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A meta-analysis to evaluate the effects of garlic supplementation on performance and blood lipids profile of broiler chickens

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HIGHLIGHTS

- 40 articles with garlic treatments on broiler chickens were used for meta-analysis.
- Garlic inclusion improved average daily gain (ADG) in in all rearing periods.
- Feed conversion ratio (FCR) and feed intake (FI) were decreased at finisher period with garlic treatments.
- Garlic powder and garlic extract had similar effect on ADG, FCR, and FI and fermented garlic had no effect on FCR.
- Cholesterol and LDL decreased while HDL increased with garlic treatments.

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ABSTRACT

The present meta-analysis examined the effects of garlic supplementation on the average daily gain (ADG) and blood lipids profile of broiler chickens by aggregating 40 peer-reviewed articles published between 1991 and 2021. The studies assessing garlic intervention effects on broiler diets were selected from Scopus, Science Direct, Web of Science, PubMed Central, and DOAJ databases based on eligibility criteria developed referring to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Hedges' *g* effect size of dietary garlic treatment was calculated to estimate the standardized means difference (SMD) at 95% Confident Interval (95% CI) using random-effects models (REM) based on DerSimonian and Laird method. A subgroup meta-analysis was performed to clarify potentially significant effect sizes of covariates (study country, garlic form, rearing period, and strains of birds). A linear mixed-effect model was used to assess the inclusion levels effect along with the above-mentioned covariates. Results suggested that dietary garlic increased ADG (SMD = 3.239, 95% CI = 2.360 to 4.120, $P < 0.001$), and decreased feed intake (FI) (SMD = -2.230, 95% CI = -3.141 to -1.320, $P < 0.001$) and feed conversion ratio (FCR) (SMD = SMD = -0.059, 95% CI = -0.080 to -0.040, P < 0.001). The increasing effects on ADG were consistent among the type of garlic (garlic powder, extracted, and fermented), rearing periods (starter, grower, and finisher), most broiler strains, and in most countries where the study was carried out), with few exceptions such as studies from Pakistan, Poland, and Indonesia but the sample sizes were small. Highest increasing effect was observed during grower period (SMD = 3.828; $P < 0.001$). Subgroup meta-analysis also showed that decreasing effects on FI and FCR were found in grower and finisher periods ($P < 0.01$) but were not observed in the starter period ($P > 0.05$). Additionally, the relationship between levels and

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performance depended on the rearing periods as shown by the significant interaction effects between levels and rearing period ($P < 0.001$). In particular, increasing garlic levels linearly increased ADG and decreased FI and FCR in the finisher period ($P < 0.05$) but no relationship was observed for starter and grower periods. This study also provided strong evidence that garlic improved blood lipids profile in broiler chickens as shown by decreasing the concentration of cholesterol, triglycerides, and LDL while increasing HDL at the same time, regardless of dietary levels ($P < 0.05$). In conclusion, the present meta-analysis demonstrated that growth-promoting, hypolipidemic and hypocholesterolemic effects of garlic supplementation on broiler chickens were confirmed in most experimental conditions and rearing periods although the minimum effect was observed in the starter period in terms of ADG. It should be noted that high levels of garlic supplementation are typically unfavorable because it would decrease feed intake. Further study to evaluate low doses of specific bioactive compounds inclusion from garlic on broiler performance and health is warranted to minimize the deleterious effect on feed intake.

Introduction

The broiler industry is growing rapidly to globalize protein sources along with the increasing world population. This trend forces producers to improve production efficiency. In addition, modern society is now being more selective about the quality of broiler meats for consumption concerning antibiotics residues in the animals' products which are being a global issue. Therefore, there has been a continuous effort to replace antibiotics used with natural additives (FAO and WHO, 2019). In this regard, the common approach is to use phytobiotics, a natural product derived from plants, as feed additives for broiler chickens. Garlic is one of the most popular herbs utilized for medicinal purposes since more than a thousand years ago because it is a source of many bioactive compounds such as essential oils and allicin ($C_6H_{10}S_{2O}$) as principal compounds (Ogbuewu et al., 2019). In many practical applications, garlic and its derivatives are recognized as effective antimicrobial and antioxidant agents for humans and animals and are proposed to have a growth promoter effect on aquatic and terrestrial animals (Kothari et al., 2019). A number of experiments have reported that garlic supplementation both in powder or extracted oils could improve gut health and integrity as well as optimize nutrient absorption thus improve growth performance (Ali et al., 2019; Kothari et al., 2019). In broiler chickens, garlic has been used as an additive since at least 30 years ago (Leontiev et al., 2018). It has received a global interest in the last few years to explore its functional properties and effects on broiler chickens and laying hens. The most recent meta-analysis in laying hens suggested that garlic diets improved hen day production and egg quality (Ogbuewu et al., 2021).

In broiler chickens, positive effects in response to dietary supplemental garlic have been proposed by numerous studies. For instance, some evidence has been reported that dietary garlic supplementation increased body weight (BW) with a concomitant effect to decrease feed conversion ratio (FCR) (Hossain et al., 2014; Karangiya et al., 2016), ameliorating bacterial infections (Ali et al., 2019) and enhanced immune system (Navidshad et al., 2019). Moreover, researchers have demonstrated that garlic supplementation in broiler diets decreased cholesterol, triglycerides, and low-density lipoprotein (LDL) concentration (Ao et al., 2011; Dehkordi et al., 2010) as well as increased high-density lipoprotein (HDL), immunoglobulin M (IgM), IgG, and oxidative stability of meat (Choi et al., 2010; Ismail et al., 2021a) which are beneficial for human health. However, several studies reported that dietary garlic did not show any effect on broiler chickens' performance (Ao et al., 2011; Horton et al., 1991; Karimi and Ebadi, 2014). According to the benefits attributed to garlic diets, several modes of action have been proposed including a gut modulatory effect that influences positive changes in the microbial population, digestive enzyme secretion, and other metabolic processes. Such mechanisms promote enhancing the broiler's defense system due to the antimicrobial and antioxidative effect of bioactive compounds present in garlic (Ismail et al., 2021b; Kothari et al., 2019; Leontiev et al., 2018; Ogbuewu et al., 2019). In several review papers, it has been comprehensively explained that garlic contains some organosulfur compounds that are responsible to bring the aforementioned effects including Allicin ($C_6H_{10}S_{2O}$), diallyl sulfide ($C_6H_{10}S$), diallyl trisulphide ($C_6H_{10}S_2$), and allyl mercaptan (C_3H_6S) (Kothari et al., 2019; Ogbuewu et al., 2019; Puvača et al., 2015). Allicin is a volatile compound with antibacterial, antifungal, and antiviral properties (Leontiev et al., 2018). Moreover, garlic is also known to contain essential oils and is also reported to function as an antimicrobial and antioxidant. In a study using garlic essential oils in the diet of broiler chickens, increasing intestinal microflora and morphology such as villus height, villus width, and crypt depth were observed (Amiri et al., 2021). A previous meta-analysis demonstrating the positive effects of essential oils in broiler chickens supports those findings (Irawan et al., 2020).

Given the fact that there are inconsistencies among empirical studies utilizing garlic in the diet of broiler chickens, research synthesis to overview the factors that may explain the discrepancies is useful. Inclusion levels, the form of garlic, strain of broiler chickens, rearing period, and environmental conditions can be explaining factors that contributed to the different results. Meta-analysis is a quantitative review that can be a valuable method since it is widely recognized to have a higher statistical power to resolve such uncertainty and provide new insights (St-Pierre, 2001) regarding the recent progress of the application of garlic in broiler diets. To our best knowledge, there is no meta-analytical study dealing with garlic effects on broiler chickens. Therefore, here we perform a meta-analysis to comprehensively quantify the effect of garlic supplementation on the performance of broiler chickens.

Material and methods

Literature search and database development

Empirical studies reporting the use of garlic in the diets of broiler chickens published in peer-reviewed journals were compiled from the online database of Scopus (www.scopus.com), Science Direct (www.sciencedirect.com), PubMed Central (www.ncbi.nlm.nih.gov/pmc/), web of science (https://www.webofscience.com/wos/woscc/basic-search), DOAJ (https://doaj.org/), and google scholar (https://scholar.google.com/). The literature was searched by using two keywords "Garlic" AND "broiler chickens" as queries in the online platform without being restricted by publication year. The output of articles from each platform was imported to a reference manager for selection purposes following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Liberati et al., 2009). In the initial stage, articles in duplicate and review or non-research articles were excluded from the database. Furthermore, inclusion criteria were developed to assess the quality of the articles referring to a previous meta-analysis (Ogbuewu et al., 2021).

