Pertanika J. Trop. Agri. Sci. 47 (3): 759 - 780 (2024)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Meta-analysis of the Use of Leaf Extract as Alternative Growth Promoter in Broiler Chickens

Bella Putri Maharani[1], Hafi Luthfi Sanjaya[1], Aji Praba Baskara[1], Bambang Ariyadi[2], Zuprizal[1] and Nanung Danar Dono[1]*

[1]*Department of Animal Nutrition and Feed Science, Faculty of Animal Science, Universitas Gadjah Mada, 55281, Special Region of Yogyakarta, Indonesia*

[2]*Department of Animal Production, Faculty of Animal Science, Universitas Gadjah Mada, 55281, Special Region of Yogyakarta, Indonesia*

ABSTRACT

Plants, especially on the leaves, have various bioactive compounds capable of becoming natural growth promoters. Plant leaf extracts have been widely studied for their ability as an antibiotic substitute for broiler chickens. This meta-analysis study was aimed to assess the effectiveness of supplementations with leaf extract on the growth performance of broiler chickens, using average daily feed intake (ADFI), average daily gain (ADG), final body weight (FBW), and feed conversion ratio (FCR) as responses observed criteria. The meta-analysis study was based on the articles published from 2006 to recent years as several countries started to ban in-feed antibiotics. Databases (PubMed, Scopus, Directory of Open Access Journals [DOAJ], and ScienceDirect) were searched for peer-reviewed randomised controlled trials (RCTs) published in English. The meta-analysis included 19 research papers that met the criteria. Overall results showed a significant increase ($P < 0.001$) in ADFI by 0.56 g/day (95% confidence interval [CI] = 0.02 to 1.11), in ADG by 1.57 g/day (95% CI = 0.77 to 2.36), and in FBW by 2.28 (95% CI = 1.40 to 3.16). At the same time, the FCR was reduced ($P < 0.001$) by -1.25 (95% CI = -1.76 to -0.73) relative to controls taking cognisance of publication bias and heterogeneity. Results in the current meta-analysis study indicated that herbal feed additives were proven to be effective as growth promoters in broiler chickens.

Keywords: Broiler chickens, growth promoter, leaves extract, meta-analysis

ARTICLE INFO

Article history:
Received: 06 December 2023
Accepted: 23 January 2024
Published: 08 August 2024

DOI: https://doi.org/10.47836/pjtas.47.3.11

E-mail addresses:
bellaputrimaharani@mail.ugm.ac.id (Bella Putri Maharani)
hafi.luthfi.s@mail.ugm.ac.id (Hafi Luthfi Sanjaya)
aji.praba.b@mail.ugm.ac.id (Aji Praba Baskara)
bambang.ariyadi@ugm.ac.id (Bambang Ariyadi)
zuprizal@ugm.ac.id (Zuprizal)
nanungdd@ugm.ac.id (Nanung Danar Dono)
*Corresponding author

ISSN: 1511-3701
e-ISSN: 2231-8542

INTRODUCTION

Phytogenic feed additives (PFAs), which are also known as herbs or phytobiotics (Gheisar and Kim, 2018), are less toxic and less residue natural bioactive substances found in the organs of some plants (M. L. Wang et al., 2008). Research by Windisch et al. (2008) has shown that the potency of dietary leaf extract can change with the presence of in-feed antibiotics. Another study (Mohamed and Hassan, 2023) showed that dietary PFAs showed promising results in the growth performance of broiler chickens. Improved growth performance by including plant materials in the diet occurs due to the increased nutrient digestibility, digestive enzyme activities, and reduced intestinal pathogens, which allow increased availability of essential nutrients in the intestine for absorption and helps improve growth performance (Hasemi et al., 2008). The principal mode of action of phytobiotics arises from the beneficial influence of the gastrointestinal microbiota ecosystem through controlling potential pathogens (Meng et al., 2023; Qureshi et al., 2015), improving immunodeficiency and intestinal vegetation (Chen et al., 2020), as well as enhance intestinal tract performance associated with villus height and crypt depth improvement (Song et al., 2023).

Several studies recommended a potential part of phytogenic as safe growth promoters in poultry nutrition. Phytogenic possesses some substances that enhance dietary palatability, gut health, growth performance, and meat production (Mohamed and Hassan, 2023). In recent years, several researchers from various countries have explored herbal supplementations in poultry production. Research in tropical countries, such as Indonesia (Anggrain et al., 2014), Malaysia (Basit et al., 2020), India (Kumar et al., 2021), Nigeria (Alabi et al., 2017), and in subtropical countries, such as China (Zhao et al., 2019), Iran (Azimi et al., 2020), and Japan (Nakamura et al., 2022) have shown the beneficial effects of the in-feed herbal additives on growth performance of poultry.

The advantageous multifunctional effects of dietary supplementations with phytogenic feed additives were attributed to the presence of biologically active constituents in plants, such as terpenoids, phenolics, glycosides, and alkaloids (Huyghebaert et al., 2011). In recent years, research on natural plants that can be used as alternative growth performance in broiler chickens has continued to be carried out. Sun et al. (2020) showed that the dietary addition of *Achyranthes japonica* Nakai improved nutrient utilisation, growth performance, and meat quality of broiler chickens. S. J. Liu et al. (2021) found that supplementation of capsicum extract in feed improved nutrient digestibility, immune status, meat quality, and growth performance. Zhang et al. (2022) reported that the dietary addition of *Glycyrrhiza uralensis* Fisch improved immune response, intestinal microflora population, and growth performance. Amongst the organs of plants, leaves were the most used in plant part (38%), followed by fruit (22%), whole plant (9%), rhizome (8%), roots (7%), flowers and bark (4% each), sap (3%), stem and tuber (2% each), and seeds (1%) (Elfrida et al., 2021). These findings prompted researchers to explore the beneficial effects of herbal feed additives as alternative growth promoters for broiler chickens, starting from leaves.

Several studies have shown that the efficacy of herbal feed additives varied due to several variables, such as geographical origin (Kokkini et al., 1994), genotype (Aligiannis et al., 2001), location (Lambert et al., 2001), processing methods (Delespaul et al., 2000), seasonal variations (McGimpsey et al., 1994), and climatic variations (Salgueiro et al., 1997). Therefore, a meta-analysis in this study was carried out from several published data in international journals to evaluate the effect of giving plant leaf extracts on the growth performance of broiler chickens.

MATERIALS AND METHODS

Literature Search and Study Selection

A comprehensive search for studies discussing the effect of leaf extract on broiler productivity was carried out in several scientific web databases, namely PubMed Central (www.ncbi.nlm.nih.gov/pmc/), ScienceDirect (www.sciencedirect.com), DOAJ (https://doaj/org/), and Scopus (www.scopus.com). An article search used the keywords 'leaf extract' and 'broiler performance'. The last search was carried out in February 2023. The criteria for articles to be included in the database were: (1) reporting the use of leaf extracts as a feed additive used to substitute antibiotics, the article must use levels as treatment and control (without additive supplementation), (2) *in vivo* studies on broiler chickens, which were peer-reviewed journals in English, (3) reports at least two performance variables: ADFI, FBW, ADG, and FCR, with the respective variance (standard deviation or standard error), (4) reports the number of replications and broiler strains. Studies using a combination of additive and challenging studies (infection of viruses/diseases, limited consumption, heat stress) were not included.

The selection process reported in Figure 1 resulted in a final paper that met the selection criteria to produce data used as a database (Page et al., 2021), information following the meta-analysis guidelines adopted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The database consisted of 19 studies with 153 treatments, as presented in Table 1. In tabulating data into the database, data relating to the parameters were converted into the same measurement units to facilitate further analyses.

Information includes: (1) name of authors and year of publication, (2) country of origin of research, (3) plant species, (4) solvent used, (5) bird strain, (6) number of birds, (7) study durations, and (8) level of treatments. Measures (standard deviation, standard error, or standard error of mean) of ADFI, ADG, FBW, and FCR were included in the database.

Meta-analysis Procedure

The effect size was calculated as the standardised mean difference (SMD) according to the method of Hedges (1981) for

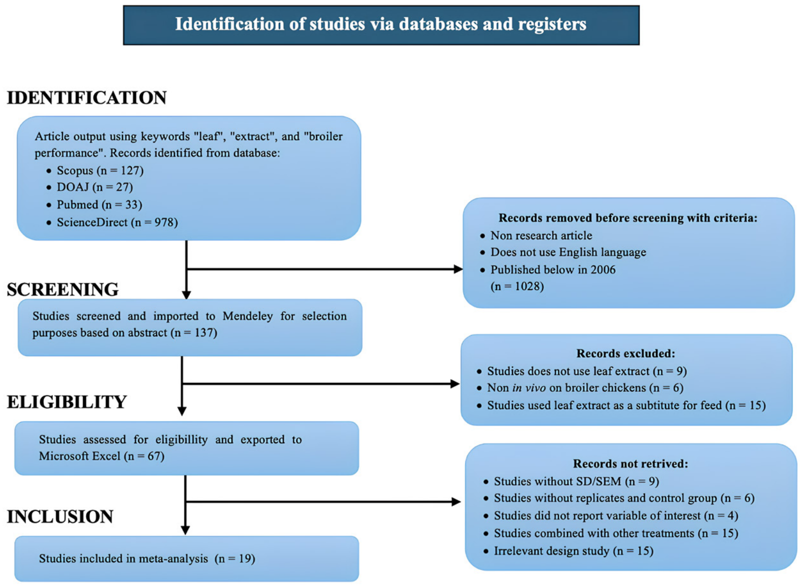

Figure 1. Flow chart of the article selection process utilised for the meta-analysis

