Kafkas Universitesi Veteriner Fakultesi Dergisi
Journal Home-Page: http://vetdergikafkas.org
E-ISSN: 1309-2251

Kafkas Univ Vet Fak Derg
31 (4): 441-450, 2025
DOI: 10.9775/kvfd.2025.34043

Review Article

Effect of Black Soldier Fly Larva Meal on Broiler Chicken Production, Meat Quality, and It's Physiological Properties: A Meta-Analysis

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How to cite this article?

Chhetri S, Fikri F, Purnomo A, Çalışkan H, Purnama MTE: Effect of black soldier fly larva meal on broiler chicken production, meat quality, and it's physiological properties: A meta-analysis. *Kafkas Univ Vet Fak Derg*, 31 (4): 441-450, 2025.
DOI: 10.9775/kvfd.2025.34043

Article ID: KVFD-2025-34043
Received: 10.03.2025
Accepted: 24.06.2025
Published Online: 26.06.2025

Abstract

This study assessed the effect of feeding black soldier fly larva (BSFL) on broiler chicken production, meat quality, and physiological characteristics using a meta-analysis. Out of the 1878 articles that were reviewed from five databases (PubMed, Scopus, Science Direct, Cochrane Library, and ProQuest), 21 papers were selected for meta-analysis using the specific keywords "black soldier fly, *Hermetia illucens*, broiler chickens, growth performance" and the PRISMA flow diagram. The R Studio software version 4.4.2 (Posit PBC, USA) was employed to analyze the meta-analysis and compute the standard mean difference (SMD), 95% confidence interval (CI), and random effects. The current meta-analysis demonstrated that providing BSFL meals for broiler chickens had a favorable impact on weight gain, feed efficiency, carcass percentage, breast and thigh muscles, cooking loss, drip loss, meat color lightness, and yellowness. On the other hand, favorable effects were also reported on erythrocytes, packed cell volume, mean corpuscular volume, heterophil: lymphocyte (H/L) ratio, serum glucose, alanine transaminase, aspartate aminotransferase, gamma-glutamyl transferase, blood urea nitrogen, creatinine, uric acid, calcium, phosphorus, magnesium, and iron. It has been demonstrated using a meta-analysis study that the BSFL meal is beneficial for weight gain, feed efficiency, meat quality, and physiological properties in broiler chickens.

Keywords: Black soldier fly, Broiler chickens, Food production, Meat quality, Physiological properties

Introduction

Poultry products and consumption have been steadily increasing globally, as they are readily accessible and popular among consumers [1]. Currently, up to 58% of protein availability comes from animal-derived goods, whereas in the 1960s, the majority came from plant-derived products like wheat. A recent study concluded that Western consumption habits will continue to shift from red meat to white meat, despite the fact that European consumers' intake of animal-based protein has historically climbed gradually, with a particular spike in chicken consumption. As a result, animal products currently make up 30% of total caloric intake and are the main source of protein (28 g/person/day). Poultry meat has seen the largest increase in consumption among the various types of meat that are sold in markets. Furthermore, there is growing pressure to change European diets to include more environmentally friendly alternatives [2].

An investigation for more effective and substitute sources of protein for animal diets has been spurred by the expanding human population, climate change, and the shrinking quantity of land available for food crop cultivation [3]. Edible insects have received attention as they natural source of food for omnivorous poultry species in the wild. The productivity and profit of the poultry industry can be improved by including insect components in poultry feed [4]. Fish meal and soybeans have been the primary sources of protein in chicken feed for decades. Small benthic forage fish, especially have grown increasingly rare as a result of ocean overfishing, and are used to make fish oil and fish meal. Additionally, there is a cap on the amount of land that can be utilized for soy cultivation [5]. This necessitates the use of economic, environmentally friendly, and highly nutritious alternative sources of protein that are also affordable and feasible to produce. In the natural habitat, poultry consume insects, which are regarded as a vital source of protein. Live insect feeding such as BSFL to chickens has already been approved in Europe [6]. Because of its exceptional capacity to ingest a wide range of organic detritus and its abundance of protein (up to 39-64%), BSFL has established a unique niche for itself in the insect-based diet [7].