In the present meta-analysis, articles were included in the database if meet the following criteria: (1) *In vivo* study published in a peer-reviewed journal in English; (2) reported the use of dietary garlic, its form, and inclusion level as treatment; (3) reported at least one response variable (body weight gain, BWG; feed intake, FI; feed conversion ratio, FCR; total cholesterol; total triglycerides; low-density lipoprotein, LDL;

and high-density lipoprotein, HDL) with the respective variance (standard deviation, SD or standard error, SE) or allowing to calculate the variable; (4) reported broiler strain used, the number of replication, and the experimental period (day). Once SE is available, SD was calculated from SE by using the equation ($SD = SE \times \sqrt{n}$) (Higgins et al., 2011), where n = number of replications. Studies using other compounds were not included in the database since they may interfere with the outcome variables. In addition, challenged studies using microorganisms or environmental conditions (i.e., heat stress challenged) were not included. The selection process as reported in Fig. 1 resulted in 40 final papers that meet the eligibility criteria and were finally extracted for the database development (Table 1).

A database was developed according to the 30 articles by extracting all information available in the paper. Numerical data from each paper were inputted in a Microsoft Excel spreadsheet while graphical data were extracted with the help of the online tool of WebPlotDigitizer (https://apps.automeris.io/wpd/). For this purpose, general information about author, country, animal strain, sex, number of birds per replicate, study period, the form of garlic or preparation method and the inclusion levels, and composition of diets in each rearing period (starter and finisher) were summarized. In addition, the outcome of interests compiled in the database was body weight (BW), feed intake (FI), feed conversion ratio (FCR), total cholesterol, total triglycerides, LDL, and HDL. The measurement unit for each variable was converted if there is any difference between each other.

Statistical analysis

Meta-analysis was conducted by employing the OpenMEE (http://www.cebm.brown.edu/openmee/index.html), open access, and freely available software for meta-analyses in the area of biology and ecology (Wallace et al., 2017). Means of the experimental units (control vs treatment) were set as continuous outcome data. The data were set in a comma-separated value (CSV) file and then submitted to the software. The effect size of each experimental unit comparing diet with or without garlic supplementation was calculated for each outcome variable with Hedges' g. The random-effects models were used where the data were displayed as standardized mean differences (SMD) between the control and treatment using the following formula:

$$g \cong d \times \left(1 - \frac{3}{4(n1 + n2) - 9}\right)$$

Where n is the sample size of the control and treatment groups (Higgins et al., 2003). The output was presented in a forest plot following a random-effects model at 95% confidence intervals (CIs). Hedges' *g* was selected since it was widely recognized to have strong analytical power when dealing with a relatively small sample size (Galkanda-Arachchige et al., 2020). Hedges' *g* outcome estimates a positive value with $P \leq 0.05$ indicates a significantly higher treatment receiving supplemental garlic compared to control. The heterogeneity index (I^2) was calculated using the DerSimonian and the Laird test (*Q*-statistic) at a significance level of $P \leq 0.05$. The degree of heterogeneity was categorized as no heterogeneity ($0 < I2 \leq 25\%$), low ($25\% < I2 \leq 50\%$), moderate ($50\% < I2 \leq 75\%$), and high ($I2 > 75\%$) (Higgins et al., 2003).

Furthermore, to evaluate covariates that contributed to the models, subgroup analysis was performed to estimate the effect sizes of factors that may contribute to the magnitude of the effect size. In this meta-analysis, country, garlic preparation method or form of garlic, rearing period (starter = 0-10 d; grower = 11-21 d; finisher = >22 d), and strain of broiler chickens were used in the subgroup meta-analysis using

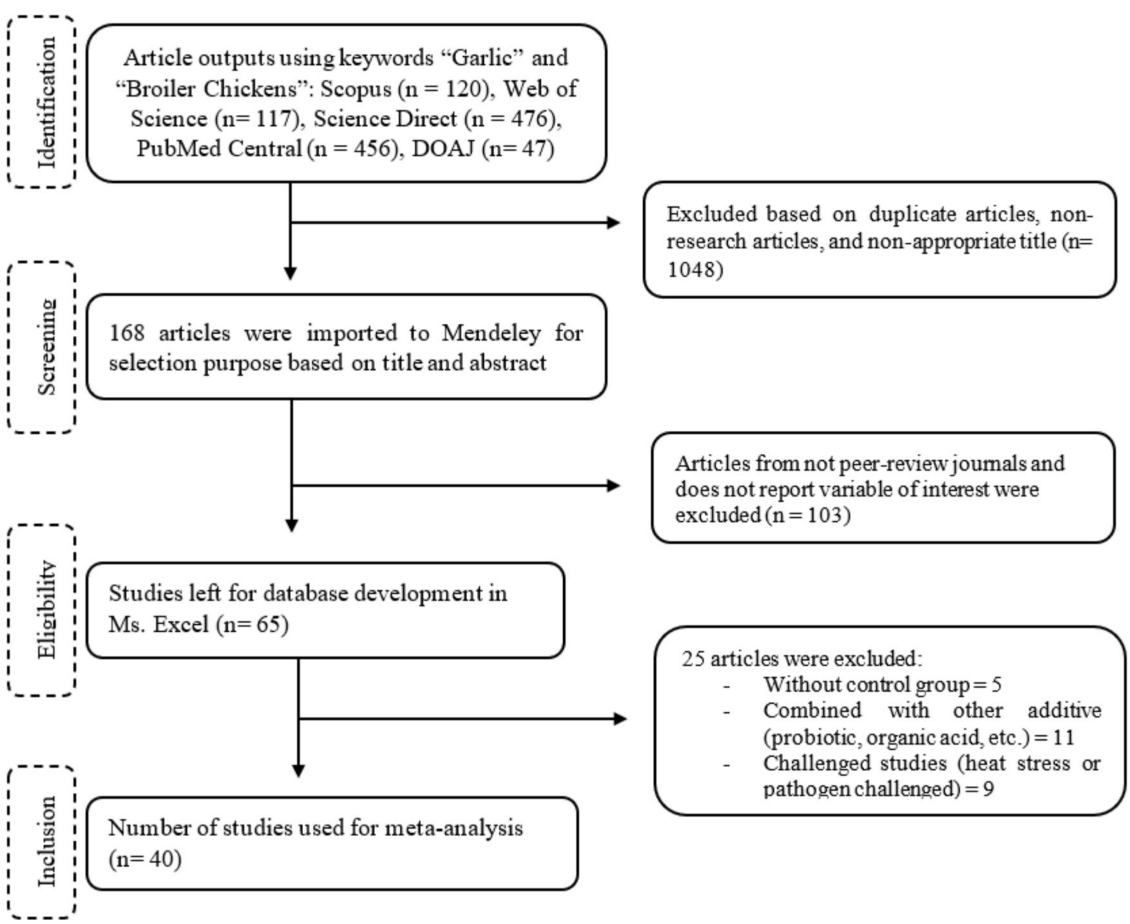

Fig. 1. Flow charts of articles selection process utilized for the meta-analysis.

Table 1
Studies included in the meta-analysis.