Note. SD = Standard deviation; SEM = Standard error of the mean

Table 1
Studies included in the meta-analysis

Study	Reference	Country	Plant species	Solvent	Strain	Birds	Period	Level (ppm)
1	Al-khalaifah et al. (2020)	Egypt	*Allium ampeloprasum*	Ethanol	Hubbard	250	1–42	0–200
2	Al-Masari and Al-Himdany (2022)	Iraq	*Cynara scolymus* L.	Not available	Ross	135	1–42	0–1,000
3	Al Salman and Al-Gharawi (2019)	Iraq	*Eucalyptus viminalis*	Distilled water	Ross	240	1–35	0–8,000
4	Al-Musawi et al. (2019)	Iraq	*Petroselinum sativum*	Water	Ross	240	1–35	0–15,000
5	Alabi et al. (2017)	Nigeria	*Moringa oleifera*	Water	Hubbard	240	1–56	0–150,000
6	Alabi et al. (2020)	Nigeria	*Moringa oleifera*	Water	Hubbard	240	1–42	0–120,000

Table 1 *(Continue)*

Study	Reference	Country	Plant species	Solvent	Strain	Birds	Periods	Level (ppm)
7	Duskaev et al. (2020)	Rusia	*Eucalyptus viminalis*	Distilled water	Abror Acres	120	1–35	0–200
8	Erener et al. (2020)	Turkey	*Olea europeae* L.	35% ethanol	Ross	375	1–42	0–600
9	Fathi et al. (2022)	Iran	*Ocimum basilcum*	80% ethanol	Ross	450	1–42	0–600
10	Khan et al. (2022)	Saudi Arabia	*Moringa oleifera*	Distilled water	Hubbard	350	1–35	0–12,000
11	Onu (2012)	Nigeria	*Telfairia occidentalis*	Water	Marshal	200	8–28	0–16,000
12	Racanicci et al. (2011)	Brazil	*Ilex paraguariensis*	Water	Cobb	100	1–25	0–1,000
13	Rasouli et al. (2020)	Oman	*Salvia officinalis* L.	Water	Ross	300	1–42	0–400
14	Sahu et al. (2017)	India	*Cassia tora*	Methanol	Cobb	90	1–42	0–400
15	Sani et al. (2013)	Iran	*Artemisia annua*	Methanol	Cobb	240	1–42	0–4,000
16	Shen et al. (2019)	China	*Bambusoideae* sp.	Not available	Abror Acres	576	1–42	0–5,000
17	Teteh et al. (2013)	Togo	*Moringa oleiifera*	Ethanol	Ross	615	1–28	0–2,000
18	Xie et al. (2022)	China	*Olea europaea* L.	75% ethanol	Abror Acres	720	1–35	0–5,000
19	Yan et al. (2022)	China	*Eucommia ulmoides*	Water	Wen Tianlu	252	1–51	0–1,000

fixed effect models as well as DerSimonian and Laird (1986) for the random effect model. The classic meta-analysis approach was carried out according to the studies used, which had variables with the same unit of measurement. The calculation was done with the raw mean difference, which allows the interpretation of the effect size in the original unit of measurement (Ranga Niroshan Appuhamy et al., 2013).

Forest plots were made to show the effect of giving plant leaf extracts on the growth performance of broiler chickens, which were represented by points and confidence intervals. Forest reports plots of effect sizes and weighted contributions to the fixed-effect and random-effect study models. The approach to random effects meta-analysis was performed using simple moment-based estimation of the between-study variance (heterogeneity) of the true effect (θ) (DerSimonian & Laird, 1986). Heterogeneity was reported with the I^2 statistic, which correlates with ($\tau 2$) as a percentage of the total variability. The statistical model used in this study was based on a P value with a significant effect indicated by $P < 0.05$. All statistical analysis was performed with OpenMEE software (Wallace et al., 2017).

RESULTS AND DISCUSSION

Study Characteristic

A total of 19 studies conducted in 12 countries worldwide were aggregated, mainly shown in Iraq (15.78%), Nigeria (15.78%), and China (15.78%). Several broiler chicken strains were used, with Ross being the most common (36.84%), followed by Hubbard (21.05%). The solvent used for the leaf extract was water (57.89%). The range used for the studies was 90 to 720 birds, with the highest period 1–42 (47.36%) (Table 1). The level of ≤1,000 ppm (42.11%), followed by 1,000 ≥ 10,000 ppm (31.57%) and 10,000 ≥ 100,000 ppm (26.31%) was included in the experiment. Based on the statistical description, the difference in the values of the average observed parameters was caused by environmental conditions, experimental settings, and housing management reported in meta-analysis studies.

Average Daily Feed Intake

Meta-analysis in the current study evaluated the effects of leaves extract supplementations as a feed additive in broiler chickens was performed using 16 articles that had a significant effect on increasing the average daily feed intake ($P < 0.001$) with SMD value of 0.56 (0.02 to 1.11) and heterogeneity among the studies ($I^2 = 81.95\%$) (Figure 2). Thus, treatment was aggregated to identify the effects of the covariates (strain and species of leaf extract) by using a subgroup meta-analysis. The strain showed an increasing effect on ADFI compared to the control in Ross ($P < 0.005$). The addition of plant extracts made from *Allium ampeloprasum* L., *Petroselinum sativum*, *Eucalyptus viminalis*, and *Bambusoideae* sp. showed increasing ADFI ($P < 0.001$). At the same time, *Artemisia annua* decreased ADFI ($P < 0.001$), as shown in Table 2. The meta-analysis results were in line with several studies showing that plant extract supplementations as a natural feed additive have a trend of increasing daily feed intake compared to controls (Ali et al., 2020; Wallace et al., 2017). Onu (2012) reported that broiler supplementation with *Telfairia occidentalis* resulted in a decrease in ADFI with increasing levels of supplementation.

A subgroup meta-analysis study on the Ross strain supplemented with leaf extract also showed increased ADFI. Supported by the research findings of Rasouli et al. (2020), adding 200 ppm of *Salvia officinalis* L. extract increased ADFI. However, the results differ from those of Alabi et al. (2020), i.e., an increase in supplementation leaf extract can affect lower daily consumption compared to controls. Overall, the phytochemical compound in the leaf extract caused an improved ADFI value.

Studies	Estimate	(95% C.I.)	
Al-Khalaifah et al. (2020)	50.329	(28.237,	72.421)
Al-Khalaifah et al. (2020)-2	80.531	(45.215,	115.846)
Al-Khalaifah et al. (2020)-3	82.895	(46.544,	119.245)
Al-Khalaifah et al. (2020)-4	74.336	(41.734,	106.938)
Al-Masari and Al-Himdany (2022)	1.765	(-0.121,	3.652)
Al-Masari and Al-Himdany (2022)-2	6.240	(2.364,	10.117)
Al-Musawi et al. (2019)	4.200	(1.335,	7.065)
Al-Musawi et al. (2019)-2	7.385	(2.911,	11.860)
Al-Musawi et al (2019)	10.100	(4.166,	16.034)
Al-Salman and Al-Gharawi (2019)	4.746	(1.620,	7.872)
Al-Salman and Al-Gharawi (2019)-2	8.006	(3.202,	12.809)
Al-Salman and Al-Gharawi (2019)-3	8.562	(3.460,	13.663)
Alabi et al. (2017)	0.266	(-1.126,	1.658)
Alabi et al. (2017)-2	-0.382	(-1.781,	1.016)
Alabi et al. (2017)-3	0.382	(-1.016,	1.781)
Alabi et al. (2017)-4	0.041	(-1.345,	1.427)
Duskaev et al. (2020)	8.477	(3.421,	13.533)
Duskaev et al. (2020)-2	3.749	(1.092,	6.406)
Duskaev et al. (2020)-3	7.406	(2.921,	11.892)
Erener et al. (2019)	-0.220	(-1.464,	1.023)
Erener et al. (2019)-2	0.073	(-1.167,	1.313)
Erener et al. (2019)-3	1.395	(0.013,	2.777)
Erener et al. (2019)-4	3.670	(1.639,	5.701)
Fathi et al (2022)	-0.137	(-1.378,	1.104)
Fathi et al (2022)-2	-0.181	(-1.423,	1.061)
Khan et al (2021)	-0.007	(-1.247,	1.233)
Khan et al (2021)-2	0.079	(-1.161,	1.319)
Khan et al (2021)-3	0.048	(-1.192,	1.288)
Onu (2012)	-1.218	(-2.727,	0.291)
Onu (2012)-2	-1.245	(-2.759,	0.269)
Onu (2012)-3	-0.625	(-2.045,	0.794)
Onu (2012)-4	-0.851	(-2.298,	0.596)
Racanicci et al. (2011)	0.448	(-0.807,	1.703)
Racanicci et al. (2011)-2	-0.571	(-1.836,	0.693)
Racanicci et al. (2011)-3	-0.552	(-1.815,	0.711)
Rasouli et al. (2020)	-3.460	(-5.989,	-0.932)
Rasouli et al. (2020)-2	-1.518	(-3.334,	0.298)
Rasouli et al. (2020)-3	-2.455	(-4.574,	-0.336)
Rasouli et al. (2020)-4	0.906	(-0.775,	2.586)
Sahu et al. (2017)	0.875	(-0.801,	2.550)
Sani et al. (2013)	-4.127	(-6.756,	-1.497)
Sani et al. (2013)-2	-5.288	(-8.436,	-2.139)
Shen et al. (2019)	1.482	(0.205,	2.760)
Shen et al. (2019)-2	2.661	(1.108,	4.215)
Shen et al. (2019)-3	1.062	(-0.147,	2.270)
Shen et al. (2019)-4	0.749	(-0.422,	1.919)
Shen et al. (2019)-5	2.065	(0.664,	3.466)
Teteh et al. (2013)	0.230	(-1.161,	1.620)
Teteh et al. (2013)-2	-0.269	(-1.662,	1.123)
Xie et al. (2022)	-0.948	(-2.142,	0.245)
Xie et al. (2022)-2	0.145	(-0.988,	1.278)
Xie et al. (2022)-3	0.697	(-0.469,	1.862)
Xie et al. (2022)-4	-7.192	(-10.283,	-4.100)
Xie et al. (2022)-5	-1.267	(-2.506,	-0.027)
Yan et al. (2022)	-0.639	(-1.799,	0.521)
Yan et al. (2022)-2	-0.687	(-1.851,	0.478)
Overall (I^2=81.95 % , P< 0.001)	**0.564**	**(0.019,**	**1.108)**