Black soldier fly larva (BSFL) has been widely used as a component in animal diets because it has a more abundant amino acid composition, i.e. leucine (44.6 g/kg), lysine (38.8 g/kg) and valine (40.1 g/kg) and is a significant source of protein (37-63% DM) and fat (7-39% DM) compared to soybean meal, these three amino acid amounts are higher, and even the valine content is larger than that of fish meal [8,9]. In previous investigations on various poultry, including BSFL feeding on turkeys [10], laying hens [11], broiler chickens [12], Barbary partridge [13], and Muscovy ducks [14], reported positive impact on meat quality and the growth performance, and supplementing partially defatted BSFL meal at portions of 5% and 15% to their diets improve productive performance in broiler chicken [15]. Numerous studies investigated hepatic and renal function, hematological characteristics, blood proteins, glucose, lipids, electrolytes, growth performance, and meat quality [16-18]. Moreover, several meta-analysis-based systematic studies solely assessed the performance of chickens, excluding meat quality and physiological characteristics as a measure of the BSFL efficacy. Comprehensive studies using meta-analysis methods crucial to be conducted to combine data from various investigations on the beneficial effects of BSFL feed involving all investigated parameters on broiler production. Therefore, this study aimed to evaluate the impacts of feeding broiler chickens BSFL meals on their productivity, meat quality, and physiological characteristics utilizing a meta-analysis.

Material and Methods

Search Strategy and Selection of Studies

The authors involved conducted the pertinent literature screening, data extraction, data analysis, and visualization processes from June to December 2024 at Universitas Airlangga, Indonesia and Eskişehir Osmangazi University, Türkiye. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram *(http://www.prisma-statement.org/)* was used in this inquiry to identify relevant papers. A methodical screening procedure was employed to find pertinent research from PubMed, Scopus, Science Direct, Cochrane Library, and ProQuest that reported the efficacy of BSFL meals in broiler chickens. The study question (P, population = broiler chickens; I, intervention = black soldier fly; C, comparison = control; and O, outcomes = meat quality and growth performance) was developed using the PICO algorithm *(Table 1)*. The search phrases "broiler chickens, meat quality, growth performance, *Hermetia illucens*, black soldier fly" were the most pertinent. The reference search included all studies indexed by the database and was not limited by study year. The MeSH term's inclusion of all pertinent and thorough keywords was confirmed. The following was the sample search algorithm used in the databases: #1 "chicken [MeSH Terms] OR broiler [Title/Abstract] OR broilers [Title/Abstract] OR broiler chickens [Title/Abstract]"; #2 "Black Soldier Fly [MeSH Terms] OR *Hermetia illucens* [Title/Abstract] OR maggot [Title/Abstract]"; #3 "meat quality [MeSH Terms] AND production performance [MeSH Terms] OR growth performance [Title/Abstract]".

Eligibility Criteria

Articles were selected based on the following eligibility specifications: full-text format and open-access documents,

Table 1. *Searching strategy based on the PICO methods*

PICO Items	PICO	Keywords
Problems, patients, population	Broiler chickens	((broiler[MeSH Terms]) OR (chicken[Title/Abstract])) OR (broiler chicken[Title/Abstract])
Intervention	Black soldier fly	((Black Soldier Fly[MeSH Terms]) OR (*Hermetia illucens*[Title/Abstract])) OR (maggot[Title/Abstract])
Comparison, control	Control	"Control groups"[MeSH Terms]
Outcomes	Primary outcome: meat quality, production performance Secondary outcomes: growth performance	((meat quality[MeSH Terms]) AND (production performance[MeSH Terms])) OR (growth performance[Title/Abstract])