Study	Reference	Country	Strain	Sex	Birds	Period	Form of garlic	Level (%)
1	(Konjufca et al., 1997)	Georgia	Ross 308	Male	>200	1 to 21	Garlic powder	0–4.5
2	(Choi et al., 2010)	South Korea	Arbor Acres	Male	>200	1 to 35	Garlic powder	0–5.0
3	(Toghyani et al., 2011)	Iran	Ross 308	Male	>200	1 to 42	Garlic powder	0–0.4
4	(Ramiah et al., 2014)	Malaysia	Cobb 500	Male	>200	1 to 21	Garlic powder	0–0.5
5	(Puvača et al., 2015)	Serbia	Hubbard	–	>200	1 to 14	Garlic powder	0–1.0
6	(Bahadoran et al., 2016)	Iran	Ross 308	–	>200	1 to 14	Garlic powder	0–1.0
7	(Abdullah et al., 2010)	Jordan	Lohmann	Male	>200	14 to 42	Garlic powder	0–1.0
8	(Mansoub et al., 2011)	Iran	Arbor Acres	–	>200	1 to 49	Garlic powder	0–0.4
9	(Milošević et al., 2013)	Serbia	Ross 308	Mixed	>200	1 to 42	Garlic powder	0–3.0
10	(Singh et al., 2015)	India	IBL-80	Mixed	>200	1 to 21	Garlic powder	0–2.0
11	(Navidshad et al., 2018)	Iran	Ross 308	Mixed	>200	1 to 10	Garlic powder	0–1.0
12	(Kharde and Soujanya, 2014)	India	Ven Cobb	Male	>200	1 to 42	Garlic powder	0–0.1
13	(Navidshad et al., 2019)	Iran	Ross 308	Mixed	>200	1 to 10	Garlic powder	0–10.0
14	(Kim et al., 2005)	South Korea	Indian River	Male	>200	1 to 7	Garlic powder	0–10.0
15	(Saeid et al., 2013)	Iraq	Hubbard	–	>200	1 to 42	Garlic powder	0–0.5
16	(Ismail et al., 2021a)	Egypt	Cobb	–	>200	1 to 42	Garlic powder	0–0.08
17	(Horton et al., 1991)	US	Hubbard	Male	< 200	1 to 21	Garlic powder	0–1.0
18	(Ali et al., 2019)	Pakistan	Hubbard	–	>200	1 to 14	Garlic powder	0–1.5
19	(Karangiya et al., 2016)	India	Cobb 400	–	>200	1 to 42	Garlic powder	0–1.0
20	(Kim et al., 2009)	Korea	Arbor Acres	Male	>200	1 to 35	Garlic powder	0–4.0
21	(Varmaghany et al., 2015)	Iran	Arian 386	Male	>200	1 to 42	Garlic powder	0–1.5
22	(Hossain et al., 2014)	South Korea	Ross 308	–	>200	1 to 14	Garlic extract	0–0.2
23	(Fazli et al., 2015)	Iran	Ross 308	–	>200	1 to 42	Garlic extract	0–0.01
24	(Rahimi et al., 2011)	Iran	Ross 308	Male	>200	1 to 42	Garlic extract	0–0.1
25	(Arczewska-Włosek and Świątkiewicz, 2013)	Poland	Ross 308	–	>200	1 to 21	Garlic extract	0–0.08
26	(Amouzmehr et al., 2012)	South Korea	Cobb 500	–	>200	1 to 14	Garlic extract	0–0.6
27	(Ao et al., 2011)	South Korea	Arbor Acres	Male	>200	1 to 21	Fermented Garlic	0–0.4
28	(Dehkordi et al., 2010)	Iran	Ross 308	Male	<200	1 to 50	Fresh garlic	0–2.0
29	(Karimi and Ebadi, 2014)	Iran	Ross 308	–	<200	1 to 10	Garlic powder	0–1.0
30	(Sunu et al., 2021)	Indonesia	NA	Mixed	<200	1 to 35	Garlic extract	0–4.0
31	(Lukanov et al., 2018)	Bulgaria	Ross 308	Male	<200	1 to 35	Garlic extract	0–0.4
32	(Shakeri et al., 2015)	Malaysia	Cobb	Male	<200	1 to 42	Garlic powder	0–0.5
33	(Suriya et al., 2012)	Malaysia	Cobb	Male	<200	1 to 42	Garlic extract	0–1.0
34	(Onibi et al., 2009)	Nigeria	Shaver	Male	>200	1 to 56	Garlic powder	0–0.5
35	(Rastad, 2020)	Iran	Ross 308	Male	>200	1 to 42	Garlic powder	0–1.0
36	(Lee et al., 2016)	South Korea	Ross 308	Male	>200	1 to 35	Fermented Garlic	0–0.5
37	(Javid et al., 2019)	Pakistan	Ross 308	Male	>200	1 to 42	Garlic powder	0–0.25
38	(Elbaz et al., 2021)	Egypt	Ross 308	Male	<200	1 to 35	Garlic powder	0–0.5
39	(Zekic et al., 2014)	Serbia	Hubbard	–	<200	1 to 42	Garlic powder	0–2.0
40	(Singh et al., 2017)	India	IBL-80	Mixed	>200	1 to 35	Garlic powder	0–2.0

random-effects models. However, this subgroup analysis was not carried out for total cholesterol, total triglycerides, LDL, and HDL variables considering that the sample sizes were too small. To assess the effect of supplementary levels, a meta-regression was performed by using a mixed model methodology (St-Pierre, 2001) by using the following statistical model:

$$\Delta Y_i = \beta_0 + \beta_1 X_i + \beta_2 X_i^2 + (\beta_{1\times}\beta_3)X_i + s_i + b_i X + \varepsilon_i,$$

where ΔY_i = estimated outcome of the variable of interest, β_0 = estimated intercept (fixed effect), β_1 = linear regression coefficient of the level of garlic supplementation (fixed effect), β_2 = quadratic regression coefficient of the level of garlic supplementation (fixed effect), $\beta_1 {}_\times \beta_3$ = interaction effect between linear model and covariates, X_i = the level value (continuous predictor variable), s_i = the random effect of the study, b_i = the random effect of study on the regression coefficient of Y on X, and ε_i = the residual error $\sim N(0,\sigma^2)$. This method used the individual study as a random effect and level of garlic. Linear and quadratic terms were evaluated, along with their interactions with covariates (strain, period, garlic form, country) (Irawan et al., 2022). However, we ended up using the linear term and its interaction with rearing periods because the quadratic pattern and the effect of other covariates were not significant for all variables of interest. Each datapoint was adjusted with its corresponding residual value for

In addition to the risk of bias that may appear in the studies, publication bias was assessed by using funnel plots asymmetry. Egger's test was conducted to determine the presence of bias (Egger et al., 1997). Bias among publications was declared to be significant at $P \leq 0.05$. Sensitivity analysis was performed in case the presence of bias was detected. This analysis was done by using the leave-one-out study analysis to compare between-study heterogeneity (I^2) (Higgins et al., 2003) and to determine the effect size of studies contributing to the bias (Nakagawa et al., 2017). Fig. 2 shows the publication bias assessment where most studies are in symmetry form with minimum publication bias. Egger's test confirmed that the publication bias was not significant ($P > 0.05$).

Results

Study characteristics

A total of 40 studies conducted in 16 countries worldwide were aggregated where they were mostly conducted in Iran (13/40), South Korea (6/40), and India (4/40). There was a variety of broiler chickens strains used with Ross 308 being the most frequently used, followed by Cobb (16.6%), and Hubbard (12%). Three forms of garlic were used 32 studies used garlic powder made from fresh garlic, 8 studies used garlic extract, and only two studies used fermented garlic. For each garlic form, garlic extract, and fermented garlic were typically used in small amounts ranging from 0–0.4% in the diet while garlic powder was incorporated up to 10% (Table 2). The descriptive statistics showed that the variability of mean values of variables of interest was due to experimental settings, rearing periods, and environmental conditions, as typically reported in meta-analyses studies. The data in each study were checked to be acceptable according to broiler chickens' normal standard for each rearing phase.

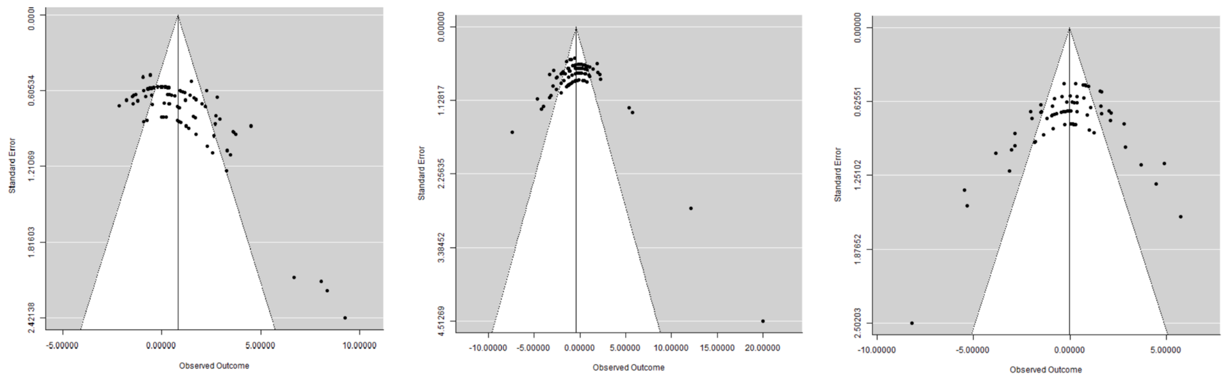

Fig. 2. Funnel plots of the effects of garlic supplement on BWG (a), FI (b), and FCR (c) in broiler chickens.

Table 2

Descriptive statistic of variable of interests used for meta-analysis of the effect of dietary garlic supplementation on body weight gain of broiler chickens.

Variable	Unit	N	Mean	SD	Min	Max
Period	Day	174	36.12	9.30	21.00	50.00
Level	% Diet	174	1.20	2.20	0.00	10.00
ADG	g/d	174	52.08	21.20	9.40	142.30
FCR		150	1.80	0.49	0.59	3.68
FI	g/d	111	90.37	36.56	14.53	172.92
Cholesterol	mg/dL	26	130.78	33.14	54.10	224.70
Triglyceride	mg/dL	23	84.44	48.92	19.30	213.70
HDL	mg/dL	21	61.51	18.56	19.20	111.00
LDL	mg/dL	21	47.69	25.33	0.90	111.70

N = sample size; SD = standard of deviation; Min = minimum value; Max = maximum value; ADG = average daily gain; FCR = feed conversion ratio; FI = feed intake; HDL = high-density lipoprotein; LDL = low-density lipoprotein

Average daily gain

A total of 38 publications satisfy the inclusion criteria in the meta-analysis to estimate the effect of supplemental garlic on the average daily gain (ADG) of broiler chickens as summarized in the Random effects models (REM) analysis in Table 3. Overall estimates of SMD suggested that dietary garlic treatment increased BWG (SMD = 3.239, 95% CI = 2.360 to 4.120, $P < 0.001$). The increase in ADG was consistent across 12 countries being assessed in this meta-analysis while decreasing in ADG was found in Jordan, Poland, Turkey, and Cameroon ($P < 0.001$). However, the studies from these four countries were small and all were only from one study. Garlic powder and garlic extract showed similar increasing results while fermented garlic from two studies ($n = 8$ comparisons) showed a non-significant effect. There was also evidence that in starter, grower, and finisher periods, ADG was increased by garlic supplementation ($P < 0.01$). Similarly, a significant increase was observed in almost all broiler strains ($P < 0.001$). Studies conducted using Lohmann (SMD = -1.867, 95% CI = -3.010 to 0.721, $P = 0.475$) and Shaver (SMD = 1.895, 95% CI = 0.720 to 3.071, $P = 0.099$), however, showed no significant effect on ADG but the sample size was small (n=4 observation units). Heterogeneity was categorized as high in overall pooled estimates ($I^2 = 73.81$, $Q < 0.001$).