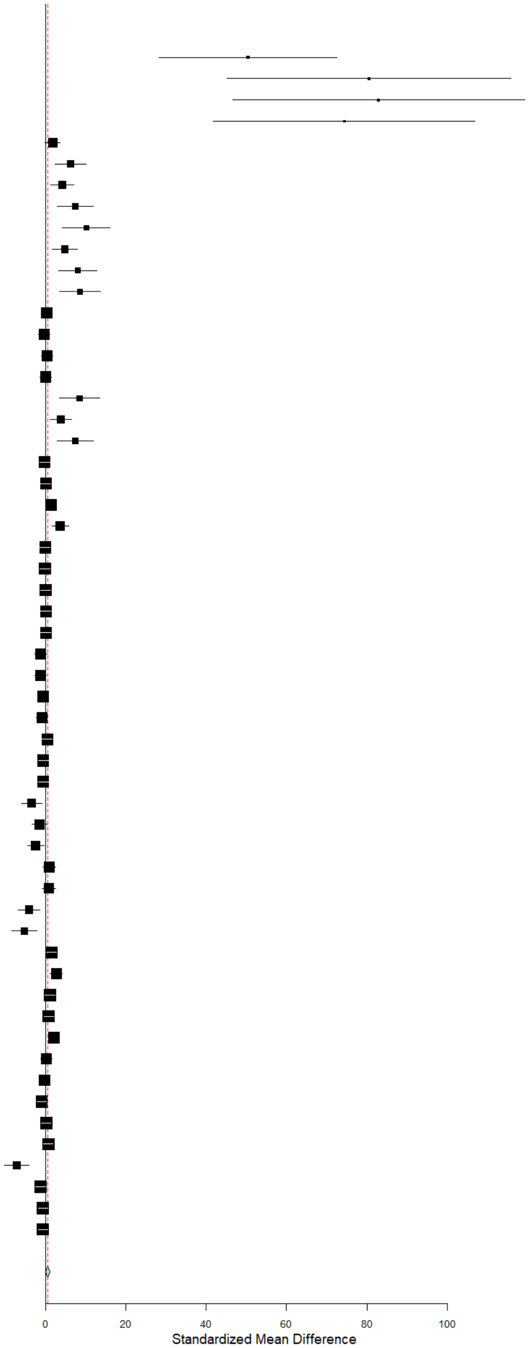

Figure 2. Forest plot of the effect of feeding leaves extract on ADFI of broiler chickens

Table 2

Subgroup analysis of the effect of leaf extract supplementation on average daily feed intake of broiler chickens

Covariates	N	SMD	95% CI		SE	*P*-value	Heterogeneity	
			Lower	Upper			I^2	*P*-value
Strain								
Hubbard	11	0.98	-0.79	2.75	0.90	0.29	87.55%	<0.001
Ross	20	1.48	0.48	2.49	0.51	<0.01	80.96%	<0.001
Arbor Acres	13	0.97	-0.13	2.07	0.56	0.08	84.45%	<0.001
Marshal	6	-0.97	-1.71	-0.24	0.36	0.01	0%	0.92
Cobb	4	-1.07	-2.46	0.32	0.71	0.13	76.18%	0.001
Wen Tialu Black	2	-0.66	-1.49	0.16	0.42	0.11	0%	0.96
Leaf extract								
Allium ampeloprasum	4	67.43	50.70	84.20	8.55	<0.001	18.13%	0.30
Cynara scolymus L.	3	3.70	-0.67	8.01	2.21	0.10	75.84%	0.04
Petroselinum sativum	3	6.49	3.16	9.82	1.70	<0.001	45.90%	0.16
Moringa oliefera	9	0.04	-0.40	0.49	0.23	0.85	0%	0.99
Eucalyptus viminalis	6	6.01	4.22	7.80	0.91	<0.001	19.73%	0.29
Olea europaea L.	9	-0.15	-1.24	0.95	0.56	0.79	82.32%	<0.001
Ocimum bassicum	2	-0.16	-1.04	0.72	0.45	0.72	0%	0.96
Telfaria ociidentalis	4	-0.97	-1.71	-0.24	0.38	0.01	0%	0.92
Ilex paraguariensis	3	-0.22	-0.95	0.51	0.37	0.55	0%	0.44
Salvia officinalis L.	4	-1.50	-3.38	0.38	0.96	0.12	71.61%	0.01
Cassia tora	1	0.88	-0.80	2.55	0.86	NA	NA	NA
Artemisia annua	2	-4.60	-6.62	-2.59	1.03	<0.001	0%	0.58
Bambusoideae sp.	5	1.49	0.85	2.13	0.33	<0.001	17.50%	0.30
Eucommia ulmoides	2	-0.66	-1.49	0.16	0.42	0.11	0%	0.96

Note. N = Number of comparisons; SMD = Standardized mean differences between the leaves extract treatment and controls; CI = Confidence interval; *P*-value = Probability value; SE = Standard error; NA = Data non-available; SMD and I^2 were considered significant at $P<0.05$

Phytogenic compounds may influence the flavour of diets, which improves appetite and consumption; they might increase feed intake (Brenes & Roura, 2010). Several bioactive substances from plants that release scents stimulate the chicken's appetite, which could be the reason for the increased appetite. On the other hand, Masyita et al. (2022) reported that terpenes and terpenoids, the secondary metabolite substances found in plants such as eugenol, geraniol, carvone, thymol, and menthol, are responsible for the production of characteristic aromas. However, the detailed explanation regarding this matter is still very limited.

In contrast, research conducted by Aroche et al. (2018) showed that diet additions containing polyphenols, the greatest of which are tannins, can limit feed intake due to astringent qualities, consequently generating protein links between saliva lubricants and hydrogen bonds. When broiler chickens are fed herbs containing bioactive components, their appetites might rise or fall, depending on the dosage supplementations. The amount administered must be carefully monitored to achieve the intended effects. Additionally, research has suggested using PFAs with nanotechnology (Baskara et al., 2021; Ibrahim et al., 2022; Xu et al., 2024).

Average Daily Gain

A total of 14 studies consisting of 32 comparisons were eligible to evaluate the leaf extract treatment effect on ADG, as summarised in Table 3. The pooled effect estimates from SMD revealed that it had a significant effect on increasing ADG (SMD 1.57 [0.77 to 2.36], shown in Figure 3). High heterogeneity within studies was 86.47% ($P < 0.001$). Ross showed an increasing result in ADG ($P < 0.001$) when studies using strains in Hubbard, Arbor Acres, Marshal, Cobb, and Wen Tialu Black showed no effect due to leaf extract supplementation. In this meta-analysis, increasing ADG was found on diet supplementations with leaf extract of *Allium ampeloprasum*, *Cynara scolymus* L., *Petroselinum sativum*, *Artemisia annua* ($P < 0.001$), and *Eucalyptus viminalis* ($P < 0.005$). At the same time, *Salvia officinalis* L. supplementation decreased the ADG of broiler chickens ($P < 0.001$).

Table 3
Subgroup analysis of the effect of leaf extract supplementation on average daily gain of broiler chickens

Covariates	N	SMD	95% CI		SE	*P*-value	Heterogeneity	
			Lower	Upper			I^2	*P*-value
Strain								
Hubbard	8	5.35	0.57	10.13	2.44	0.03	92.85%	<0.001
Ross	20	3.60	1.92	5.28	0.86	<0.001	88.33%	<0.001
Arbor Acres	8	0.59	-0.52	1.70	0.57	0.30	78.29%	<0.001
Marshal	4	0.23	-0.48	0.93	0.36	0.53	0%	0.82
Cobb	6	1.44	-0.49	3.38	0.99	0.14	71.35%	0.02
Wen Tialu Black	2	1.04	-0.05	2.12	0.55	0.06	35.52%	0.21
Leaves extract								
Allium ampeloprasum	4	51.94	25.86	78.01	13.30	<0.001	84.14%	<0.001
Cynara scolymus L.	2	8.54	4.93	12.16	1.84	<0.001	0%	0.68
Petroselinum sativum	3	9.80	5.42	14.18	2.23	<0.001	35.41%	0.21
Moringa oliefera	6	0.11	-2.60	2.83	1.39	0.94	89.35%	<0.001
Eucalyptus viminalis	6	5.16	1.93	8.39	1.65	<0.01	81.86%	<0.001

Table 3 *(Continue)*

Covariates	N	SMD	95% CI		SE	*P*-value	Heterogeneity	
			Lower	Upper			I^2	*P*-value
Olea europaea L.	9	1.19	-0.14	2.51	0.68	0.08	81.86%	<0.001
Ocimum basilicum	2	-0.18	-1.06	0.70	0.45	0.69	0%	0.99
Telfairia occidentalis	4	0.23	-0.48	0.93	0.36	0.53	0%	0.82
Ilex paraguariensis	4	-0.75	-1.50	0.00	0.38	0.05	0%	0.37
Salvia officinalis L.	4	-2.28	-3.34	-1.22	0.54	<0.001	0%	0.42
Cassia tora	1	2.64	-0.45	4.83	1.26	NA	NA	NA
Artemisia annua	2	4.68	2.76	6.60	0.98	<0.001	0%	0.38
Eucommia ulmoides	2	1.04	-0.05	2.12	0.55	0.06	35.52%	0.21

