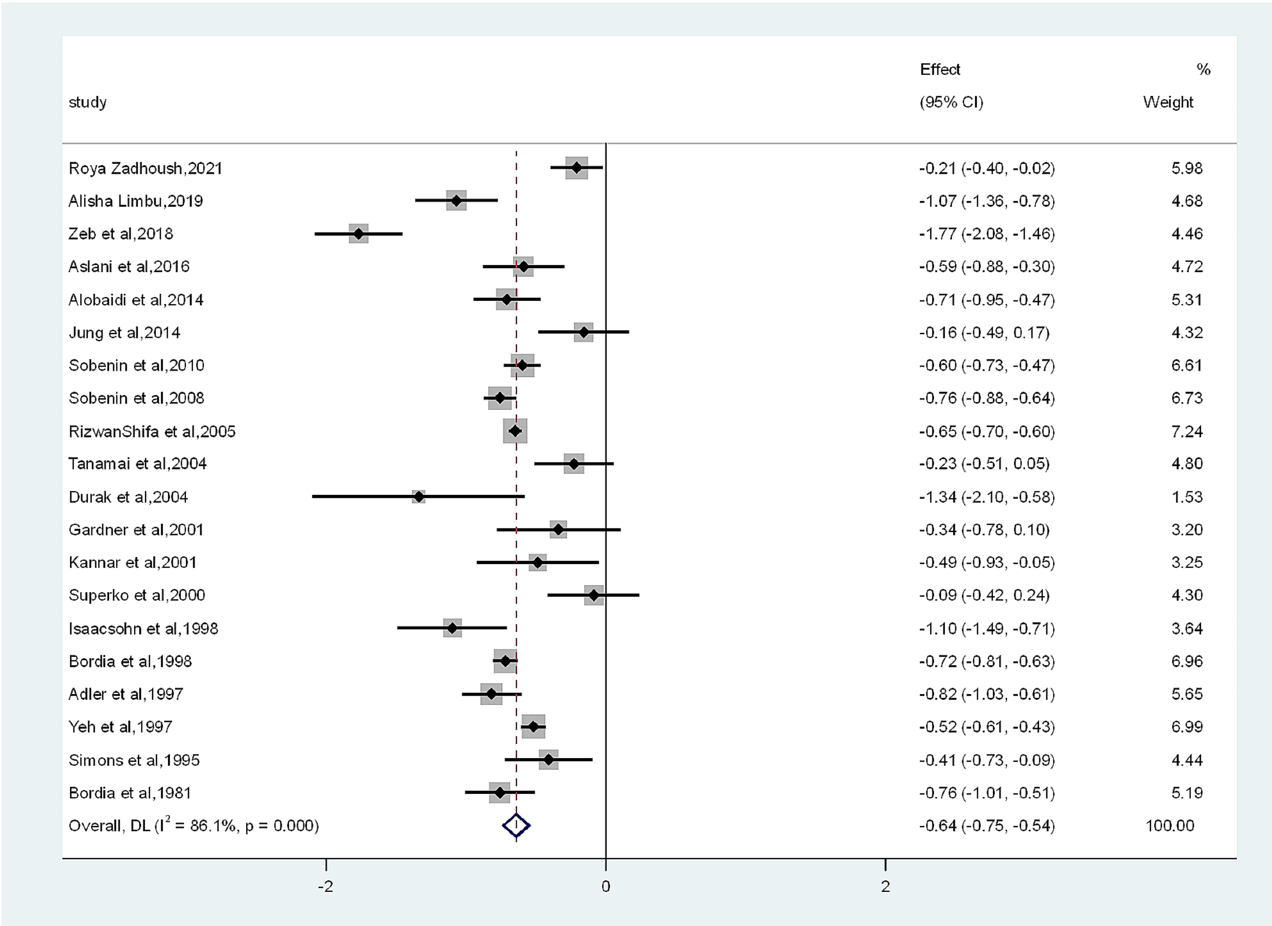

Fig. 2 Effects of garlic consumption on changes in TC(mmol/L)

Table 3 Summary of findings and quality of evidence assessment using GRADE approach

Outcome measure	Summary findings		Quality of evidence assessment(GRADE)					
	No of patients (meta-analysis)	**WMD (95%CI)**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication bias**	**Quality of evidence**
TC (mmol/L)	1329(20)	-0.64 (-0.75,-0.54)	Not serious	Not serious	Serious	Not serious	Not serious	Moderate
TG (mmol/L)	1328(19)	-0.17 (-0.26,-0.09)	Not serious	Not serious	Serious	Not serious	Not serious	Moderate
LDL-C (mmol/L)	1262(18)	-0.44 (-0.57,-0.31)	Not serious	Not serious	Serious	Not serious	Not serious	Moderate
HDL-C (mmol/L)	1389(20)	0.04 (-0.00,0.08)	Not serious	Not serious	Serious	Serious	Not serious	Low

Abbreviations: TC: total cholesterol; TG: triglyceride; LDL-C: low density lipoprotein; HDL-C: high density lipoprotein; WMD (95%CI): Weighted mean differences and 95% confidence intervals

significant (TC: $P=0.465$; TG: $P=0.105$; LDL-C: $P=0.079$; HDL-C: $P=0.609$).