Feed intake

Meta-analysis to evaluate the effect of garlic diets on feed intake of broiler chickens was performed using 30 articles where the pooled mean effect estimate was -2.230 (95% CI = -3.141 to -1.320). Overall, there was a decreasing effect of dietary garlic inclusion on FI (Table 4) but high heterogeneity between studies was observed ($I^2 = 99.98$, $Q < 0.001$). Subgroup analysis by countries indicated that garlic supplementation increased FI in South Korea, the USA, and Nigeria ($P < 0.05$). Garlic form, altogether, showed to decrease FI of broiler chickens ($P < 0.001$). However, when looking at the rearing periods, the garlic supplementary effects did not affect FI on starter period (SMD = 0.203; 95% CI = -0.45 to 0.86; $P = 0.545$) but decreased FI on grower (SMD = -3.683; 95% CI = -5.65 to -1.71; $P < 0.001$) and finisher (SMD = -2.858; 95% CI = -4.04 to -1.68; $P < 0.001$). Moreover, treatment using garlic also had significantly decreasing effects on Ross, Cobb, Hubbard, and IBL-80 while absent effects were noticed on Arian 386, Arbor Acres, Lohmann, and Shaver ($P > 0.05$).

Feed conversion ratio

A total of 34 studies consisting of 150 comparisons were eligible for evaluation of the garlic treatment effect on FCR as summarized in Table 5. The pooled effect estimates from SMD revealed that garlic had a significant effect to decrease FCR (SMD = -0.059, 95% CI = -0.080 to -0.040, $P < 0.001$). High heterogeneity within-studies were observed to be 98.15% ($P < 0.001$). Thus, treatment was aggregated to identify the covariates effects (country, garlic preparation form, rearing period, and strain of broiler chickens) by using a subgroup meta-analysis. The subgroup meta-analysis revealed a significant decreased in finisher period (SMD = -0.709, 95% CI= -1.11 to -0.05, $P < 0.001$) but it was not observed in the starter and grower periods ($P > 0.05$). Similar to FI, all garlic forms decreased FCR significantly ($P < 0.05$). When observed in the strains of birds, a decrease in FCR was found in the studies using Ross, Cobb, IBL-80, and Arian 386 ($P < 0.01$), which represented 59.3% of sample studies while the remaining did not show a significant effect ($P > 0.05$). Across countries, most studies showed decreasing trends in FCR ($P < 0.01$) but studies that were conducted in Serbia, Jordan, Poland, Bulgaria, and Nigeria did not show any effect due to garlic supplementation ($P > 0.05$). Most of factors contributing to the effect sizes showed a high heterogeneity ($I^2 > 75\%$, $Q < 0.05$) but no significant publication bias was detected ($P > 0.05$).

Blood lipid profile parameters

Of the 40 studies that satisfy met inclusion criteria for the analysis, 11 studies evaluating garlic effect on total cholesterol were used (Fig. 3). The pooled SMD estimates indicated that dietary garlic inclusion had positive effect to decrease total cholesterol concentration in the serum of broiler chickens (SMD = -11.682, 95% CI = -18.834 to -4.453, $P < 0.001$). In addition, garlic supplementation also reduced triglycerides (SMD = -8.766, 95% CI = -17.394 to -0.138, $P < 0.008$) as quantified from 9 publication (Fig. 4) and LDL concentration (SMD = -5.831, 95% CI = -9.506 to -2.155, $P < 0.001$) by using 9 studies (Fig. 5). By aggregating 9 studies, a positive effect was also observed by the increased of HDL concentration in the serum (SMD = 2.899, 95% CI = 1.240 to 4.558, $P < 0.010$; Fig. 6. Heterogeneity was high for all the lipid profile parameters included in this analysis ($I^2 > 75\%$, $Q < 0.001$).

Table 3
Subgroup meta-analysis comparing the effect of dietary garlic supplementation on average daily gain of broiler chickens.

Covariates	N	SMD	CI 95% Lower	Upper	SE	*P*-value	Heterogeneity I^2	Q
Overall	174	3.239	2.36	4.12	0.448	<0.001	99.48	<0.001
Period								
Starter	52	2.541	1.37	3.71	0.596	<0.001	99.43	<0.001
Grower	27	3.828	2.24	5.41	0.809	<0.001	89.3.0	<0.001
Finisher	95	2.563	1.83	3.30	0.374	<0.001	99.59	<0.001
Garlic form								
Garlic Powder	136	3.286	2.29	4.28	0.506	<0.001	99.48	<0.001
Garlic Extract	30	3.651	1.44	5.87	1.130	0.001	99.49	<0.001
Fermented Garlic	8	0.526	0.11	0.94	0.213	0.013	7.42	0.373
Strain								
Ross	63	3.210	2.21	4.221	0.514	<0.001	98.84	<0.001
Arbor Acres	13	0.307	-1.47	2.09	0.909	0.735	98.06	<0.001
Cobb	29	4.820	2.74	6.897	1.06	<0.001	99.48	<0.001
Hubbard	25	4.633	1.07	8.20	1.820	0.011	99.85	<0.001
Lohmann	3	-1.867	-3.01	-0.72	0.584	0.001	0.00	0.475
IBL-80	6	1.037	0.47	1.60	0.288	<0.001	83.14	<0.001
Indian River	24	0.389	-0.72	1.50	0.566	0.492	86.98	<0.001
Arian 386	7	11.59	7.70	15.49	1.986	0.001	99.35	<0.001
Shaver	4	1.895	0.72	3.07	0.601	0.002	52.25	0.099
Country								
Georgia	13	2.299	1.20	3.40	0.563	<0.001	69.79	<0.001
South Korea	50	2.168	1.32	3.02	0.435	<0.001	83.84	<0.001
Iran	39	5.760	3.63	7.89	1.087	<0.001	99.47	<0.001
Malaysia	8	9.150	2.15	16.16	3.574	0.01	99.83	<0.001
Serbia	8	8.678	2.88	14.47	2.956	0.003	99.84	<0.001
Jordan	3	-1.867	-3.01	-0.72	0.584	0.001	0.00	<0.001
India	10	2.534	0.49	4.58	1.044	0.015	98.89	<0.001
Egypt	10	3.357	1.76	4.95	0.814	<0.001	98.89	<0.001
USA	9	2.064	1.24	2.89	0.423	<0.001	79.30	0.001
Pakistan	10	3.075	-2.63	8.78	2.912	0.291	99.92	<0.001
Poland	2	-3.335	-15.34	8.67	6.125	0.586	99.69	<0.001
Turkey	1	-1.530	-2.42	-0.64	0.456	NA	NA	NA
Cameroon	3	-3.131	-3.86	-2.40	0.373	<0.001	71.10	0.031
Indonesia	2	8.276	-3.89	20.44	6.205	0.182	94.51	<0.001
Bulgaria	1	1.850	-5.02	8.72	3.507	NA	NA	NA
Nigeria	4	1.895	0.72	3.07	0.601	0.002	52.25	0.099

I^2 = heterogeneity within-studies used in meta-analysis; *Q* = p-value for *Q* statistics; CI = confidence interval at 95% (lower and upper); *n* = sample size; SE = standard error; SMD = standardized means difference. Starter = measured between 0-10 d; grower = 11-21 d; finisher = 22 d and after

Meta-regression

Table 6 shows the results of a meta-regression analysis of the dietary garlic inclusion levels on broiler performance and blood lipid profile. The effect of levels of garlic supplementation depended on rearing periods for ADG, FCR, and FI ($P < 0.01$). As shown in Fig. 7, increasing the garlic supplementary levels increased ADG in the finisher period but the magnitude was small ($P < 0.05$; $R^2 = 0.33$). In starter and grower periods, the dietary levels did not affect ADG ($P > 0.05$). FCR and FI were decreased by increasing levels of garlic supplement, especially in finisher periods ($P < 0.05$). There was no linear relationship effect between levels of garlic supplementation and FCR and FI in the starter period ($P > 0.05$). No relationship was observed between supplementary levels and the concentration of cholesterol, triglycerides, HDL, and LDL ($P > 0.05$). All covariates also had no effects on those blood lipid parameters ($P > 0.05$).