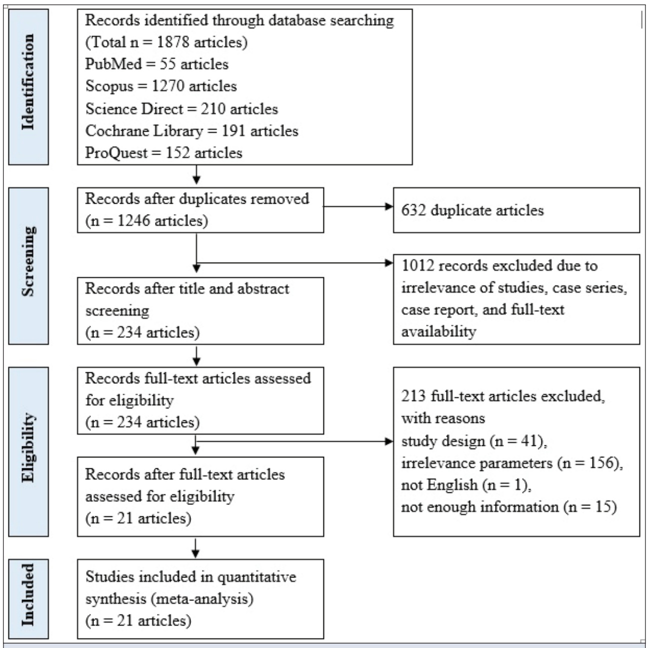

Fig 1. PRISMA flow diagram of the study selection process

in vivo investigations, randomized experimental studies, use of BSFL meals for feeding, original research papers written in English, and comprehensive disclosure of parameters. Exclusion criteria included duplicate studies, irrelevant studies, full-text not available, irrelevant types of studies (case series, case report), non-English language, and insufficient data. The PRISMA guidelines were adhered to in order to obtain references that were pertinent to the current study *(Fig. 1)*.

Data Extraction

The following data was presented once the data extraction process from the retrieved studies were completed: study reference, study year, country, broiler chicken breeds, BSFL ratio as the amount of BSFL mixed with the concentrates, breeding period, and total samples. Comprehensive data on the results were also extracted, such as the meat quality (slaughter weight, carcass yield, visceral organ weight, cooking loss, drip loss, shear force, meat color, and pH ultimate); hematological traits; serum proteins, glucose, and lipids; serum liver enzymes; renal physiology; and electrolyte levels; and chicken productivity (initial and final body weight, weight gain, feed intake, and feed efficiency).

Statistical Analysis

The "Meta package version 8.0-1" and "Metafor package version 4.6-0" in R Studio software version 4.4.2 (Posit PBC, USA) were used for statistical analysis and pooled cumulative meta-analysis. Following a pairwise meta-analysis of the data between the control group and the BSFL meals, the 95% CI, random effect, and standard mean difference (SMD) were calculated. Chi-squared tests (χ^2) were utilized to determine the heterogeneity during the investigation. The presence of considerable heterogeneity was determined based on a P-value <0.05 and an I^2 value >50%. The information displayed in the forest plot was verified and accurately depicted in the tables. The Egger's test was utilized to determine publication bias by considering the z-score and P-value <0.05.

Results

Identification and Selection of Studies

A total of 1878 articles have been identified from advanced searches across five electronic databases (PubMed supplied 55 articles, Scopus 1270 articles, Science Direct 210 articles, Cochrane Library 191 articles, and ProQuest 152 articles). Out of these, 1012 were eliminated due to the case reports, unavailability of pertinent research, and the complete text of the study, while 632 were duplicates. There were 234 full-text publications left after titles and abstracts were screened. Out of these, 213 papers were considered unsuitable for this analysis due to reasons including technical parameters, unsuitable study designs, non-English language, and inadequate data. In the end, 21 publications that could be evaluated were incorporated in meta-analysis *(Fig. 1)*.

Characteristics of The Included Studies

From the 21 incorporated studies, a total of 4676 broiler chicken samples representing the various BSFL feed treatment ratios were reviewed. Those studies were published in the period 2016-2024. A total of twelve studies reported from Europe, one reported from North America, four reported from Africa, and four reported from Asia were among the eleven countries whose data were published. Of the 4676 broiler chickens evaluated, 120 were Arbor Acres breed, 1382 Cobb 500, 280 New Lohmann strain MB 202, 2198 Ross 308, 480 Ross 708, and 216 Turkeys *(Table 2)*.