Discussion

This meta-analysis evaluated the blood lipid-lowering effects of garlic with a sample size of over 1600 from 21 RCTs. The evidence from this meta-analysis revealed that garlic consumption significantly reduced TC, TG, LDL-C and slightly increased HDL-C concentration.

Studies have shown that a 1mmol/L reduction in TC and LDL-C levels results in a 26.6–29.5% decrease for any cardiovascular disease–related event [6]. And our study found a 0.64, 0.17, 0.44mmol/L reduction in TC, TG, LDL-C separately and a 0.04mmol/L increase in HDL-C after 3 weeks to 12 weeks of garlic consumption. This

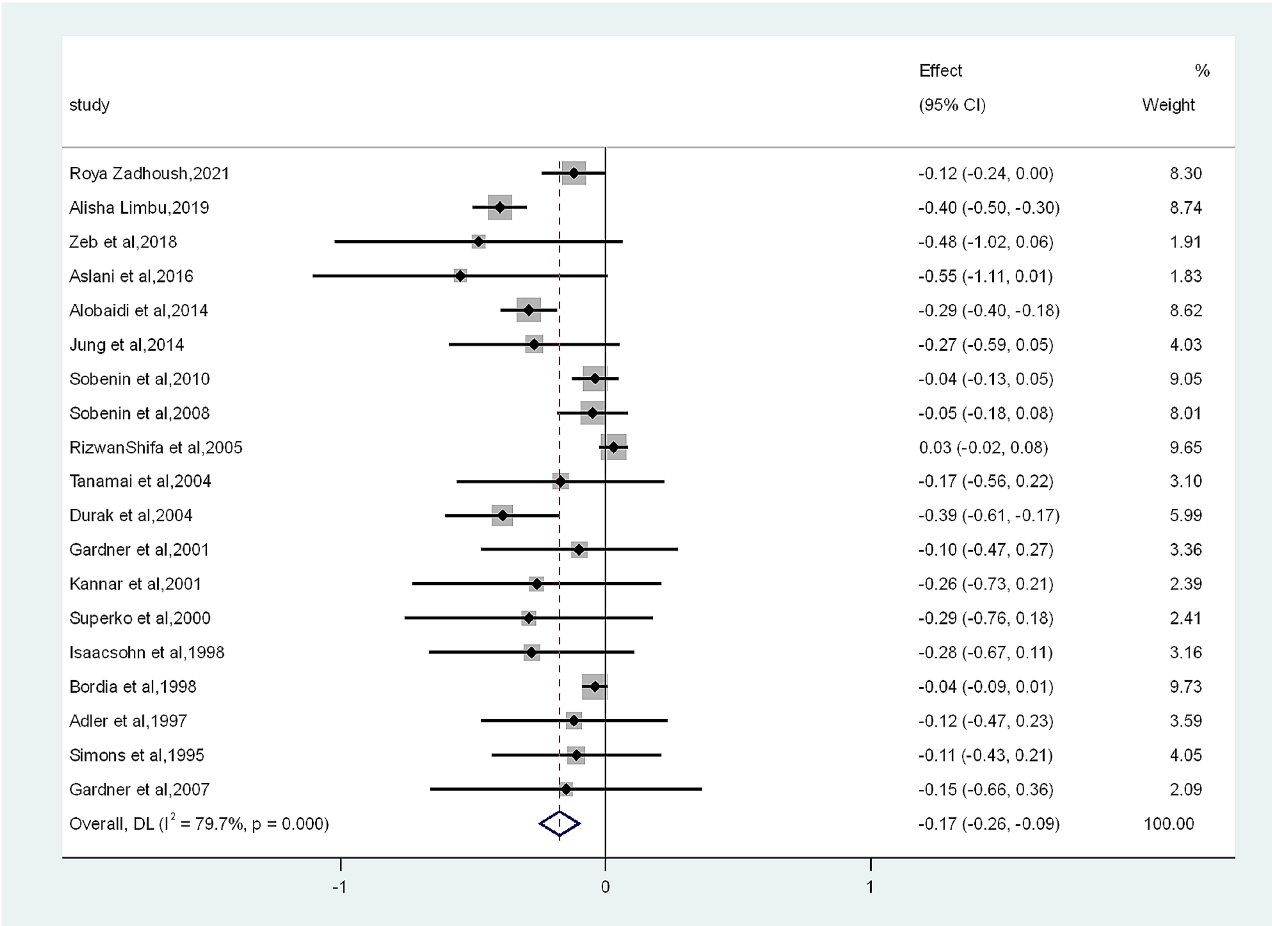

Fig. 3 Effects of garlic consumption on changes in TG(mmol/L)