Note. N = Number of comparisons; SMD = Standardized mean differences between the leaves extract treatment and controls; CI = Confidence interval; *P*-value = Probability value; SE = Standard error; NA = Data non-available; SMD and I^2 were considered significant at P<0.05

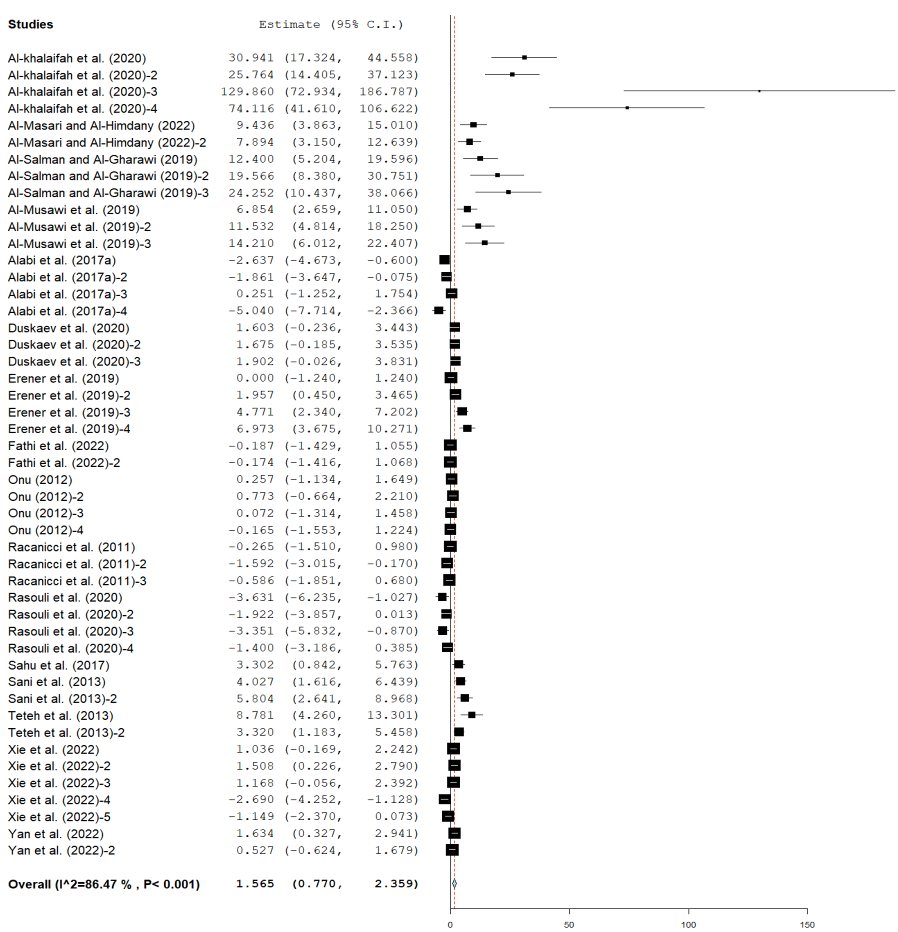

Figure 3. Forest plot of feeding leaves extract effect on broiler chickens' average daily gain

Based on this meta-analysis study, dietary leaf extract supplementations improved the ADG of broiler chickens compared to that of the control group ($P < 0.001$). In line with this result, several experiments showed that dietary supplementation of plant extracts increased the ADG of broiler chickens (Erener et al., 2020; Yan et al., 2022). The increased value of ADG showed a linear relationship with ADFI, which is one of the results of this meta-analysis study. Cheng et al. (2021)'s study showed that lotus leaf extract supplementation improved the growth and population of beneficial bacteria in the intestine and reduced the colonisation of pathogenic bacteria, resulting in the reduction of toxic metabolites produced by the pathogens. Reduction of toxic substances might reduce mucus secretion and increase micro-nutrient absorption, which in turn will optimise the conversion of nutrients into meat (Aljumaah et al., 2020).

Subsequently, the increase in daily body weight of birds might also be related to the antioxidant attributes in secondary plant metabolites. Platzer et al. (2022) showed that phenolic compounds are the most important natural antioxidants and can be classified into subgroups based on their structural properties. The terpene group has activity in counteracting free radicals and preventing oxidative stress (Luo et al., 2022). Apart from that, plants containing alkaloids can also reduce free radicals, disrupting the immune system, changing gene expression, and protecting against degenerative diseases, which can cause abnormal protein production (Albarrak, 2021).

Oxygen is essential for aerobic organisms and produces reactive oxygen species (ROS). ROS are molecules formed sequentially, adding electrons to oxygen, making them more reactive. However, when present in excessive amounts, it shows adverse effects on cells, including deoxyribonucleic acid (DNA) changes, lipid peroxidation, and protein degradation (Escorcia et al., 2020). Plant-derived supplementation can prevent various oxidative stress-induced diseases that lead to decreased productivity and quality in livestock. Supporting this statement, the study by M. Liu et al. (2023) showed that dietary supplementation of a polyherbal mixture containing various bioactive compounds, e.g., flavonoids, alkaloids, and essential oils, increased broiler chickens' daily body weight. This increase might be due to the presence of antioxidant properties of the bioactive compounds in herbs.

Research findings of Yang et al. (2015) also showed that a mixture of herbs containing capsicum, cinnamaldehyde, and carvacrol correlated with modifying the Nrf2 and NF-κB pathways to protect against oxidative stress with improved growth performance. In another study, the increased total antioxidant capacity in a broiler meat-fed diet containing herbal additives increased the activity of the superoxide dismutase (SOD) enzyme and a decrease in malondialdehyde (MDA) levels, which ultimately had the effect of reducing protein denaturation in the meat, resulting in increased meat quality (S. Wang et al., 2017).

Final Body Weight

As summarised in the random effect models (REM) analysis in Table 4. A total of 18 publications, which met the inclusion criteria were used in the meta-analysis to estimate the effect of supplementation leaves extract on the FBW of broiler chickens. The overall estimate of the SMD suggested that the increased levels of supplementation enhance FBW ($P < 0.001$) (SMD = 2.28; 95% CI = 1.40 to 3.16) and heterogeneity among the studies ($I^2 = 86.65\%$) (Figure 4). Subgroup analysis by the strain indicated that leaf extract supplementations increased on FBW ($P < 0.001$) in Ross and Arbor Acres (Table 3). Moreover, treatment using leaf extracts derived from *Allium ampeloprasum*, *Cynara scolymus* L., *Petroselinum sativum*, *Eucalyptus viminalis*, and *Bambusoideae* sp. increased FBW of broiler chickens ($P < 0.001$). The final body weight from the current meta-analysis study showed an increase in value at the end of the period compared to the control ($P < 0.001$). This finding was similar to the result of Al and Al-Gharawi (2019), who reported a gradual increase in body weight gain when the dose of *Eucalyptus viminalis* was 4,000 ppm or more.

Table 4
Subgroup analysis of the effect of leaves extract supplementation on final body weight of broiler chickens

Covariates	N	SMD	Ci 95%		SE	*P*-value	Heterogeneity	
			Lower	Upper			I^2	*P*-value
Strain								
Hubbard	15	0.48	-1.17	2.13	0.84	0.56	89.03%	<0.001
Ross	10	9.22	6.79	11.65	1.24	<0.001	48.56%	0.04
Arbor Acres	13	3.14	2.29	4.00	0.44	<0.001	34.32%	0.15
Marshal	8	0.56	-0.42	1.55	0.50	0.26	43.86%	0.15
Cobb	4	-0.08	-1.45	1.29	0.70	0.91	71.35%	0.02
Wen Tialu Black	2	1.01	-0.04	2.06	0.53	0.06	31.76%	0.23
Leaves extract								
Allium ampeloprasum	4	51.65	25.78	77.51	13.20	<0.001	83.98%	<0.001
Cynara scolymus L.	2	8.51	4.91	12.10	1.84	<0.001	0%	0.68
Petroselinum sativum	3	9.61	5.46	13.76	2.12	<0.001	31.17%	0.23
Moringa oliefera	13	0.12	-1.08	1.31	0.61	0.85	83.92%	<0.001
Eucalyptus viminalis	6	7.20	3.48	10.91	1.90	<0.001	77.89%	<0.001
Telfaria ociidentalis	4	0.56	-0.42	1.55	0.50	0.26	43.86%	0.15
Ilex paraguariensis	3	-0.67	-1.55	0.20	0.45	0.13	25.6%	0.26
Cassia tora	1	2.64	-0.45	4.83	1.12	NA	NA	NA
Bambusoideae sp.	5	3.11	1.99	4.23	0.57	<0.001	52.49%	0.08
Eucommia ulmoides	2	1.01	-0.04	2.06	0.53	0.11	31.76%	0.23

Note. N = Number of comparisons; SMD = Standardized mean differences between the leaves extract treatment and controls; CI = Confidence interval; *P*-value = Probability value; SE = Standard error; NA = Data non-available; SMD and I^2 were considered significant at $P < 0.05$