Growth Performance

According to the current meta-analysis, feeding BSFL meals improved weight gain (SMD = 0.29; P<0.001) and feed efficiency (SMD = 0.14; P = 0.01). On the other hand, feed intake was not significantly affected by providing BSFL meal (SMD = -0.26; P<0.001) *(Table 3)*.

Meat Quality

According to a meat quality assessment, feeding BSFL improved the carcass percentage (SMD = 0.76; P<0.001), breast muscle (SMD = 0.61; P<0.001), thigh muscle (SMD = 0.19; P = 0.19), total muscles (SMD = 5.15; P<0.001), cooking loss (SMD = 1.45; P<0.001), drip loss (SMD = 0.67; P<0.001), meat color lightness (SMD = 0.76; P<0.001), and yellowness (SMD = 0.66; P<0.001), respectively *(Table 4)*.

Table 2. *Characteristics of the studies*

Study Reference	Country	Breeds	BSFL Ratio (%)	Age (days)	Samples (n)
Aprianto et al.[12]	Indonesia	New Lohmann strain MB 202	0; 1; 2; 3	1-35	280
Attia et al.[22]	Saudi Arabia	Arbor Acres	SBM; FM; BSFL; BSFP	1-42	120
Beller et al.[20]	Germany	Cobb 500	0; 7.5; 15	1-35	72
Dabbou et al.[19]	Italy	Ross 308	0; 5; 10; 15	1-35	256
Dabbou et al.[24]	Italy	Ross 308	0; 1.6; 4; 1.8	1-33	200
Elangovan et al.[23]	India	Cobb 500	0; 50	1-21	90
Fruci et al.[38]	Canada	Ross 708	0; 12.5; 25; 50; 100	1-35	480
Kierończyk et al.[33]	Poland	Ross 308	0; 3; 6; 9	1-35	400
Mat et al.[16]	Malaysia	Cobb 500	0; 4; 8; 12	1-42	360
Mohammed et al.[29]	Ghana	Cobb 500	0; 4	1-49	32
Murawska et al.[17]	Poland	Ross 308	0; 50; 75; 100	1-42	384
Mutisya et al.[30]	Kenya	Cobb 500	0; 25; 50; 75	1-42	120
Oddon et al.[35]	Italy	Ross 308	C; HI; TM	1-38	180
Onsongo et al.[39]	Kenya	Cobb 500	0; 11; 37.2; 55.5	1-49	288
Pieterse et al.[15]	South Africa	Cobb 500	0; 5; 10; 15	1-31	320
Schäfer et al.[31]	Germany	Cobb 500	0; 2.5; 5	1-35	100
Schiavone et al.[25]	Italy	Ross 308	0; 50; 100	1-35	150
Schiavone et al.[36]	Italy	Ross 308	0; 50; 100	1-48	120
Schiavone et al.[18]	Italy	Ross 308	0; 5; 10; 15	1-35	256
Seyedalmoosavi et al.[40]	Germany	Ross 308	0; 10; 20; 30	1-42	252
Sypniewski et al.[10]	Poland	Turkeys	0; 50; 100	7-35	216

Table 3. *Efficacy of BSFL meals on production performance of broiler chickens*

Parameter	n	Random Effect			Heterogeneity			Egger's Test	
		SMD	95% CI	P-value	Chi^2	I^2	P-value	z	P-value
Initial body weight (g)	1359	0.02	-0.10 - 0.14	0.74	596.97	98%	< 0.001	2.3432	0.0191
Final body weight (g)	1767	-0.24	-0.35 - -0.12	< 0.001	1109.65	99%	< 0.001	0.9560	0.3391
Weight gain (g)	2001	0.29	0.17 - 0.41	< 0.001	1730.28	99%	< 0.001	-0.4462	0.6555
Feed intake (g/bird/day)	1875	-0.26	-0.39 - -0.13	< 0.001	1846.72	99%	< 0.001	-0.7626	0.4457
Feed efficiency	2169	0.14	0.03 - 0.25	0.01	1701.72	99%	< 0.001	N/A	N/A

n = total samples, SMD = standard mean difference, 95% CI = 95% confidence intervals, I^2 = the primary index for reporting heterogeneity, z = significance tests for the weighted average effect size, N/A = not applicable