conclusion about effects of garlic consumption on TC is consistent with the most previous studies [38, 39, 43]. However, the conclusion in TG is contrary to two studies [46, 47]. And a significantly reduced effects on TC, TG and LDL-C in our study compared to garlic consumption had no any significantly effects in some studies [27–30]. In addition, most previous studies have not found that garlic has a significant effect on HDL-C. But we found garlic consumption slightly increased HDL-C concentration. This difference may be caused by several reasons: First, in previous studies, they repeatedly used the data of different time points measurements in the same article. And in our study, we only used the data of the highest garlic consumption and the longest observation time. Second, most previous studies did not limit the health status of participants. And in our meta-analysis, all studies involved hyperlipemia patients. Third, we include the latest data from 2014 to 2023. So, we confirmed the significant blood lipid-lowering effect of garlic.

Subgroup analyses indicated that there was not significant difference in TC, TG and LDL-C changes between sample size. However, TC, TG and LDL-C significantly decreased in people aged > 50 years. It indicated that older people were more susceptible to the protective effects of garlic; In addition, we found TC significantly decreased in male patients, while not for TG and LDL-C. The study by Zhang et al. suggested that women may benefit more than men from garlic treatment [59], while the study by Zeng et al. showed that the effects of garlic in men were greater than those in subjects of both gender [60]. Besides, TC, LDL-C significantly decreased in subgroup of ≤12 weeks intervention duration while for TG in subgroup of > 12 weeks intervention. Some studies showed significant reduction in TC vs. placebo over 4–12 weeks intervention with unclear effects after 20 weeks [61, 62]. So age, sex and intervention duration may be important sources of heterogeneity.

In addition, garlic oil and garlic tables greatly reduced TC and LDL-C compared with garlic power. So, the effect of garlic consumption on blood lipid levels may depend on the method of preparation and the type of garlic. Studies have shown that garlic in non-powder form which lowered TC and TG more significantly than powder form garlic preparation over 1–3 months [63].