Discussion

Growth performance

During the last few decades, explorations of various types of phytobiotics have been increasing. Many studies in poultry have highlighted the benefits attributed to specific phytobiotics, including garlic. In particular, the most recent meta-analysis provided strong evidence that dietary interventions with garlic increased the hen day egg production, egg mass and egg weight, and eggshell thickness without interfering with feed intake and FCR (Ogbuewu et al., 2021). They found that moderating variables such as the country where the experiments were conducted, the strain of the laying hens, age, level of inclusion, and duration of the intervention are the source of heterogeneity that contributed to the variables observed. This meta-analysis is the first study to identify factors contributing to the productive performance response of broiler chickens on garlic feeding intervention that supports the previous findings in laying hens. Dietary levels, rearing periods, form of garlic used as the treatment, strain of broiler chickens, and country where the studies were conducted, were examined. This moderating variable evaluation allows to systematically check the consistency of the efficacy of garlic supplementation. All studies included in the analysis were quality-checked and publication bias was not presented (Egger's test $P > 0.05$).

Under current investigation, positive responses were observed on the increasing of ADG throughout the rearing period (starter, grower, and finisher periods) by 2.54 g/d, 3.83 g/d, and 2.56 g/d, respectively. These findings confirm that garlic can be used as a growth-promoting additive as it has been previously proposed to have growth-enhancing ability attributed to its antimicrobial and antioxidant properties (Ogbuewu et al., 2019). Previous experiments suggested that growth-promoting effects were exhibited in broiler chickens received diets with garlic in replacement for antibiotics without any negative effects on blood profiles and dressing percentage (Mansoub et al., 2011; Ramiah et al., 2014; Toghyani et al., 2011). This is strongly supported by the fact that the positive responses on ADG were consistent under most broiler strains as well as all types of garlic forms supplemented to the diets. Moreover, the impacts of dietary garlic treatment on FI and FCR were dependent on rearing periods but were consistent in all forms of

Table 4
Subgroup meta-analysis comparing the effect of dietary garlic supplementation on feed intake of broiler chickens.

Covariates	N	SMD	CI 95% Lower	Upper	SE	*p*-value	Heterogeneity I^2	Q
Overall	111	-2.230	-3.14	-1.32	0.463	0.001	99.98	<0.001
Period								
Starter	25	0.203	-0.45	0.86	0.335	0.545	96.99	<0.001
Grower	18	-3.683	-5.65	-1.71	1.006	<0.001	92.42	<0.001
Finisher	68	-2.858	-4.04	-1.68	0.602	<0.001	99.99	<0.001
Garlic form								
Garlic Powder	73	-1.751	-2.37	-1.14	0.314	<0.001	98.78	<0.001
Garlic Extract	29	-2.966	-4.19	-1.74	0.625	<0.001	99.45	<0.001
Fermented Garlic	9	-1.748	-4.25	0.76	1.277	0.171	90.65	<0.001
Strain								
Ross	45	-0.948	-1.49	-0.41	0.276	<0.001	96.90	<0.001
Arbor Acres	13	-0.772	-2.64	1.10	0.955	0.419	90.66	<0.001
Cobb	18	-5.286	-6.91	-3.66	0.830	<0.001	99.40	<0.001
Hubbard	16	-3.532	-6.24	-0.83	1.380	0.01	95.09	<0.001
Lohmann	3	-0.333	-7.61	6.94	3.712	0.928	91.29	<0.001
IBL-80	6	-1.437	-2.70	-0.18	0.642	0.025	89.97	<0.001
Arian 386	6	-5.748	-9.71	-1.79	2.020	0.229	90.90	<0.001
Shaver	4	1.962	-1.24	5.16	1.632	0.229	0.00	0.438
Country								
South Korea	27	0.446	0.31	0.58	0.068	<0.001	86.23	<0.001
Iran	37	-1.590	-2.48	-0.70	0.455	<0.001	95.71	<0.001
Malaysia	9	-8.868	-11.02	-6.72	1.096	<0.001	99.97	<0.001
Jordan	3	-0.333	-7.61	6.94	3.712	0.928	91.29	<0.001
India	7	-1.251	-2.35	-0.15	0.563	0.026	87.98	<0.001
Iraq	1	0.150	-3.37	3.67	1.798	NA	NA	NA
USA	9	0.837	-1.90	3.58	1.398	0.549	84.57	<0.001
Pakistan	5	-12.216	-19.58	-4.86	3.755	0.001	94.48	<0.001
Poland	2	-5.933	-9.01	-2.85	1.571	<0.001	91.41	<0.001
Turkey	1	-4.140	-4.15	-4.13	0.006	NA	NA	NA
Cameroon	3	-2.669	-3.64	-1.70	0.493	<0.001	0.00	0.634
Indonesia	2	-3.851	-19.27	11.56	7.864	0.624	98.32	<0.001
Nigeria	4	1.962	-1.24	5.16	1.632	0.229	0.00	0.438
Egypt	1	-0.520	-0.65	-0.39	0.064	NA	NA	NA

I^2 = heterogeneity within-studies used in meta-analysis; Q = p-value for Q statistics; CI = confidence interval at 95% (lower and upper); n = sample size; SE = standard error; SMD = standardized means difference. Starter = measured between 0-10 d; grower = 11-21 d; finisher = 22 d and after

garlic and most of the strains used, indicating that the physiological phase of broiler chickens responded differently to the biological effect of garlic. This study also showed that the results across the countries were consistent with few inconsistencies, indicating that garlic is appropriate to be supplemented in various conditions. The previous meta-analysis has suggested that environmental factors largely contribute to the discrepancies across studies (Ogbuewu et al., 2021), but the environmental factors' effect was minimum in this study.

Our findings were supported by previous research conducted in a controlled environmental house in various regions. For example, an experiment in Egypt suggested that garlic supplemented at 0.25 to 0.75 g/kg diets increased BW both in the starter and finisher period, enhanced immunity, antioxidant capacity, and blood biochemistry parameters (Ismail et al., 2021b). Similarly, an increase in production performance was also reported in studies conducted in India, Malaysia, and South Korea (Hossain et al., 2014; Karangiya et al., 2016; Ramiah et al., 2014) where broiler chickens were reared in a controlled-temperature room. Meanwhile, study under commercial farm conditions in Jordan, garlic interventions resulted in lower final BW (Abdullah et al., 2010). Indeed, the conclusion obtained from a commercial broiler farm condition needs to be validated with more trials since it might be susceptible to environmental errors during the experiment than that of controlled-trial studies. Thus, a negative result from one study in this research cannot be utilized as a basis for global implications. Broiler chickens are sensitive to environmental conditions where a maximal genetic potential can be achieved only when the birds grow in their optimal environmental condition (Tahamtani et al., 2020). The environmental factors include microclimate parameters (temperature, relative humidity, and wind velocity), litter types, and drinking water quality which greatly vary among countries (Zaghari et al., 2011).

Regarding the growth-enhancing ability, several modes of action have been proposed associated with garlic growth-promoting effects in broiler chickens including antimicrobial, hypocholesterolemic, and antioxidant (Kothari et al., 2019; Ogbuewu et al., 2019; Puvača et al., 2015). Garlic was reported to contain a large number of functional properties, such as sulfur-containing compounds, essential oils (EO), and polyphenol compounds (Puvača et al., 2015). Though less, non-sulfur components are also present to work synergistically in enhancing broiler performance and health status (Amagase et al., 2001). Several classes of organosulfur components such as cysteines, S-alk(en)yl-L--cysteine sulfoxides (ACSOs), thiosulfate, and sulfides and their derivatives have been well-studied for antimicrobial agents. They have been proposed to have multiple inhibitory effects on microbial cells as well as act as an antioxidant (Anthony et al., 2005; Ogbuewu et al., 2019; Velkers et al., 2011). Previous research has reported that garlic is effective to inhibit pathogenic bacteria such as *Clostridium, Staphylococcus aureus, Bacillus subtilis, Escherichia coli, Salmonella*, etc., and fungus such as *Saccharomyces cerevisiae* (Leontiev et al., 2018; Rehman and Munir, 2010). In addition, the presence of EO and polyphenols have suggested involving many metabolic pathways which can enhance lipid metabolism, stimulate digestive enzyme secretion and activity, and enhance the gut integrity of broiler chickens (Brenes and Roura, 2010; Irawan et al., 2020). A study using garlic oil was reported to suppress the population of *Clostridium* in the small intestine of broiler chickens (Kirkpinar et al., 2011). These inhibitory effects consequently improve the gut microbial balance of broiler chickens.