Hematological Profile, Electrolytes, Liver and Renal Physiology

Based on hematological traits evaluation, the BSFL meals were revealed to have a favorable effect on erythrocytes (SMD = 1.10; P<0.001), PCV (SMD = 1.67; P<0.001), MCV (SMD = 1.41; P<0.001), H/L ratio (SMD = 0.31; P = 0.005) (*Table 5*), and serum glucose (SMD = 0.30; P = 0.03). In contrast, we reported that BSFL meals did not have a favorable effect on triglycerides (SMD = -0.72; P<0.001) and cholesterol (SMD = -0.65; P<0.001) (*Table 6*). Concurrently, this meta-analysis study investigated the favorable effects of BSFL meals on various physiological indicators related to the liver, kidneys, and electrolyte balance. These yielded favorable findings on the following parameters: ALT (SMD = 0.20; P = 0.02), AST (SMD = 0.24; P = 0.003), GGT (SMD = 0.09; P = 0.36) (*Table 6*), blood urea nitrogen (SMD = 0.49; P = 0.004), creatinine (SMD = 0.07; P = 0.48), uric acid (SMD = 0.83; P<0.001) (*Table 7*), calcium (SMD = 1.64; P<0.001), phosphorus (SMD = 0.78; P<0.001), magnesium (SMD = 0.44; P<0.001), and iron (SMD = 0.19; P = 0.07) (*Table 8*), respectively.

Publication Bias

The current meta-analysis revealed an accurate publication bias assessment using Egger's test, as several parameters

Table 4. Efficacy of BSFL meals on meat quality and carcass trait of broiler chickens

Parameter	n	Random Effect			Heterogeneity			Egger's Test	
		SMD	95% CI	P-value	Chi²	I²	P-value	z	P-value
Slaughter weight (g)	1084	-0.76	-0.92 - -0.59	< 0.001	952.04	99%	< 0.001	-0.8334	0.4046
Carcass yield (g)	1112	-0.18	-0.33 - -0.02	0.02	879.52	99%	< 0.001	0.1425	0.8866
Carcass percentage (%)	1020	0.76	0.61 - 0.90	< 0.001	468.04	98%	< 0.001	3.7575	0.0002
Breast yield (g)	764	0.61	0.40 - 0.81	< 0.001	735.26	99%	< 0.001	1.3603	0.1737
Breast percentage (%)	860	-0.81	-1.01 - -0.61	< 0.001	856.13	99%	< 0.001	-3.0604	0.0022
Thigh yield (g)	572	0.19	-0.10 - 0.48	0.19	743.49	100%	< 0.001	1.9006	0.0574
Thigh percentage (%)	860	0.98	0.82 - 1.14	< 0.001	391.87	98%	< 0.001	-0.8671	0.3859
Muscles (%)	352	5.15	4.89 - 5.60	< 0.001	44.31	98%	< 0.001	N/A	N/A
Abdominal fat (g)	556	-2.88	-3.21 - -2.56	< 0.001	481.94	99%	< 0.001	1.7928	0.0730
Abdominal fat (%)	680	-1.06	-1.33 - -0.79	< 0.001	846.53	100%	< 0.001	N/A	N/A
Liver (g)	638	0.64	0.42 - 0.86	< 0.001	585.30	99%	< 0.001	-0.5610	0.5748
Liver (%)	744	-1.14	-1.31 - -0.96	< 0.001	325.07	98%	< 0.001	0.4124	0.6800
Heart (g)	548	0.77	0.56 - 0.98	< 0.001	308.12	99%	< 0.001	1.4430	0.1490
Heart (%)	744	-0.63	-0.81 - -0.45	< 0.001	481.20	99%	< 0.001	N/A	N/A
Spleen (g)	446	-0.29	-0.48 - -0.09	0.003	50.92	92%	< 0.001	2.2077	0.0273
Spleen (%)	552	-0.18	-0.38 - 0.01	0.07	301.30	99%	< 0.001	N/A	N/A
Bursa fabricius (g)	170	-0.23	-0.57 - 0.12	0.19	75.39	99%	< 0.001	N/A	N/A
Bursa fabricius (%)	492	-1.09	-1.34 - -0.85	< 0.001	387.82	99%	< 0.001	N/A	N/A
Gizzard (g)	314	-0.43	-0.66 - -0.20	0.0003	29.02	93%	< 0.001	0.2941	0.7686
Gizzard (%)	616	-1.12	-1.32 - -0.93	< 0.001	269.37	99%	< 0.001	N/A	N/A
Cooking loss (%)	620	1.45	1.23 - 1.67	< 0.001	423.11	99%	< 0.001	0.9313	0.3517
Drip loss 24 h (%)	780	0.67	0.51 - 0.83	< 0.001	267.09	99%	< 0.001	0.8542	0.3930
Shear force (kg/cm²)	460	-0.25	-0.47 - -0.04	0.02	247.68	99%	< 0.001	-4.4825	< 0.001
Meat color lightness (L*)	1020	0.76	0.59 - 0.93	< 0.001	869.75	99%	< 0.001	-0.1746	0.8614
Meat color redness (a*)	1020	-1.06	-1.21 - -0.92	< 0.001	289.18	98%	< 0.001	-0.4460	0.6556
Meat color yellowness (b*)	1020	0.66	0.46 - 0.87	< 0.001	1228.72	100%	< 0.001	0.2375	0.8123
pH 60 min	360	-0.35	-0.64 - -0.05	0.02	351.69	100%	< 0.001	N/A	N/A
pH 24 h	880	-0.55	-0.72 - -0.37	< 0.001	684.97	99%	< 0.001	N/A	N/A