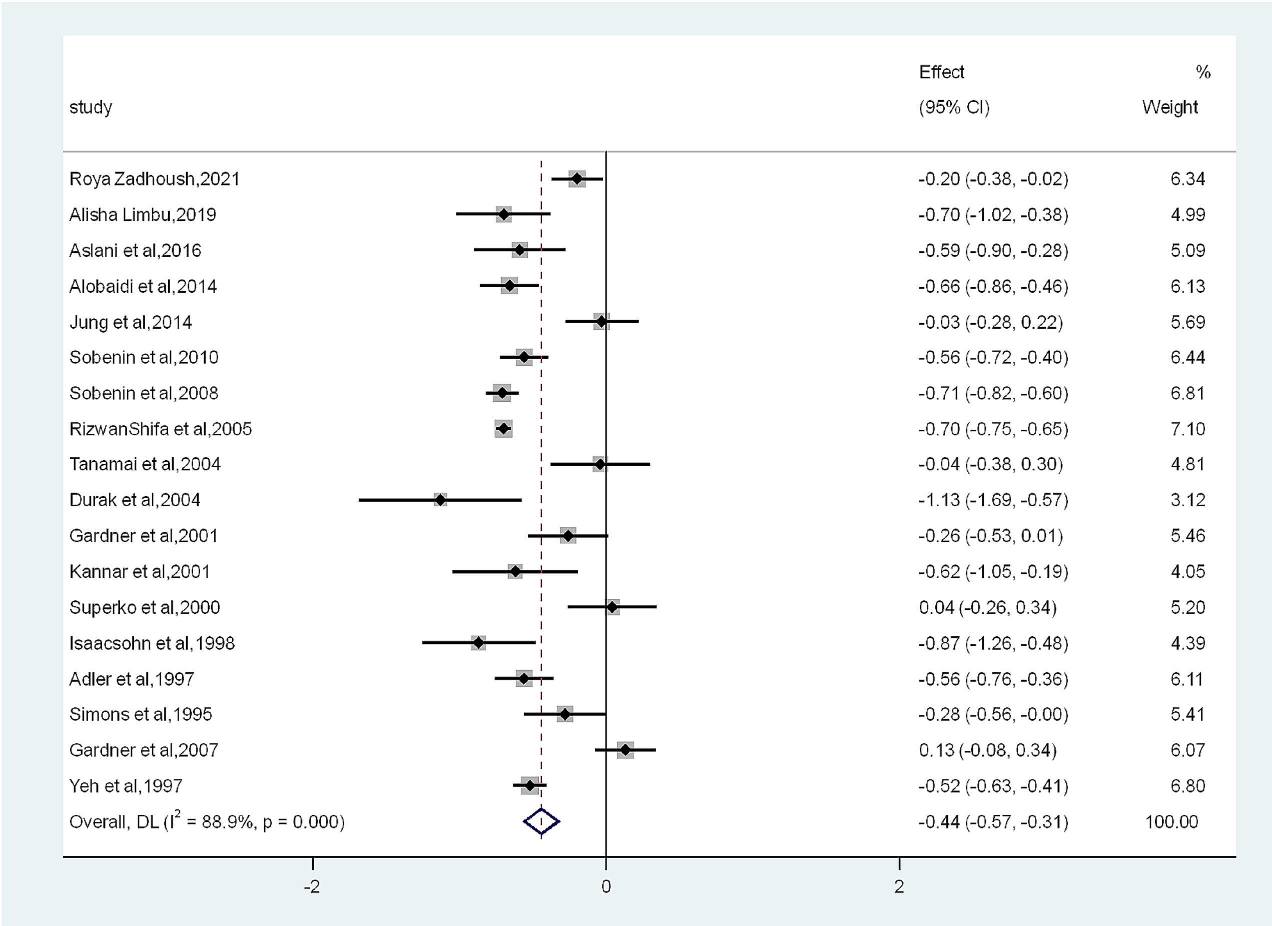

Fig. 4 Effects of garlic consumption on changes in LDL-C(mmol/L)

Several mechanisms of garlic as hypolipidemic action has been proposed, including: (1) Depressed activity of hepatic lipogenesis and cholesterolegenic enzyme such as malic enzyme, fatty acid synthetase(FAS), glucose 6–phosphate dehydrogenase and 3-hydroxy, 3-methyl glutaryl CoA (HMG-CoA) reductase [64]; (2) Inhanced excreation of acidic and neutral steroid into bile after garlic feeding [65] and increased loss of bile salt in faeces and mobilization of tissue lipid into circulation as garlic has a profound effect in post-prandial hyperlipidemia [30]; (3) Suppressed LDL oxidation by garlic preparation, especially by aged garlic extract (AGE) and aqueous garlic extract, thus having anti-atherogenic effect [66, 67]. Allicin present in garlic has been identified as the active compound responsible for anti-atherosclerotic effects. Recent in-vitro studies revealed that water soluble organosulfur compounds especially S-allyl cysteine (SAC) present in aged garlic extract and diallyldisulphide (DADS) present in garlic oil are also potent inhibitors of cholesterol synthesis [64, 68]; (4) Garlic is a potential stimulant of lipase enzyme thereby, decreasing blood triglyceride level [69].

This meta-analysis has its own strengths. First, this is the latest study that explore the blood lipid-lowering effects of garlic in human. And, we synthesized and quantified evidence from 21 independent RCTs which from more strict inclusion criteria. Second, in data analysis, we only used the data of the highest dose garlic consumption and the longest observation time in each trial. The results found that garlic consumption significantly decreased TC, TG, LDL-C and slightly increased HDL-C concentration. Third, participants of the studies reviewed had a very low heterogeneity and were similar in levels of primary cholesterol and health status. All studies involved dyslipidemia patients. And the results were unlikely to be affected by publication bias.

Meanwhile, several potential limitations of our study deserve mention. Firstly, we only searched studies from English databases and missed non-English articles may affect the final results. Secondly, moderate to high heterogeneity was present for the TC, TG, LDL-C, and HDL-C analyses and was only partly explained by subgroup analyses. Third, in each trial, the type and dose of garlic are different, this may be also an important sources