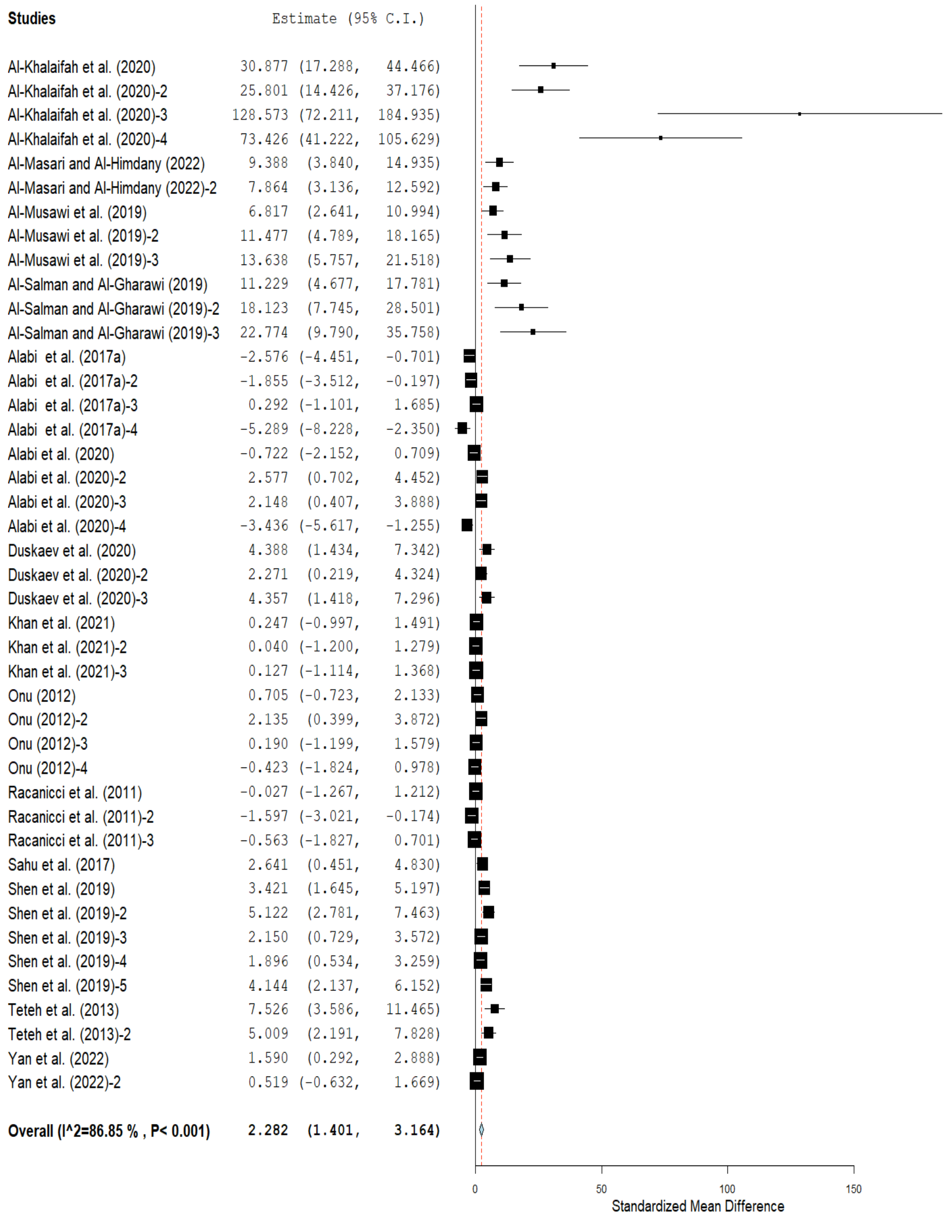

Figure 4. Forest plot on the effect of feeding leaves extract on final body weight of broiler chickens

Supplementations of 100 to 150 ppm *Ilex paraguariensis* reduced the BW of broiler chickens (Racanicci et al., 2011). The changes in the intestinal epithelium, resulting from poor digestion and absorption of nutrients due to changes in the intestinal epithelial lining and reduced bird performance (Islam et al., 2023). Thus, leaf extract supplementations carried out in various studies have an impact on stimulating the intestinal epithelium to work optimally. Improvement in final body weight in broilers associated with the supplementation of leaf extract might be due to the increased appetite shown by feed intake.

Furthermore, the intestine of broiler chicken contains important bacteria, including *Firmicutes*, *Proteobacteria*, *Bacteroidetes*, and *Actinobacteria* (Clavijo & Flórez, 2018). In the cecum, colonised microbiota also plays an important role in immune function, compromising the impact of nutrient absorption on the ultimate heaviness of the chicken body. The mode of action when using natural herbal additives could be responsible for the decreased number of hydrophobic pathogenic bacteria, thereby affecting the surface properties of microbial cells (Rashid et al., 2020). Pathogenic bacteria in the intestine are inhibited, but the growth of beneficial bacteria is promoted, which in turn will be important for nutrient absorption by the wall of the intestine (Han et al., 2016). Eventually, nutrient accumulation in the meat could increase as intestinal absorption increases.

Feed Conversion Ratio

Assessing the effect of leaf extract supplementation on the FCR of broiler chickens in 18 articles with 56 comparisons that met the eligibility rule for inclusion in the meta-analysis was used (Table 5). The addition of leaf extract as a feed additive for chickens had a significant effect on decreasing FCR ($P < 0.001$) with an SMD value of -1.25 (-1.76 to -0.73) and heterogeneity among the studies ($I^2 = 81.95\%$) (Figure 5). Arbor Acres and Wen Tialu Black showed a decreasing result in FCR ($P < 0.001$). The decrease in FCR was consistent in the supplementation leaf extract of *Petroselinum sativum*, *Olea europaea* L., *Artemisia annua*, *Bambusoideae* sp., and *Eucommia ulmoides* ($P < 0.001$). At the same time, the increase in FCR was found in *Allium ampeloprasum* L. ($P < 0.005$). The result of dietary supplementation of leaf extract shown a decrease in FCR ($P < 0.001$).

Various studies indicated that supplementations of plant extracts reduced FCR (Erener et al., 2020; Teteh et al., 2013; Yan et al., 2022). The lower FCR indicated the higher feed efficiency (Huang et al., 2022). Better growth performance, as shown in the lower FCR, could be attributed to the presence of various secondary metabolites in leaf extract, which increased the number of lactic acid bacteria, increased crypt depth and villus height, and hence improved nutrient absorption (M. Liu et al., 2023). A study performed by Parobali et al. (2024) showed that absorption of dietary nutrients into the body of birds through the bloodstream leads to increased feed utilisation efficiency, shown by increased villus height, crypt depth, and the ratio of villus height and crypt depth. A shorter villus may indicate inflammation, infection, nutritional deficiencies, and various diseases in the walls of the digestive tract. In addition, small villus can also be related to the small number of secretory and absorptive cells.

Overall, the decrease in the intestinal wall environment could have implications on micro-nutrient absorption and utilisation and, therefore, must be maintained properly (Prakatur et al., 2019). In addition, results in the current study suggest that the low value is closely related to the high values of ADFI and BW.

Table 5
Subgroup analysis of the effect of leaf extract supplementation on feed conversion ratio of broiler chickens

Covariates	N	SMD	95% CI		SE	*P*-value	Heterogeneity	
			Lower	Upper			I^2	*P*-value
Strain								
Hubbard	11	-0.82	-2.20	0.57	0.71	0.25	85.92%	<0.001
Ross	20	-1.65	-2.74	-0.57	0.56	<0.01	82.06%	<0.001
Arbor Acres	13	-1.37	-1.79	-0.96	0.21	<0.001	14.19%	0.30
Marshal	4	-0.84	-1.57	-0.10	0.38	0.03	0%	0.58
Cobb	6	-2.39	-5.34	0.56	1.51	0.11	89.35%	<0.001
Wen Tialu Black	2	-2.11	-3.12	-1.11	0.51	<0.001	0%	0.39
Leaves extract								
Allium ampeloprasum	4	6.81	-11.12	-2.51	2.20	0.01	89.16%	<0.001
Cynara scolymus L.	2	-0.06	-4.62	4.50	2.33	0.98	89.66%	<0.01
Petroselinum sativum	3	-5.28	-8.20	-2.37	1.49	<0.001	49.26%	0.12
Moringa oliefera	9	0.12	-0.86	1.11	0.50	0.81	73.68%	<0.001
Eucalyptus viminalis	6	-5.57	3.48	10.91	1.82	<0.01	83.38%	<0.001
Olea europaea L.	9	-1.51	-2.24	-0.78	0.37	<0.001	59.13%	0.01
Ocimum basilicum	2	0.24	-0.64	1.12	0.45	0.59	0%	0.86
Telfaria ociidentalis	4	-0.84	-1.57	1.10	0.38	0.03	0%	0.58
Ilex paraguariensis	3	-0.67	-1.55	0.20	0.41	0.04	10.82%	0.33
Salvia officinalis L.	4	0.82	-0.04	1.67	0.44	0.06	0%	0.51
Cassia tora	1	-5.55	-9.08	-2.03	1.80	NA	NA	NA
Artemisia annua	2	-30.71	-41.52	-19.90	5.51	<0.001	0%	0.40
Bambusoideae sp.	5	-1.50	-2.07	-0.92	0.30	<0.001	0%	0.60
Eucommia ulmoides	2	-2.11	-3.12	-1.11	0.51	<0.001	0%	0.40

Note. N = Number of comparisons; SMD = Standardized mean differences between the leaves extract treatment and controls; CI = Confidence interval; *P*-value = Probability value; SE = Standard error; NA = Data non-available; SMD and I^2 were considered significant at $P < 0.05$