Furthermore, balancing gut microorganisms is beneficial for the host and maybe resulted in increasing digestive enzyme secretion whilst improving intestinal morphology and nutrient absorption, and metabolism and therefore improving the growth of broiler chickens (Kothari et al., 2019). Such evidence was reported in several experiments whereas garlic supplementation enhanced intestinal epithelium

Table 5
Subgroup meta-analysis comparing the effect of dietary garlic supplementation on feed conversion ratio of broiler chickens.

Covariates	N	SMD	CI 95%		SE	*P*-value	Heterogeneity	
			Lower	Upper			I^2	*Q*
Overall	150	-0.059	-0.08	-0.04	0.011	0.001	98.15	<0.001
Period								
Starter	42	-0.013	-0.04	0.02	0.014	0.367	97.94	<0.001
Grower	28	-0.069	-0.16	0.02	0.044	0.022	98.20	<0.001
Finisher	80	-0.079	-0.11	-0.05	0.017	<0.001	97.97	<0.001
Garlic form								
Garlic Powder	112	-0.068	-0.10	-0.04	0.015	<0.001	98.39	<0.001
Garlic Extract	29	-0.032	-0.06	0.00	0.014	0.025	96.55	<0.001
Fermented Garlic	9	-0.026	-0.05	0.00	0.012	0.037	45.90	0.063
Strain								
Ross	58	-0.072	-0.10	-0.04	0.014	<0.001	97.56	<0.001
Arbor Acres	13	-0.012	-0.09	0.07	0.041	0.771	98.81	<0.001
Cobb	19	-0.048	-0.08	-0.02	0.015	0.001	92.21	<0.001
Hubbard	17	-0.062	-0.20	0.08	0.072	0.39	99.56	<0.001
Lohmann	3	0.033	-0.03	0.10	0.033	0.317	80.80	0.005
IBL-80	6	-0.085	-0.12	-0.06	0.015	<0.001	80.82	<0.001
Indian River	24	-0.015	-0.05	0.02	0.018	0.418	82.92	<0.001
Arian 386	6	-0.163	-0.24	-0.09	0.037	<0.001	84.95	<0.001
Shaver	4	-0.075	-0.20	0.05	0.062	0.231	58.47	0.065
Country								
Georgia	13	-0.056	-0.10	-0.01	0.024	0.019	97.09	<0.001
South Korea	51	-0.037	-0.08	0.00	0.020	0.009	79.09	<0.001
Iran	34	-0.133	-0.21	-0.06	0.038	<0.001	97.37	<0.001
Malaysia	8	-0.094	-0.20	0.01	0.052	0.070	91.73	<0.001
Serbia	8	-0.143	-0.30	0.02	0.082	0.081	99.72	<0.001
Jordan	3	0.033	-0.03	0.10	0.033	0.317	80.80	0.005
India	9	-0.075	-0.09	-0.06	0.010	<0.001	83.60	<0.001
Iraq	1	-0.130	-0.69	0.43	0.284	NA	NA	NA
USA	3	-0.087	-0.11	-0.06	0.013	<0.001	0.00	0.939
Pakistan	7	0.349	0.33	0.37	0.010	<0.001	0.00	0.712
Poland	2	0.110	-0.36	0.58	0.240	0.646	99.57	<0.001
Cameroon	3	0.100	0.07	0.13	0.015	<0.001	38.10	0.199
Indonesia	2	-0.161	-0.30	-0.02	0.070	0.022	90.43	0.001
Bulgaria	1	-0.080	-0.43	0.27	0.176	NA	NA	NA
Nigeria	4	-0.075	-0.20	0.05	0.062	0.231	58.47	0.065
Egypt	1	-0.040	-0.12	0.04	0.043	NA	NA	NA

I^2 = heterogeneity within-studies used in meta-analysis; *Q* = p-value for *Q* statistics; CI = confidence interval at 95% (lower and upper); *n* = sample size; SE = standard error; SMD = standardized means difference. Starter = measured between 0-10 d; grower = 11-21 d; finisher = 22 d and after

structure as measured by villus height, crypt depth, and goblet cell number (Abdullah et al., 2010; Reisinger et al., 2011; Saeid et al., 2013; Singh et al., 2017). An increase in the surface area of the intestine is important for higher nutrient absorption. This is in agreement with the present meta-analysis showing that broiler chickens assigned to diets containing garlic powder had lower FCR and higher BWG with comparable FI. These results indicate that feed efficiency and nutrient absorption are higher in the garlic treatment group. Although the current findings fit with available theoretical backgrounds on the positive correlation between intestinal morphological indices with higher nutrient utilization, nevertheless, the mechanistic reason for better growth performance effect via improvement of nutrient metabolism remains unclear. To our knowledge, a study evaluating the impact of garlic on nutrient digestibility is limited so far. Therefore, it is important to further investigate the direct effect of garlic on digestibility and to more extent on the digestive enzyme secretion and activity.

Blood lipids profile

Results on blood lipid profiles provide strong evidence that garlic supplementation can enhance the lipid profile of broiler chickens by lowering total cholesterol, triglycerides, and LDL while increasing the HDL concentration. It has been well-reported in the literature that the main benefit attributed to garlic is its hypolipidemic, hypocholesterolemic, and antioxidant effects both in humans and animals (Ismail et al., 2021b; Kothari et al., 2019; Ogbuewu et al., 2019). Meats with lower cholesterol and LDL contents benefit human health because they can reduce the risk of atherosclerosis and cardiovascular diseases for consumers (Kothari et al., 2019). Researchers have speculated that garlic has an inhibitory effect on key enzymes involved in cholesterol synthesis including hydroxymethylglutaryl-Coenzyme A reductase, cholesterol 7a-hydroxylase, and fatty acid synthetase (Canogullari et al., 2010; Mahmoud et al., 1984; Qureshi et al., 1983). In addition, recent studies have also reported that garlic essential oil can act as an effective antioxidant by reducing TBARS and inhibiting DPPH-free radicals in the breast muscle of the broiler (Amiri et al., 2021). Previous studies using garlic powder also showed to similar effect on reducing TBARS and pH in the thick muscle of broiler chickens, confirming the antioxidant activity presented in garlic material (Choi et al., 2010). Other possible reasons can be attributed to the steroidal saponins that may inhibit the absorption of cholesterol in the intestine thus decreasing blood cholesterol concentration or via a direct effect on cholesterol formation (Sobolewska et al., 2016). This reason was supported by an experiment using compounds containing an allyl-disulfide or allyl-sulfhydryl group that successfully inhibited cholesterol synthesis probably due to mediation of sterol 4a-methyl oxidase (Singh and Porter, 2006).

The depressive effect on cholesterol synthesis implies the increase in dressing percentage and decreasing abdominal fat content in broiler chickens as reported by several previous studies. The inclusion of garlic powder was reported to decrease cholesterol in serum, breast, and thigh muscle, and increase breast meat weight (Milošević et al., 2013). Similarly, supplementing garlic powder to broiler diets up to 5% or fermented garlic resulted in lower cholesterol and LDL concentration and greater HDL concentration (Ao et al., 2011; Choi et al., 2010). Garlic is also exhibited to enhance oxidative stability of broiler meat as indicated by the decrease of TBARS level. Garlic is rich in bioactive components