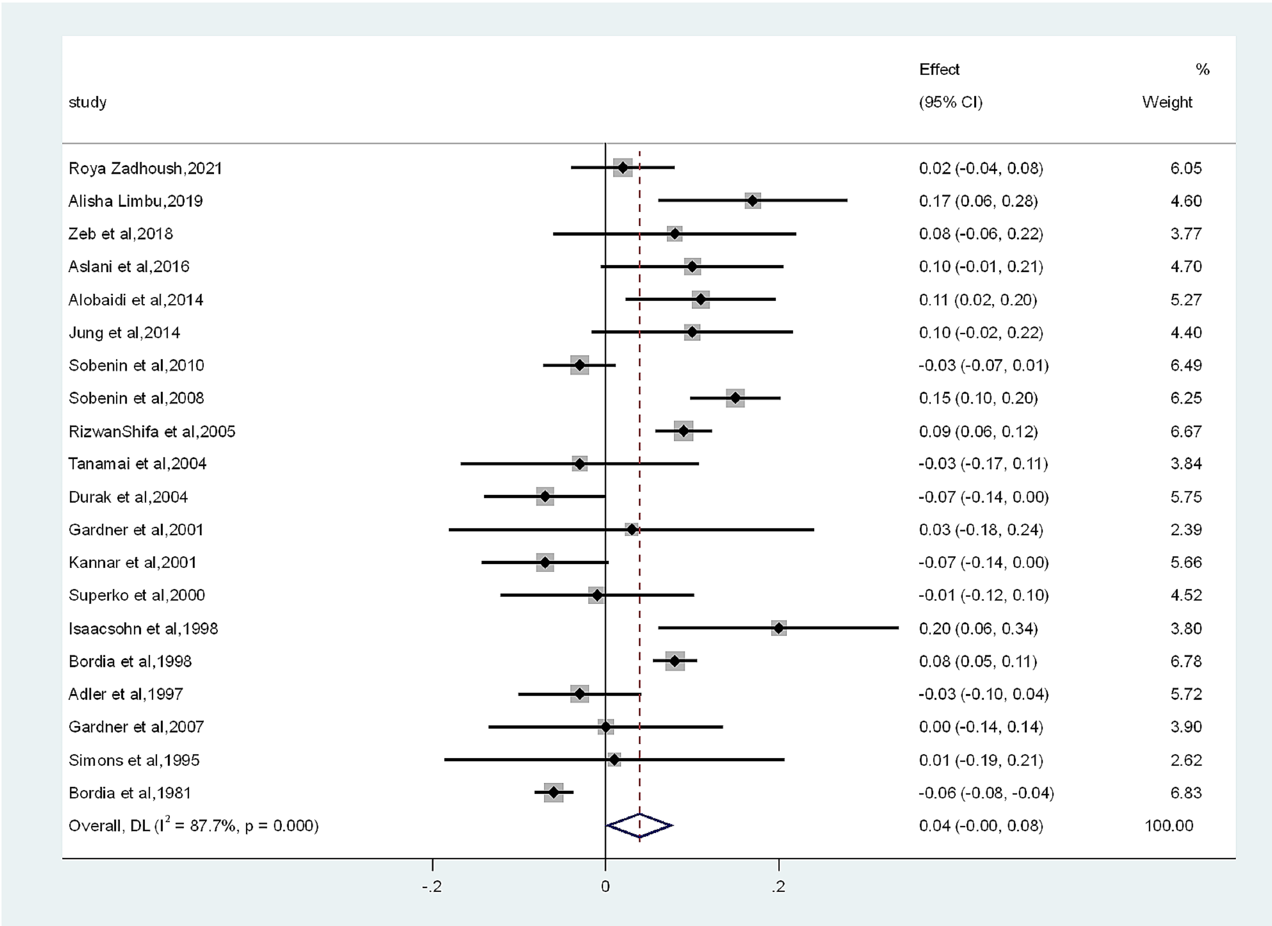

Fig. 5 Effects of garlic consumption on changes in HDL-C(mmol/L)

of heterogeneity. Thereby, the correlations between garlic consumption and serum lipid levels require further investigation through epidemiological studies with a larger sample size.

Conclusions

In conclusion, results from this meta-analysis indicate that garlic consumption is beneficial for the treatment of dyslipidemia and prevention of CVDs. This result from a significant reduction in TC, TG, and LDL-C. These findings also suggest that garlic can be used as an effective herbal medicine in clinical practice of hyperlipidemia.

Supplementary Information

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Supplementary Material 1

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No.

Author contributions
Yanbin Du conceived the idea, performed the statistical analysis and drafted this meta-analysis. Hua Zhou and Wenting Zha conducted the systematic search, screened the articles and extracted the data. Yanbin Du is the guarantor of the overall content. All authors revised and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
All authors have given their consent for this publication.

Competing interests
The authors declare no competing interests.