n = total samples, SMD = standard mean difference, 95% CI = 95% confidence intervals, I^2 = the primary index for reporting heterogeneity, z = significance tests for the weighted average effect size, N/A = not applicable

Table 5. Efficacy of BSFL meals on hematological traits of broiler chickens

Parameter	n	Random Effect			Heterogeneity			Egger's Test	
		SMD	95% CI	P-value	Chi²	I²	P-value	z	P-value
Erythrocytes (x 10⁶/µL)	700	1.10	0.90 - 1.30	< 0.001	505.72	99%	< 0.001	-0.2203	0.8257
Leukocytes (x 10³/µL)	640	-0.29	-0.47 - -0.11	0.001	311.60	98%	< 0.001	-0.4568	0.6478
Hemoglobin (g/dL)	272	-1.45	-1.79 - -1.12	< 0.001	177.84	99%	< 0.001	3.2698	0.0011
PCV (%)	92	1.67	0.98 - 2.35	< 0.001	84.58	99%	< 0.001	0.9603	0.3369
MCV (µm³)	272	1.41	1.04 - 1.77	< 0.001	243.20	99%	< 0.001	N/A	N/A
MCH (pg/dL)	272	-1.47	-1.86 - -1.08	< 0.001	280.57	99%	< 0.001	2.1084	0.0350
MCHC (%)	272	-1.29	-1.69 - -0.88	< 0.001	309.92	99%	< 0.001	N/A	N/A
H/L ratio	428	0.31	0.09 - 0.52	0.005	180.47	98%	< 0.001	0.8246	0.4096

n = total samples, SMD = standard mean difference, 95% CI = 95% confidence intervals, I^2 = the primary index for reporting heterogeneity, z = significance tests for the weighted average effect size, N/A = not applicable
PCV = packed cell volume, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCHC = mean corpuscular hemoglobin concentration

Table 6. *Efficacy of BSFL meals on serum proteins, glucose, lipids, and liver enzymes of broiler chickens*