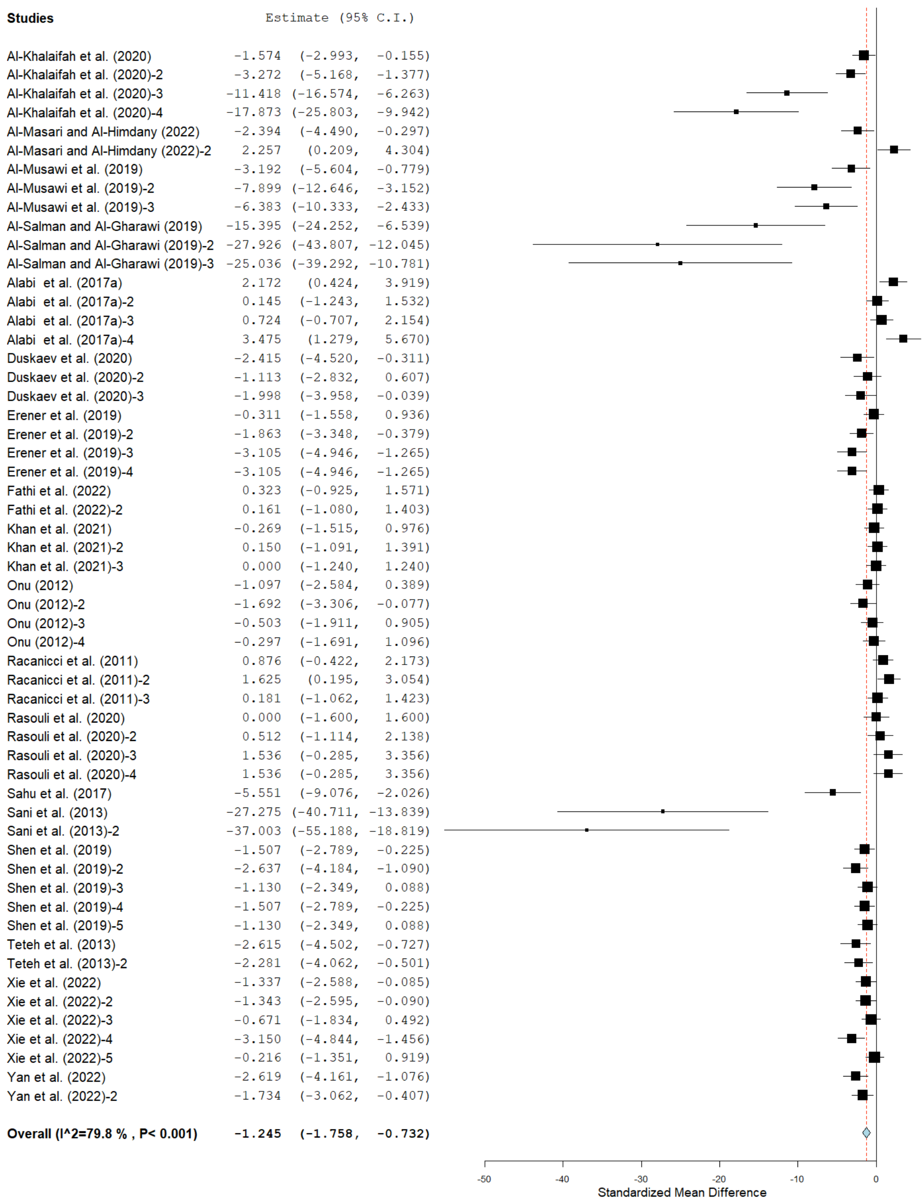

Figure 5. Forest plot on the effect of feeding leaves extract on broiler chicken's feed conversion ratio

CONCLUSION

The results of this meta-analysis study provided promising data on leaf extracts' potency as a natural growth promoter in broiler chickens. Future research should focus on the proper dosages of plant extract supplementation to change the presence of in-feed antibiotics.

ACKNOWLEDGMENTS

The authors thank the Directorate-General for Science, Technology and

Higher Education Resources, Ministry of Research, and Technology/National Agency for Research and Innovation of the Republic of Indonesia, for financial support of the study research through the Pendidikan Magister Menuju Doktor untuk Sarjana Unggul (PMDSU) scholarship, with contract number 089/E5/PG/02.00.PT/2022; 2010/UN1/DITLIT/DitLit/PT/01/03/2022.

REFERENCES

Al Salman, N. T. S., & Al-Gharawi, J. K. M. (2019). Effect of eucalyptus leaves water extract on some productive traits of broilers. *Plant Archives*, *19*(Supplement 1), 920-923.

Alabi, O. J., Malik, A. D., Ng'Ambi, J. W., Obaje, P., & Ojo, B. K. (2017). Effect of aqueous *Moringa oleifera* (Lam) leaf extracts on growth performance and carcass characteristics of Hubbard broiler chicken. *Revista Brasileira de Ciência Avícola*, *19*(2), 273–280. https://doi.org/10.1590/1806-9061-2016-0373

Alabi, O. J., Ng'ambi, J. W., & Mbajiorgu, E. F. (2020). Aqueous extract of moringa (*Moringa oleifera*) leaf (AEMOL) on the growth, sensory and histology parameters of broiler chickens. *Applied Ecology and Environmental Research*, *18*(5), 6753–6764. https://doi.org/10.15666/aeer/1805_67536764

Albarrak, S. M. (2021). Antioxidant and immune responses of broiler chickens supplemented with *Rhazya stricta* extract in drinking water. *Veterinary World*, *14*(6), 1437-1449. https://doi.org/10.14202/vetworld.2021.1437-1449

Ali, H., Al-Khalifa, A. R., Aouf, A., Boukhebti, H., & Farouk, A. (2020). Effect of nanoencapsulation on volatile constituents, and antioxidant and anticancer activities of Algerian *Origanum glandulosum* Desf. essential oil. *Scientific Reports*, *10*, 2812. https://doi.org/10.1038/s41598-020-59686-w

Aligiannis, N., Kalpoutzakis, E., Mitaku, S., & Chinou, I. B. (2001). Composition and antimicrobial activity of the essential oils of two *Origanum* species. *Journal of Agricultural and Food Chemistry*, *49*(9), 4168–4170. https://doi.org/10.1021/jf001494m

Aljumaah, M. R., Suliman, G. M., Abdullatif, A. A., & Abudabos, A. M. (2020). Effects of phytobiotic feed additives on growth traits, blood biochemistry, and meat characteristics of broiler chickens exposed to *Salmonella typhimurium*. *Poultry Science*, *99*(11), 5744–5751. https://doi.org/10.1016/j.psj.2020.07.033

Al-khalaifah, H. S., Badawi, M. E., Abd El-Aziz, R. M., Ali, M. A., & Omar, A. E. (2020). Effect of Egyptian leek leaf extract supplementation on productive and economic performance of Broilers. *Frontiers in Veterinary Science*, *7*, 584921. https://doi.org/10.3389/fvets.2020.584921

Al-Masari, A. I., & Al-Himdany, H. Q. (2022). Effect of adding artichoke leaves extract powder (*Cynara scolymus* L.) to the diet on the productive performance of broilers. *Iraqi Journal of Agricultural Sciences*, *53*(1), 9–15. https://doi.org/10.36103/ijas.v53i1.1500

Al-Musawi, T. A. M., Hassan, M. A., Al-Gharawi, J. K. M., & Al-Ziadi, R. A. (2019). Effect of water of extract of parsley (*Petroselinum sativum*) leaves in some productive traits of broiler. *Plant Archives*, *19*(Supplement 1), 1284-1287.

Anggrain, N., Kurtini, T., & Septinova, D. (2014). Perbandingan fase produksi telur kalkun terhadap fertilitas, susut tetas, daya tetas, dan bobot tetas [The comparison of production phase of turkey eggs on fertility, weight loss, hatchability, and hatching weight]. *Jurnal Ilmiah Peternakan Terpadu*, *2*(1), 5-10. https://doi.org/10.23960/jipt.v2i1.523

Aroche, R., Martínez, Y., Ruan, Z., Guan, G., Waititu, S., Nyachoti, C. M., Más, D., & Lan, S. (2018). Dietary inclusion of a mixed powder of medicinal plant leaves enhances the feed efficiency and immune function in broiler chickens. *Journal of Chemistry*, *2018*, 4073068. https://doi.org/10.1155/2018/4073068

Azimi, V., Mirakzehi, M. T., & Saleh, H. (2020). Hydroalcoholic extract of *Withania somnifera* leaf and α-tocopherol acetate in diets containing oxidised oil: Effects on growth performance, immune response, and oxidative status in broiler chickens. *Italian Journal of Animal Science*, *19*(1), 917–928. https://doi.org/10.1080/1828051X.2020.1808537

Basit, M. A., Arifah, A. K., Loh, T. C., Saleha, A. A., Salleh, A., Kaka, U., & Idris, S. B. (2020). Effects of graded dose dietary supplementation of *Piper betle* leaf meal and *Persicaria odorata* leaf meal on growth performance, apparent ileal digestibility, and gut morphology in broilers. *Saudi Journal of Biological Sciences*, *27*(6), 1503–1513. https://doi.org/10.1016/j.sjbs.2020.04.017

Baskara, A. P., Sharma, S., Sener-Aydemir, A., Koger, S., Ariyadi, B., Dono, N. D., Zuprizal, Z. & Metzler-Zebeli, B. U. (2021). Cinnamon bark oil and coconut oil emulsions modified small intestinal motility and barrier function in laying hens in an *ex vivo* experiment. *British Poultry Science*, *62*(3), 435-442. https://doi.org/10.1080/00071668.2020.1870662

Brenes, A., & Roura, E. (2010). Essential oils in poultry nutrition: Main effects and modes of action. *Animal Feed Science and Technology*, *158*(1-2), 1-14. https://doi.org/10.1016/j.anifeedsci.2010.03.007

Chen, M., Ding, Y., & Tong, Z. (2020). Efficacy and safety of *Sophora flavescens* (Kushen) based traditional Chinese medicine in the treatment of ulcerative colitis: Clinical evidence and potential mechanisms. *Frontiers in Pharmacology*, *11*, 603476. https://doi.org/10.3389/fphar.2020.603476