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References

1. Organization WH. Cardiovascular disease (CVDs). 2017. https://www.who.int/en/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds).
2. Rahimlou M, Mirzaei K, Keshavarz SA, et al. Association of circulating adipokines with metabolic dyslipidemia in obese versus non-obese individuals[J]. Diabetes Metab Syndr. 2016:S60–5.
3. Farhangi MA, Dehghan P, Musazadeh V, Kavyani M. Parham Maleki. Effectiveness of omega-3 and prebiotics on adiponectin, leptin, liver enzymes lipid profile and anthropometric indices in patients with non-alcoholic fatty liver disease: a randomized controlled trial. J Funct Foods. 2022;105074(92)1756–4646.
4. Musazadeh V, Mohammadi Anilou M, Vajdi M, Karimi A, Sedgh Ahrabi S, Dehghan P. Effects of synbiotics supplementation on anthropometric and lipid profile parameters: finding from an umbrella meta-analysis. Front Nutr. 2023. https://doi.org/10.3389/fnut.2023.1121541
5. Bhandari S, Gupta P, Quinn P, Sandhu J, Ng L. Pleiotropic effects of statins in hypercholesterolaemia: a prospective observational study using a lipoproteomic based approach. Lancet. 2015;385:S21.
6. Koene RJ, Prizment AE, Blaes A, Konety SH. Shared risk factors in cardiovascular disease and cancer. Circulation. 2016;133:1104–14.
7. Morvaridzadeh M, Sepidarkish M, Fazelian S, et al. Effect of calcium and vitamin D co-supplementation on blood pressure: a systematic review and meta-analysis[J]. Clin Ther. 2020;42(3). https://doi.org/10.1016/j.clinthera.2020.01.005
8. Ghanavati M, Rahmani J, Clark CCT, et al. Pistachios and cardiometabolic risk factors: a systematic review and meta-analysis of randomized controlled clinical trials[J]. Complement Ther Med. 2020;52:102513.
9. Rahimlou M, Morshedzadeh N, Karimi S, et al. Association between dietary glycemic index and glycemic load with depression: a systematic review[J]. Eur J Nutr. 2018. https://doi.org/10.1007/s00394-018-1710-5
10. Msc MB, Msc MM, Shahram APD et al. Effect of Probiotic, Prebiotic, and Synbiotic supplementation on cardiometabolic and oxidative stress parameters in patients with chronic kidney disease: a systematic review and Meta-analysis[J]. Clinical therapeutics. 2021;43(3). https://doi.org/10.1016/j.clinthera.2020.12.021
11. El-Bayoumy K, Sinha R, Pinto JT, Rivlin RS. Cancer chemoprevention by garlic and garliccontaining sulfur and selenium compounds. J Nutr. 2006;136(3):S864–9.
12. Iciek M, Kwiecien I, Wlodek L. Biological properties of garlic and garlic-derived organosulfur compounds. Environ Mol Mutagen. 2010;50:247–65.
13. Dini C, Fabbri A, Geraci A. The potential role of garlic (Allium sativum) against the multi-drug resistant tuberculosis pandemic: a review. Ann Ist Super Sanita. 2011;47:465–473.
14. Denisov LN , Andrianova IV, Timofeeva SS. Garlic effectiveness in rheumatoid arthritis. Terapevticheskii arkhiv, 1999;71(8):55–58.
15. Sisson D, Balmer C. A chemical burn from a garlic poultice applied to the face to treat toothache: a Case Report. Primary Dent J. 2014;3(1):28–29.
16. Xiong X, Wang P, Li S, Li X, Zhang Y, Wang J. Garlic for hypertension: a systematic review and meta-analysis of randomized controlled trials. Phytomedicine. 2015;22:352–61.
17. Sun HC, Choi MJ, Chang KJ. Effects of garlic powder and soy protein supplementation on blood lipid profiles and amino acid concentrations in postmenopausal hyperlipidemic model rats. Adv Experimental Med Biology. 2016;583:227.
18. Sher A, Fakhar-Ul-Mahmood M, Shah SNH, Bukhsh S, Murtaza G. Effect of garlic extract on blood glucose level and lipid profile in normal and alloxan diabetic rabbits. Adv Clin Experimental Med. 2012;21(6):705–11.
19. Warshafsky S, Kamer RS, Sivak SL. Effect of garlic on total serum cholesterol: a meta-analysis. Ann Intern Med. 1993;119:599–605.
20. Alder R, Lookinland S, Berry JA, Williams M. A systematic review of the effectiveness of garlic as an anti-hyperlipidemic agent. J Am Acad Nurse Pract. 2003;15:120–9.
21. Kannar D, Wattanapenpaiboon N, Savige GS, Wahlqvist ML. Hypocholesterolemic effect of an enteric-coated garlic supplement. J Am Coll Nutr. 2001;20:225–31.
22. Mader FH. Treatment of hyperlipidaemia with garlic-powder tablets. Evidence from the German Association of General Practitioners' multicentric placebo-controlled double-blind study. Arzneimittelforschung. 1990;40:1111–6.
23. Lau BH. Suppression of LDL oxidation by garlic compounds is a possible mechanism of cardiovascular health benefit. J Nutr. 2006;136:S765–8.