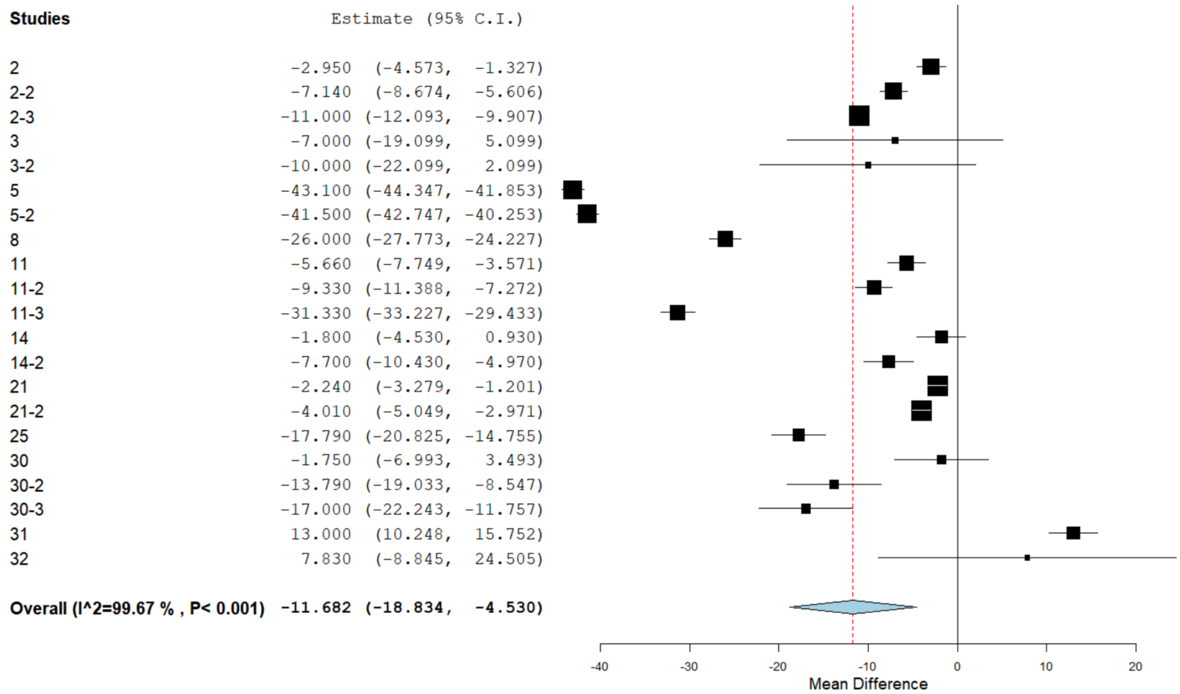

Fig. 3. Forest plot of the effect of garlic supplementation on total blood cholesterol concentration of broiler chickens. SMD = Standardized means difference; CI = Confidence interval; I^2 = Inconsistency or heterogeneity index. The diamond at the base showing the pooled SMD estimation at 95% CI. Studies are listed as number according to Table 1 with dash-number represents the number of comparisons in each study.

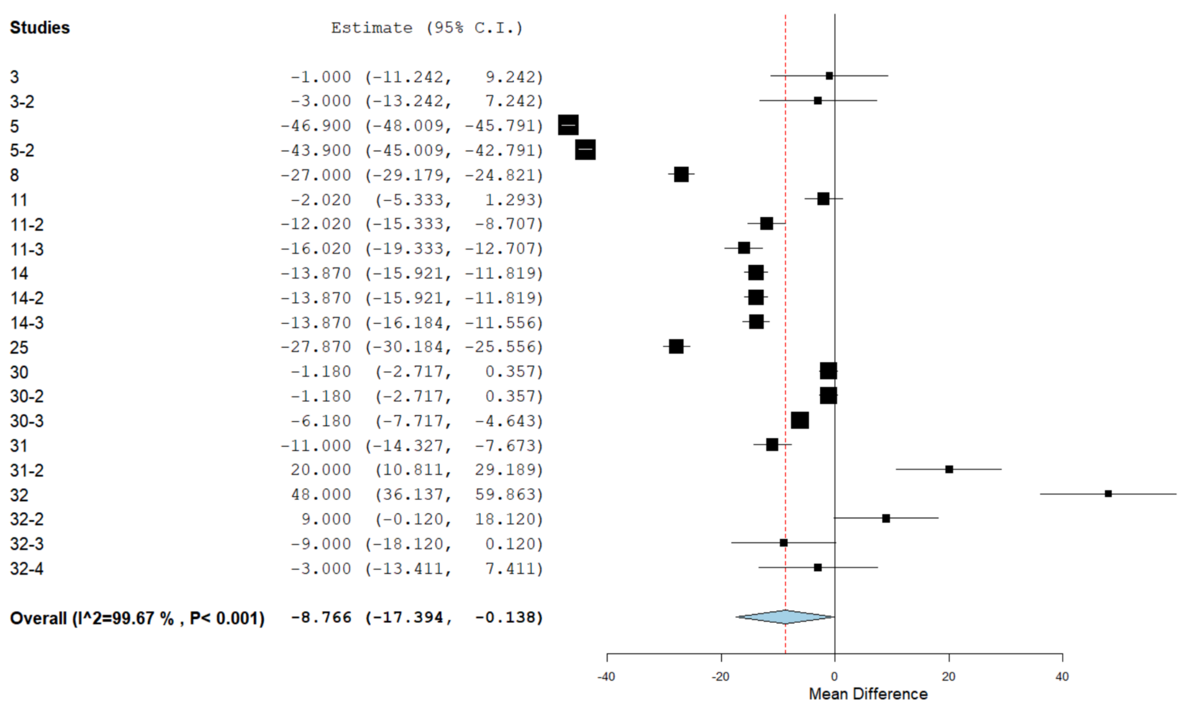

Fig. 4. Forest plot of the effect of garlic supplementation on blood triglycerides concentration of broiler chickens. SMD = Standardized means difference; CI = Confidence interval; I^2 = Inconsistency or heterogeneity index. The diamond at the base showing the pooled SMD estimation at 95% CI. Studies are listed as number according to Table 1 with dash-number represents the number of comparisons in each study.

such as flavonoid and organosulfur compounds with high antioxidant activity (Puvača et al., 2015). The antioxidant effects of these compounds have been confirmed in this study as reflected by the lower cholesterol and LDL concentration in response to garlic supplementation.

Conclusion

The present meta-analysis demonstrated that growth-promoting, hypolipidemic and hypocholesterolemic effects are greatly associated with dietary garlic supplementation in broiler chickens. Garlic inclusion, in any preparation form, improved average daily gain especially in

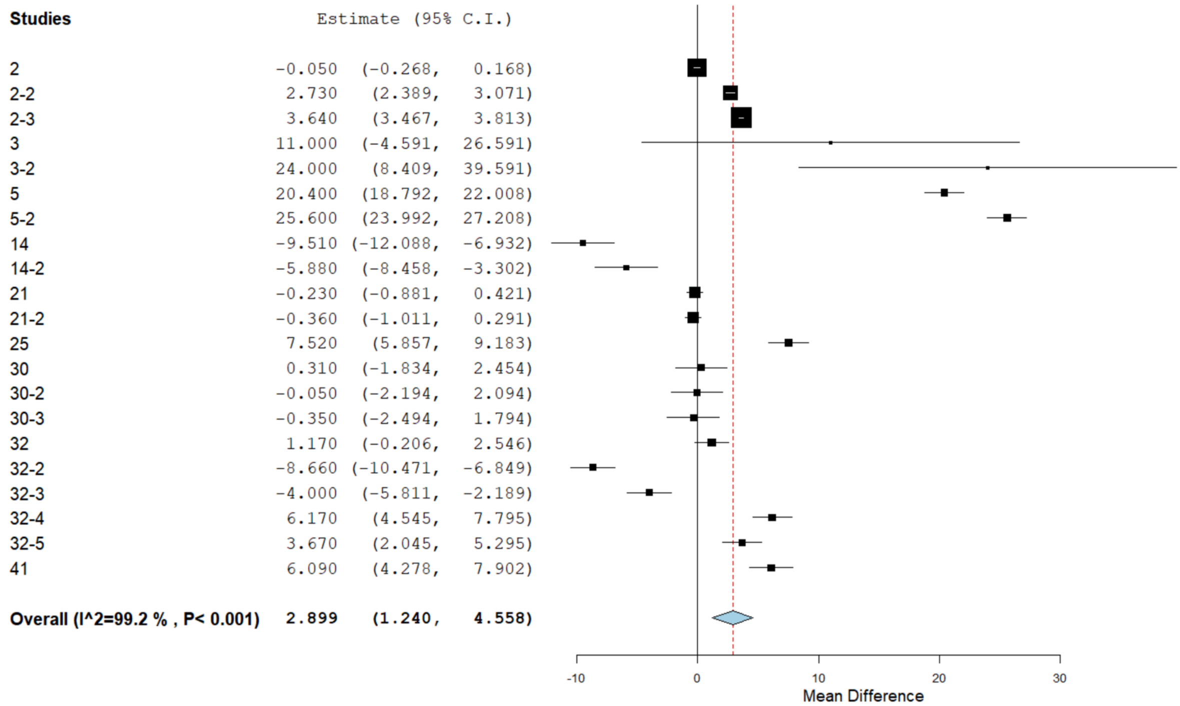

Fig. 5. Forest plot of the effect of garlic supplementation on blood high-density lipoprotein (HDL) concentration of broiler chickens. SMD = Standardized means difference; CI = Confidence interval; I^2 = Inconsistency or heterogeneity index. The diamond at the base showing the pooled SMD estimation at 95% CI. Studies are listed as number according to Table 1 with dash-number represents the number of comparisons in each study.