Cheng, L., Zhang, W., Jin, Q., Zhu, Y., Chen, R., Tian, Q., Yan, N., & Guo, L. (2021). The effects of dietary supplementation with lotus leaf extract on the immune response and intestinal microbiota composition of broiler chickens. *Poultry Science*, *100*(3), 100925. https://doi.org/10.1016/j.psj.2020.12.023

Clavijo, V., & Flórez, M. J. V. (2018). The gastrointestinal microbiome and its association with the control of pathogens in broiler chicken production: A review. *Poultry science*, *97*(3), 1006-1021. https://doi.org/10.3382/ps/pex359

Delespaul, Q., de Billerbeck, V. G., Roques, C. G., Michel, G., Marquier-Viñuales, C., & Bessière, J.-M. (2000). The antifungal activity of essential oils as determined by different screening methods. *Journal of Essential Oil Research*, *12*(2), 256–266. https://doi.org/10.1080/10412905.2000.9699510

DerSimonian, R., & Laird, N. (1986). Meta-analysis in clinical trials. *Controlled Clinical Trials*, *7*(3), 177–188. https://doi.org/10.1016/0197-2456(86)90046-2

Duskaev, G. K., Kvan, O. V., & Rakhmatullin, S. G. (2020). *Eucalyptus viminalis* leaf extract alters the productivity and blood parameters of healthy broiler chickens. *Veterinary World*, *13*(12), 2673–2680. https://doi.org/10.14202/vetworld.2020.2673-2680

Elfrida., Tarigan, N. S., & Suwardi, A. B. (2021). Ethnobotanical study of medicinal plants used by community in Jambur Labu Village, East Aceh, Indonesia. *Biodiversitas*, *22*(7), 2893–2900. https://doi.org/10.13057/biodiv/d220741

Erener, G., Ocak, N., Ozturk, E., Cankaya, S., Ozkanca, R., & Altop, A. (2020). Evaluation of olive leaf extract as a growth promoter on the performance, blood biochemical parameters, and caecal microflora of broiler chickens. *Revista Brasileira de Zootecnia*, *49*, e20180300. https://doi.org/10.37496/RBZ4920180300

Escorcia, M., Sánchez-Godoy, F., Ramos-Vidales, D., Medina-Campos, O. N., & Pedraza- Chaverri, J. (2020). Effect of the age and body weight of the broiler breeders male on the presentation of oxidative stress and its correlation with the quality of testicular parenchyma and physiological antioxidant levels. *Veterinary Sciences*, *7*(2), 69. https://doi.org/10.3390/vetsci7020069

Fathi, M., Mohammad, H. N., Abdolah, K. A., Saeidian, S., & Haydari, M. (2022). Effects of basil (*Ocimum basilicum*) leaf extract (BLE) on performance, blood biochemistry, antioxidant status, and oxidative stability of the meat of broiler chickens. *Poultry Science Journal*, *10*(1), 91–97. https://doi.org/10.22069/psj.2022.19725.1753

Gheisar, M. M., & Kim, I. H. (2018). Phytobiotics in poultry and swine nutrition – A review. *Italian Journal of Animal Science*, *17*(1), 92-99. https://doi.org/10.1080/1828051X.2017.1350120

Han, G. G., Kim, E. B., Lee, J., Lee, J.-Y., Jin, G., Park, J., Huh, C.-S., Kwon, I.-K., Kil, D. Y., Choi, Y.-J., & Kong, C. (2016). Relationship between the microbiota in different sections of the gastrointestinal tract, and the body weight of broiler chickens. *SpringerPlus*, *5*, 911. https://doi.org/10.1186/s40064-016-2604-8

Hasemi, S. R., Zulkifli, I., Bejo, M. H., Farida, A., & Somchit, M. N. (2008). Acute toxicity study and phytochemical screening of selected herbal aqueous extract in broiler chicken. *International Journal of Pharmacology*, *4*(5), 352–360. https://doi.org/10.3923/ijp.2008.352.360

Hedges, L. V. (1981). Distribution theory for glass's estimator of effect size and related estimators. *Journal of Educational Statistics*, *6*(2), 107–128. https://doi.org/10.3102/10769986006002107

Huang, Z., Jin, S., & Lv, Z. (2022). Dietary genistein supplementation alters mRNA expression profile and alternative splicing signature in the thymus of chicks with lipopolysaccharide challenge. *Poultry Science*, *101*(2), 101561. https://doi.org/10.1016/j.psj.2021.101561

Huyghebaert, G., Ducatelle, R., & Van Immerseel, F. (2011). An update on alternatives to antimicrobial growth promoters for broilers. *Veterinary Journal*, *187*(2), 182–188. https://doi.org/10.1016/j.tvjl.2010.03.003

Ibrahim, D., Eldemery, F., Metwally, A. S., Abd-Allah, E. M., Mohamed, D. T., Ismail, T. A., Hamed, T. A., Al Sadik, G. M., Neamat-Allah, A. N., & Abd El-Hamid, M. I. (2022). Dietary eugenol nanoemulsion potentiated performance of broiler chickens: Orchestration of digestive enzymes, intestinal barrier functions and cytokines related gene expression with a consequence of attenuating the severity of *E. coli* O78 infection. *Frontiers in Veterinary Science*, *9*, 847580. https://doi.org/10.3389/fvets.2022.847580

Islam, R., Sultana, N., Bhakta, S., Haque, Z., Hasan, A., Siddique, M. P., & Islam, M. R. (2023). Modulation of growth performance, gut morphometry, and cecal microbiota in broilers by clove (*Syzygium aromaticum*) and tulsi (*Ocimum sanctum*) supplementation. *Poultry Science*, *102*(1), 102266. https://doi.org/10.1016/j.psj.2022.102266

Khan, A., Tahir, M., Alhidary, I., Abdelrahman, M., Swelum, A. A., & Khan, R. U. (2022). Role of dietary *Moringa oleifera* leaf extract on productive parameters, humoral immunity, and lipid peroxidation in broiler chicks. *Animal Biotechnology*, *33*(6), 1353–1358. https://doi.org/10.1080/10495398.2021.1899936

Kokkini, S., Karousou, R., & Vokout, D. (1994). Pattern of geographic variation of *Origanum vulgare* trichomes and essential oil content in Greece. *Biochemical Systematics and Ecology*, *22*(5), 517–528. https://doi.org/10.1016/0305-1978(94)90046-9

Kumar, R., Kumar, K., Kumar, A., Kumar, S., Singh, P. K., Sinha, R. R. K., & Moni, C. (2021). Nutritional and physiological responses of broiler chicken to the dietary supplementation of *Moringa oleifera* aqueous leaf extract and ascorbic acid in tropics. *Tropical Animal Health and Production*, *53*, 428. https://doi.org/10.1007/s11250-021-02864-3

Lambert, R. J. W., Skandamis, P. N., Coote, P. J., & Nychas, G.-J. E. (2001). A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol, and carvacrol. *Journal of Applied Microbiology*, *91*(3), 453–462. https://doi.org/10.1046/j.1365-2672.2001.01428.x

Liu, M., Zhou, J., Li, Y., Ding, Y., Lian, J., Dong, Q., Qu, Q., Lv, W., & Guo, S. (2023). Effects of dietary polyherbal mixtures on growth performance, antioxidant capacity, immune function, and jejunal health of yellow-feathered broilers. *Poultry Science*, *102*(7), 102714. https://doi.org/10.1016/j.psj.2023.102714

Liu, S. J., Wang, J., He, T. F., Liu, H. S., & Piao, X. S. (2021). Effects of natural capsicum extract on growth performance, nutrient utilization, antioxidant status, immune function, and meat quality in broilers. *Poultry Science*, *100*(9), 101301. https://doi.org/10.1016/j.psj.2021.101301

Luo, Q., Tian, Z., Zheng, T., Xu, S., Ma, Y., Zou, S., & Zuo, Z. (2022). Terpenoid composition and antioxidant activity of extracts from four chemotypes of *Cinnamomum camphora* and their main antioxidant agents. *Biofuels, Bioproducts, and Biorefining*, *16*(2), 510-522. https://doi.org/10.1002/bbb.2320

Masyita, A., Sari, R. M., Astuti, A. D., Yasir, B., Rumata, N. R., Emran, T. B., Nainu, F., & Simal-Gandara, J. (2022). Terpenes and terpenoids as main bioactive compounds of essential oils, their roles in human health, and potential application as natural food preservatives. *Food chemistry: X*, *13*, 100217. https://doi.org/10.1016/j.fochx.2022.100217

McGimpsey, J. A., Douglas, M. H., Van Klink, J. W., Beauregard, D. A., & Perry, N. B. (1994). Seasonal variation in essential oil yield and composition from naturalized *Thymus vulgaris* L. in New Zealand. *Flavour and Fragrance Journal*, *9*(6), 347-352. https://doi.org/10.1002/ffj.2730090613

Meng, W. S., Zou, Q., Xiao, Y., Ma, W., Zhang, J., Wang, T., & Li, D. (2023). Growth performance and cecal microbiota of broiler chicks as affected by drinking water disinfection and/or herbal extract blend supplementation. *Poultry Science*, *102*(7), 102707. https://doi.org/10.1016/j.psj.2023.102707

Mohamed, M. A., & Hassan, H. M. A. (2023). Phytogenic substances as safe growth promoters in poultry nutrition. *International Journal of Veterinary Science*, *12*(1), 89–100. https://doi.org/10.47278/journal.ijvs/2022.134