24. Iker Durak, Kavutcu M, Ayta B, et al. Effects of garlic extract consumption on blood lipid and oxidant/antioxidant parameters in humans with high blood cholesterol[J]. J Nutr Biochem. 2004;15(6):373–7.
25. Van Doorn MB, Espirito Santo SM, Meijer P, Kamerling IM, Schoemaker RC, Dirsch V. Effect of garlic powder on C-reactive protein and plasma lipids in overweight and smoking subjects. Am J Clin Nutr. 2006;84:1324–9.
26. Rahmani M, Tabari A, Niaki M, Allahaverdian S, Sheikholeslami M. Effect of dried garlic supplementation on blood lipids in mild and moderate hypercholesterolemic patients. Arch Iran Med. 1999;2:19–23.
27. Satitvipawee P, Rawdaree P, Indrabhakti S, Ratanasuwan T, Viwatwongkasem C. No effect of garlic extract supplement on serum lipid levels in hypercholesterolemic subjects. J Med Association Thail = Chotmaihet Thangphaet. 2003;86(8):750–7.
28. Fu Z, Lv J, Gao X, et al. Effects of garlic supplementation on components of metabolic syndrome: a systematic review, meta-analysis, and meta-regression of randomized controlled trials[J]. BMC Complement Med Ther. 2023;23(1). https://doi.org/10.1186/s12906-023-04038-0
29. Sook KJ, Yeon KJ, Eun PJ, et al. Garlic powder intake and cardiovascular risk factors: a meta-analysis of randomized controlled clinical trials[J]. Nutr Res Pract. 2014;8(6):644–54.
30. Gadidala SK, Johny E, Thomas C, et al. Effect of garlic extract on markers of lipid metabolism and inflammation in coronary artery disease (CAD) patients: a systematic review and meta-analysis[J]. Phytotherapy research. PTR. 2023. https://doi.org/10.1002/ptr.7729
31. Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ. 2015;349(1):g7647–7647.
32. Wohlin C. Guidelines for snowballing in systematic literature studies and a replication in software engineering[J]. ACM. 2014. https://doi.org/10.1145/2601248.2601268
33. Musazadeh V, Kavyani Z, Naghshbandi B, Dehghan P, Vajdi M. The beneficial effects of omega-3 polyunsaturated fatty acids on controlling blood pressure: an umbrella meta-analysis. Front Nutr. 2022;9(985451). https://doi.org/10.3389/fnut.2022.985451
34. Wang F, Zheng J, Yang B, Jiang J, Fu Y, Li D. Effects of vegetarian diets on blood lipids: a systematic review and meta-analysis of randomized controlled trials. J Am Heart Association. 2015;4(10):e002408.
35. Vajdi M, Musazadeh V, Karimi A et al. Effects of Chromium supplementation on lipid Profile: an umbrella of systematic review and meta-analysis[J]. Biol Trace Elem Res. 2022:1–12.
36. Musazadeh V, Dehghan P, Khoshbaten M. Efficacy of omega-3-rich Camelina sativa on the metabolic and clinical markers in nonalcoholic fatty liver disease: a randomized, controlled trial[J]. Eur J Gastroenterol Hepatol. 2022. https://doi.org/10.1097/MEG.0000000000002297
37. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ (Clinical Res ed). 1997;315:629–34.
38. Zadhoush R, AlavikmAeini A, Feizi A et al. The effect of garlic (Allium sativum) supplementation on the lipid parameters and blood pressure levels in women with polycystic ovary syndrome: a randomized controlled trial[J]. Phytother Res. 2021;(2):1–8.
39. Limbu A, Rauniar GP, Sharma SK, et al. Short-term effect of garlic extract on patients with dyslipidemia[J]. Nepal Med Coll J. 2019;21(4):301–5.
40. Zeb F, Safdar M, Fatima S, et al. Supplementation of garlic and coriander seed powder: impact on body mass index, lipid profile and blood pressure of hyperlipidemic patients. Pak J Pharm Sci. 2018;31(5):1935–41.
41. Negar A, Entezari MH, Askari G, Maghsoudi Z, MohammadReza M. Effect of garlic and lemon juice mixture on lipid profile and some cardiovascular risk factors in people 30–60 years old with moderate hyperlipidaemia: a randomized clinical trial. Int J Prev Med. 2016;7(1):95.
42. Amina A. Effect of nigella sativa and allium sativum coadminstered with simvastatin in dyslipidemia patients: a prospective, randomized, double-blind trial. AntiInflammatory Antiallergy Agents Med Chem. 2014;13(1):68–74.
43. Jung ES, Park SH, Choi EK, Ryu BH, Park BH, Kim DS, Kim YG. Reduction of blood lipid parameters by a 12-wk supplementation of aged black garlic: a randomized controlled trial. Nutrition. 2014;30(9):1034–9.
44. Sobenin IA, Pryanishnikov VV, Kunnova LM, Rabinovich YA, Orekhov AN. The effects of time-released garlic powder tablets on multifunctional cardiovascular risk in patients with coronary artery disease. Lipids Health Dis. 2010;9(1):119.
45. Sobenin IA, Andrianova IV, Demidova ON, Gorchakova T, Orekhov AN. Lipid-lowering effects of time-released garlic powder tablets in double-blinded