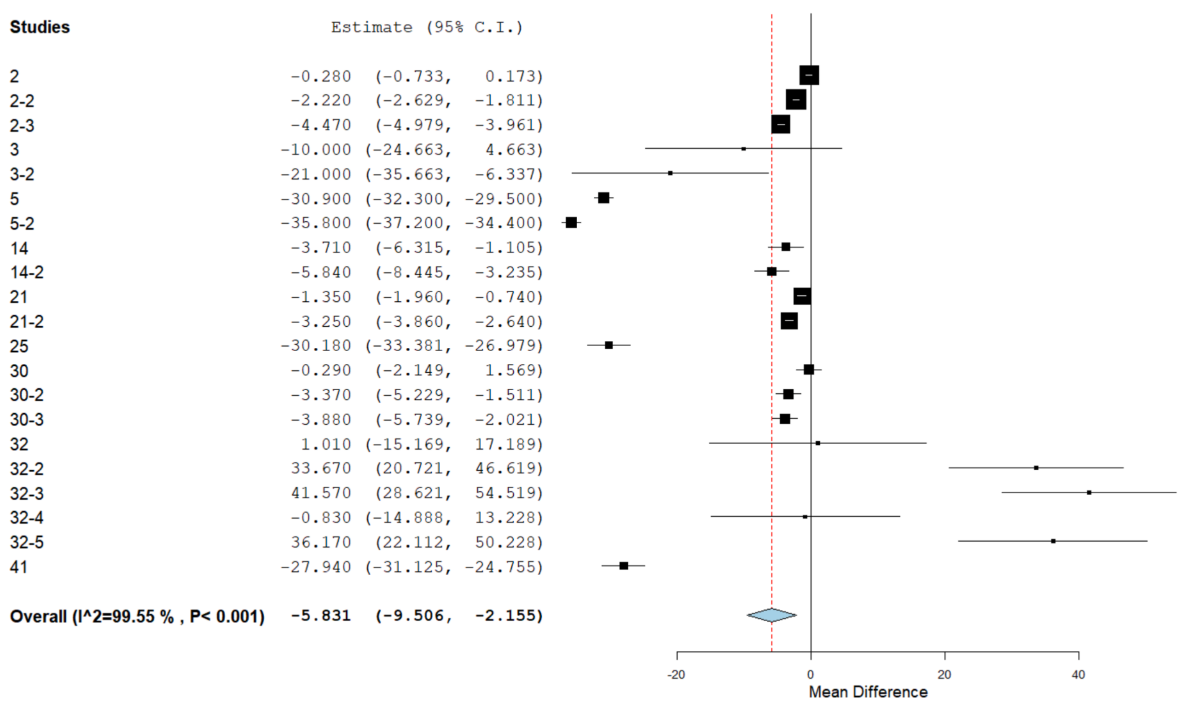

Fig. 6. Forest plot of the effect of garlic supplementation on blood low-density lipoprotein (LDL) concentration of broiler chickens. SMD = Standardized means difference; CI = Confidence interval; I^2 = Inconsistency or heterogeneity index. The diamond at the base showing the pooled SMD estimation at 95% CI. Studies are listed as number according to Table 1 with dash-number represents the number of comparisons in each study.

grower and finisher periods. However, it should be noted that high levels of garlic supplementation are typically unfavorable because it would decrease feed intake. Few inconsistent results were found to be attributed to different environmental factors. In addition, positive effects on lowering cholesterol, triglycerides, and LDL while increasing HDL concentration are confirmed as shown by the pooled SMD estimates of each variable. Further study to evaluate low doses of specific bioactive compounds inclusion from garlic on broiler performance and health is warranted to minimize the deleterious effect on feed intake.

Table 6
Meta-regression analysis of the supplementary levels effect of garlic on broiler chickens' performance and blood lipid profile.

Response variable	Unit	N	Model	Parameter estimates				Model statistics			*P*-value	
				Intercept	SE intercept	Slope	SE slope	AIC	RMSE	R^2	L	L x Period
ADG	g/d	174	L	49.53	1.829	-3.622	0.829	2083	20.89	0.269	0.587	<.0001
FCR		150	L	1.77	0.060	-0.067	0.023	316	0.491	0.198	0.049	0.001
FI	g/d	111	L	89.2	3.425	-7.089	2.400	1598	36.64	0.085	0.004	<.0001
Cholesterol	mg/dL	26	L	134.40	9.648	5.418	18.41	344	33.50	0.006	0.771	0.718
Triglyceride	mg/dL	23	L	85.47	16.13	7.044	13.99	276	48.76	0.039	0.621	0.521
HDL	mg/dL	21	L	60.80	4.017	-7.386	15.59	265	18.52	0.037	0.641	0.572
LDL	mg/dL	21	L	48.32	7.149	7.378	13.64	268	25.34	0.031	0.596	0.542

N = sample size; RMSE = root means squared error; AIC = Akaike information criterion; L = P-value of the linear term; L × Period = *P*-value of the interaction effect between linear term and rearing period of broiler chickens; ADG = average daily gain; FCR = feed conversion ratio; FI = feed intake; HDL = high-density lipoprotein; LDL = low-density lipoprotein

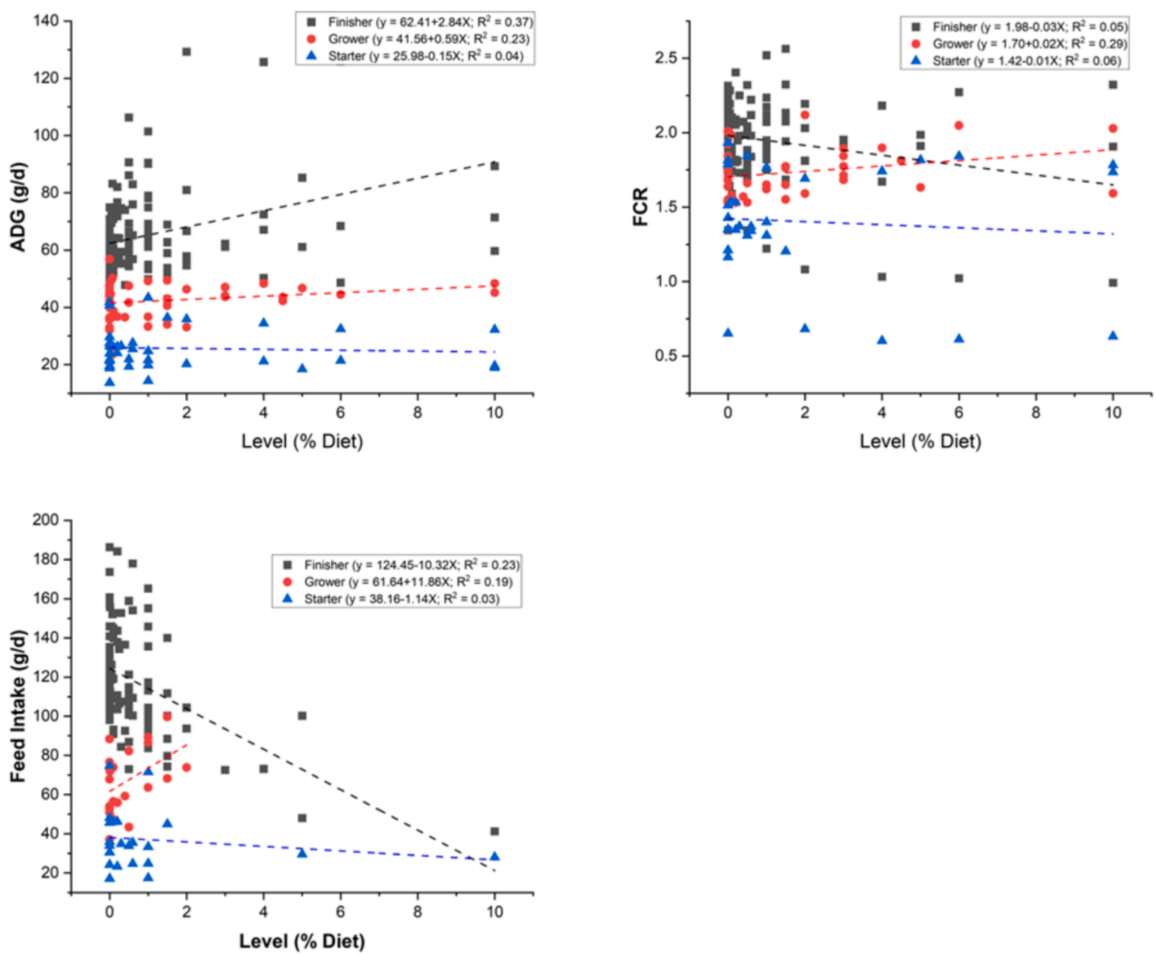

Fig. 7. Relationship between inclusion levels of garlic in the diets and ADG, FCR, and FI of broiler chickens according to the rearing periods. The relationships were constructed based on mixed effect model.

Data and model availability statement

All data included in this study are available upon request by contacting the corresponding author.

CRediT authorship contribution statement

R.K. Rusli: Data curation, Validation, Investigation, Methodology, Writing – original draft. **S. Sadarman:** Validation, Investigation, Project administration, Writing – review & editing. **C. Hidayat:** Validation, Writing – review & editing. **M.M. Sholikin:** Formal analysis, Software, Validation, Writing – review & editing. **M. Hilmi:** Project administration, Writing – review & editing. **A. Yuniza:** Project administration, Writing – review & editing. **R. Mutia:** Project administration, Writing – review & editing. **A. Jayanegara:** Supervision, Validation, Writing – review & editing. **A. Irawan:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.livsci.2022.105022.

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