Nakamura, K., Shishido, M., Shimamoto, S., Ogawa, G., Khandelwal, N., Tatsugawa, K., Fujita, Y., Ohtsuka, A., & Ijiri, D. (2022). Effects of supplementation with dried neem leaf extract on lipid peroxidation and antioxidant enzyme mRNA expression in the pectoralis major muscle of broiler chickens. *Journal of Poultry Science*, *59*(1), 75-80. https://doi.org/10.2141/jpsa.0200120

Onu, P. N. (2012). Effect of aqueous extract of *Telfairia occidentalis* leaf on the performance and haematological indices of starter broilers. *ISRN Veterinary Science*, *2012*, 726515. https://doi.org/10.5402/2012/726515

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLOS Medicine*, *18*(3), e1003583. https://doi.org/10.1371/JOURNAL.PMED.1003583

Parobali, T., Adjei-Mensah, B., Songuine, T., Yarkoa, T., Karou, S. D., & Eklu-Gadegbeku, K. (2024). Influence of *Citrus sinensis* seed powder on growth performance, morphological, and histological development of the small intestine of broiler chickens. *Journal of Applied Poultry Research*, *33*(2), 100395. https://doi.org/10.1016/j.japr.2023.100395

Platzer, M., Kiese, S., Tybussek, T., Herfellner, T., Schneider, F., Schweiggert-Weisz, U., & Eisner, P. (2022). Radical scavenging mechanisms of phenolic compounds: A quantitative structure-property relationship (QSPR) study. *Frontiers in Nutrition*, *9*, 882458. https://doi.org/10.3389/fnut.2022.882458

Prakatur, I., Miskulin, M., Pavic, M., Marjanovic, K., Blazicevic, V., Miskulin, I., & Domacinovic, M. (2019). Intestinal morphology in broiler chickens supplemented with propolis and bee pollen. *Animals*, *9*(6), 301. https://doi.org/10.3390/ani9060301

Qureshi, S., Banday, M., Adil, S., Shakeel, I., & Munshi, Z. H. (2015). Effect of dandelion leaves and fenugreek seeds with or without enzyme addition on performance and blood biochemistry of broiler chicken, and evaluation of their *in vitro* antibacterial activity. *Indian Journal of Animal Sciences*, *85*(11), 1248–1254.

Racanicci, A. M. C., Menten, J. F. M., Alencar, S. M., Buissa, R. S., & Skibsted, L. H. (2011). Mate (*Ilex paraguariensis*) as dietary additive for broilers: Performance and oxidative stability of meat. *European Food Research and Technology*, *232*, 655–661. https://doi.org/10.1007/s00217-011-1432-x

Ranga Niroshan Appuhamy, J. A. D., Strathe, A. B., Jayasundara, S., Wagner-Riddle, C., Dijkstra, J., France, J., & Kebreab, E. (2013). Anti-methanogenic effects of monensin in dairy and beef cattle: A meta-analysis. *Journal of Dairy Science*, *96*(8), 5161–5173. https://doi.org/10.3168/jds.2012-5923

Rashid, Z., Mirani, Z. A., Zehra, S., Gilani, S. M. H., Ashraf, A., Azhar, A., Al-Ghanim, K. A., Al-Misned, F., Al-Mulahim, N., Mahboob, S., & Galani, S. (2020). Enhanced modulation of gut microbial dynamics affecting body weight in birds triggered by natural growth promoters administered in conventional feed. *Saudi Journal of Biological Sciences*, *27*(10), 2747-2755. https://doi.org/10.1016/j.sjbs.2020.06.027

Rasouli, B., Movahhedkhah, S., Seidavi, A., Haq, Q. M. I., Kadim, I., Laudadio, V., Mazzei, D., & Tufarelli, V. (2020). Effect of sage (*Salvia officinalis* L.) aqueous leaf extract on performance, blood constituents, immunity response, and ileal microflora of broiler chickens. *Agroforestry Systems*, *94*, 1179–1187. https://doi.org/10.1007/s10457-019-00401-8

Sahu, J., Koley, K. M., & Sahu, B. D. (2017). Attribution of antibacterial and antioxidant activity of *Cassia tora* extract toward its growth promoting effect in broiler birds. *Veterinary World*, *10*(2), 221–226. https://doi.org/10.14202/vetworld.2017.221-226

Salgueiro, A. R., Vila, R., Cristina Figue, A., Barroso, G., Canigueral, S., Casanova, J., da Cunha, A. P., & Adzet, T (1997). Variability of essential oils of *Thymus caespititis* from Portugal. *Phytochemistry*, *45*(2), 307–311. https://doi.org/10.1016/S0031-9422(96)00872-2

Sani, G. L., Mohammadi, M., Jalali Sendi, J., Abolghasemi, S. A., & Roostaie Ali Mehr, M. (2013). Extract and leaf powder effect of *Artemisia annua* on performance, cellular, and humoral immunity in broilers. *Iranian Journal of Veterinary Research*, *14*(1), 15-20.

Shen, M., Xie, Z., Jia, M., Li, A., Han, H., Wang, T., & Zhang, L. (2019). Effect of bamboo leaf extract on antioxidant status and cholesterol metabolism in broiler chickens. *Animals*, *9*(9), 699. https://doi.org/10.3390/ani9090699

Song, B., He, J., Pan, X., Kong, L., Xiao, C., Keerqin, C., & Song, Z. (2023). Dietary *Macleaya cordata* extract supplementation improves the growth performance and gut health of broiler chickens with necrotic enteritis. *Journal of Animal Science and Biotechnology*, *14*, 113. https://doi.org/10.1186/s40104-023-00916-2

Sun, H. Y., Kim, Y. M., & Kim, I. H. (2020). Evaluation of *Achyranthes japonica* Nakai extract on growth performance, nutrient utilization, cecal microbiota, excreta noxious gas emission, and meat quality in broilers fed corn–wheat–soybean meal diet. *Poultry Science*, *99*(11), 5728–5735. https://doi.org/10.1016/j.psj.2020.07.023

Teteh, A., Lawson, E., Tona, K., Decuypere, E., & Gbeassor, M. (2013). *Moringa oleifera* leave: Hydro-alcoholic extract and effects on growth performance of broilers. *International Journal of Poultry Science*, *12*(7), 401–405. https://doi.org/10.3923/ijps.2013.401.405

Wallace, B. C., Lajeunesse, M. J., Dietz, G., Dahabreh, I. J., Trikalinos, T. A., Schmid, C. H., & Gurevitch, J. (2017). OpenMEE: Intuitive, open-source software for meta-analysis in ecology and evolutionary biology. *British Ecological Society*, *8*(8), 941–947. https://doi.org/10.1111/2041-210X.12708

Wang, M. L., Suo, X., Gu, J. H., Zhang, W. W., Fang, Q., & Wang, X. (2008). Influence of grape seed proanthocyanidin extract in broiler chickens: Effect on chicken coccidiosis and antioxidant status. *Poultry Science*, *87*(11), 2273–2280. https://doi.org/10.3382/ps.2008-00077

Wang, S., Zhang, L., Li, J., Cong, J., Gao, F., & Zhou, G. (2017). Effects of dietary marigold extract supplementation on growth performance, pigmentation, antioxidant capacity and meat quality in broiler chickens. *Asian-Australasian Journal of Animal Sciences*, *30*(1), 71-77. https://doi.org/10.5713/ajas.16.0075

Windisch, W., Schedle, K., Plitzner, C., & Kroismayr, A. (2008). Use of phytogenic products as feed additives for swine and poultry. *Journal of Animal Science*, *86*(suppl_14), E140–E148. https://doi.org/10.2527/jas.2007-0459

Xie, P., Deng, Y., Huang, L., & Zhang, C. (2022). Effect of olive leaf (*Olea europaea* L.) extract addition to broiler diets on the growth performance, breast meat quality, antioxidant capacity, and caecal bacterial populations. *Italian Journal of Animal Science*, *21*(1), 1246–1258. https://doi.org/10.1080/1828051X.2022.2105265

Xu, P., Wang, J., Chen, P., Ding, H., Wang, X., Li, S., Fan, X., Zhou, Z., Shi, D., Li, Z., Cao, S., & Xiao, Y. (2024). Effects of pomegranate (*Punica granatum* L.) peel on the growth performance and intestinal microbiota of broilers challenged with *Escherichia coli*. *Poultry Science*, *103*(2), 103304. https://doi.org/10.1016/j.psj.2023.103304

Yan, J., Hu, R., Li, B., Tan, J., Wang, Y., Tang, Z., Liu, M., Fu, C., He, J., & Wu, X. (2022). Effect of *Eucommia ulmoides* leaf extract on growth performance, carcass traits, parameters of oxidative stress, and lipid metabolism in broiler chickens. *Frontiers in Veterinary Science*, *9*, 945981. https://doi.org/10.3389/fvets.2022.945981

Yang, C., Kabir Chowdhury, M. A., Hou, Y., & Gong, J. (2015). Phytogenic compounds as alternatives to in-feed antibiotics: Potentials and challenges in application. *Pathogens*, *4*(1), 137-156. https://doi.org/10.3390/pathogens4010137

Zhang, S., Zhu, C., Xie, H., Wang, L., & Hu, J. (2022). Effect of Gan Cao (*Glycyrrhiza uralensis* Fisch) polysaccharide on growth performance, immune function, and gut microflora of broiler chickens. *Poultry Science*, *101*(10), 102068. https://doi.org/10.1016/j.psj.2022.102068

Zhao, J. S., Deng, W., & Liu, H. W. (2019). Effects of chlorogenic acid-enriched extract from *Eucommia ulmoides* leaf on performance, meat quality, oxidative stability, and fatty acid profile of meat in heat-stressed broilers. *Poultry Science*, *98*(7), 3040–3049. https://doi.org/10.3382/ps/pez081