placebo-controlled randomized study. J Japan Atherosclerosis Soc. 2008;15(6):334.
46. Gardner CD, Lawson LD, Block E, Chatterjee LM, Kiazand A, Balise RR, Kraemer HC. Effect of raw garlic vs commercial garlic supplements on plasma lipid concentrations in adults with moderate hypercholesterolemia: a randomized clinical trial. Arch Intern Med. 2007;167(4):346.
47. Ashraf R, Aamir K, Shaikh AR, Ahmed T. Effects of garlic on dyslipidemia in patients with type 2 diabetes mellitus. J Ayub Med Coll Abbottabad: JAMC. 2004;17(3):60–4.
48. Tanamai J, Veeramanomai S, Indrakosas N. The efficacy of cholesterol-lowering action and side effects of garlic enteric coated tablets in man. J Med Assoc Thai. 2004;87(10):1156–61.
49. Durak I, Kavutcu M, Aytac B, Avcl A, Devrim E, OZbek H, Ozturk HS. Effects of garlic extract consumption on blood lipid and oxidant/antioxidant parameters in humans with high blood cholesterol. J Nutr Biochem. 2004;15(6):373–7.
50. Gardner CD, Chatterjee LM, Carlson JJ. The effect of a garlic preparation on plasma lipid levels in moderately hypercholesterolemic adults. Atherosclerosis. 2001;154(1):213–20.
51. Kannar D, Wattanapenpaiboon N, Savige GS, Wahlqvist ML. Hypocholesterolemic effect of an enteric-coated garlic supplement. J Am Coll Nutr. 2001;20(3):225–31.
52. Superko HR, Krauss RM. Garlic powder, effect on plasma lipids, postprandial lipemia, low-density lipoprotein particle size, high-density lipoprotein subclass distribution and lipoprotein(a). J Am Coll Cardiol. 2000;35(2):321–6.
53. Bordia A, Verma SK, Srivastava KC. Effect of garlic (allium sativum) on blood lipids, blood sugar, fibrinogen and fibrinolytic activity in patients with coronary artery disease. Prostaglandins Leukotrienes Essent Fat Acids. 1998;58(4):257–63.
54. Isaacsohn JL, Moser M, Stein EA, Dudley K, Black HR. Garlic powder and plasma lipids and lipoproteins: a multicenter, randomized, placebo-controlled trial. Arch Intern Med. 1998;158(11):1189–94.
55. Yeh YY, Lin RI, Yeh SM, Evans S. Garlic reduces plasma cholesterol in hypercholesterolemic men maintaining habitual diets. Food Factors for Cancer Prevention; 1997.
56. Adler AJ, Holub BJ. Effect of garlic and fish-oil supplementation on serum lipid and lipoprotein concentrations in hypercholesterolemic men. Am J Clin Nutr. 1997;65(2):445–50.
57. Simons LA, Balasubramaniam S, Konigsmark MV, Parfitt A, Simons J, Peters W. On the effect of garlic on plasma lipids and lipoproteins in mild hypercholesterolaemia. Atherosclerosis. 1995;113(2):219–25.
58. Bordia A. Effect of garlic on blood lipids in patients with heart disease. Am J Clin Nutr. 1981;34(10):2100–3.
59. Zhang XH, Lowe D, Giles P, Fell S, Connock MJ, Maslin DJ. Gender may affect the action of garlic oil on plasma cholesterol and glucose levels of normal subjects1. J Nutr. 2001;131(5):1471–8.
60. Zeng T, Guo FF, Zhang CL, Song FY, Zhao XL, Xie KQ. A meta-analysis of randomized, double-blind,placebo-controlled trials for the effects of garlic on serum lipid profiles. J Sci Food Agric. 2012;92:1892–902.
61. Mulrow C, Lawrence V, Ackermann R, Ramirez GG, Young V. Garlic: effects on cardiovascular risks and disease, protective effects against cancer, and clinical adverse effects. Evid Rep Technol Assess (Summ). 2002;20:1–4.
62. Reinhart KM, Talati R, White CM, Coleman C. I. The impact of garlic on lipid parameters: a systematic review and meta-analysis. Nutr Res Rev. 2009;22(01):39.
63. Silagy C, Neil A. Garlic as a lipid lowering agent–a meta-analysis. J R Coll Physicians Lond. 1994;28(1):39–45.
64. Yeh YY, Liu L. Cholesterol-lowering effect of garlic extracts and organosulfur compounds: human and animal studies. J Nutr. 2001;131(3s):989.
65. Chi MS. Effects of garlic products on lipid metabolism in cholesterol-fed rats. Proceedings of the Society for Experimental Biology & Medicine Society for Experimental Biology & Medicine. 1982;171(2):174–8.
66. Mccrindle BW, Helden E, Conner WT. Garlic extract therapy in children with hypercholesterolemia. Arch Pediatr Adolesc Med. 1998;152(11):1089.
67. Bordia A, Verma SK, Shrivastava KC. Effect of garlic (Allium Sativum) on blood lipids, blood sugar, fibrinogen and fibrinolytic activity in patients with coronary artery disease. Prostaglandins Leukot Essent Fat Acid. 1998;58(4):257–63.
68. Gebhardt R, Beck H. Differential inhibitory effect of garlic derived organo sulfur compounds on cholesterol biosynthesis in primary rat hepatocyte culture. Lipids. 1996;31:1269–76.
69. Bordia A, Sharma KD, Parmar YK, Verma SK. Protective effect of garlic oil on the changes produced by 3 weeks of fatty diet on serum cholesterol, serum triglycerides, fibrinolytic activity and platelet adhesiveness in man. Indian Heart J. 1982;34(2):86.

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