Parameter	n	Random Effect			Heterogeneity			Egger's test	
		SMD	95% CI	P-value	Chi²	I²	P-value	z	P-value
Total protein (g/dL)	990	-0.75	-0.90 - -0.60	< 0.001	548.55	99%	< 0.001	2.5507	0.0108
Albumin (g/dL)	630	-1.13	-1.35 - -0.92	< 0.001	482.63	99%	< 0.001	0.8934	0.3716
Glucose (mg/dL)	284	0.30	0.03 - 0.56	0.03	116.61	99%	< 0.001	N/A	N/A
Triglyceride (mg/dL)	872	-0.72	-0.90 - -0.55	< 0.001	631.13	99%	< 0.001	1.1622	0.2452
Cholesterol (mg/dL)	872	-0.65	-0.81 - -0.48	< 0.001	545.37	99%	< 0.001	-1.9403	0.0523
HDL (mg/dL)	564	-1.86	-2.12 - -1.61	< 0.001	433.38	99%	< 0.001	-0.3318	0.7400
LDL (mg/dL)	564	-0.28	-0.47 - -0.08	0.006	307.94	99%	< 0.001	N/A	N/A
ALT (IU/L)	784	0.20	0.04 - 0.37	0.02	426.61	99%	< 0.001	7.6141	< 0.001
AST (IU/L)	732	0.24	0.08 - 0.40	0.003	222.15	97%	< 0.001	-0.8821	0.3777
ALP (IU/L)	160	-1.10	-1.43 - -0.77	< 0.001	1.71	42%	0.19	N/A	N/A
GGT (IU/L)	460	0.09	-0.10 - 0.29	0.36	108.94	97%	< 0.001	5.1303	< 0.001

n = total samples, SMD = standard mean difference, 95% CI = 95% confidence intervals, I^2 = the primary index for reporting heterogeneity, z = significance tests for the weighted average effect size, N/A = not applicable
HDL = high-density lipoprotein, LDL = low-density lipoprotein, ALT = alanine transaminase, AST = aspartate aminotransferase, ALP = alkaline phosphatase, GGT = gamma-glutamyl transferase

Table 7. *Efficacy of BSFL meals on renal physiology of broiler chickens*

Parameter	n	Random Effect			Heterogeneity			Egger's test	
		SMD	95% CI	P-value	Chi²	I²	P-value	z	P-value
Blood urea nitrogen (mg/dL)	368	0.49	0.16 - 0.82	0.004	130.26	100%	< 0.001	-1.2092	0.2266
Creatinine (mg/dL)	468	0.07	-0.13 - 0.27	0.48	169.25	98%	< 0.001	-3.7100	0.0002
Uric acid (mg/dL)	528	0.83	0.64 - 1.01	< 0.001	61.12	93%	< 0.001	N/A	N/A

n= total samples, SMD= standard mean difference, 95% CI= 95% confidence intervals, I^2= the primary index for reporting heterogeneity, z= significance tests for the weighted average effect size, N/A= not applicable

Table 8. *Efficacy of BSFL meals on electrolyte levels of broiler chickens*

Parameter	n	Random Effect			Heterogeneity			Egger's test	
		SMD	95% CI	P-value	Chi²	I²	P-value	z	P-value
Calcium (mg/dL)	408	1.64	1.34 - 1.95	< 0.001	353.99	99%	< 0.001	4.5363	< 0.001
Phosphorus (mg/dL)	588	0.78	0.54 - 1.02	< 0.001	568.42	99%	< 0.001	1.8924	0.0584
Magnesium (mEq/L)	588	0.44	0.27 - 0.62	< 0.001	106.59	96%	< 0.001	N/A	N/A
Iron (µg/dL)	408	0.19	-0.02 - 0.40	0.07	115.88	97%	< 0.001	1.2430	0.2139

n = total samples, SMD = standard mean difference, 95% CI = 95% confidence intervals, I^2 = the primary index for reporting heterogeneity, z = significance tests for the weighted average effect size, N/A = not applicable

were reported P-values <0.05. Meanwhile, the parameters of weight gain, feed intake, slaughter weight, carcass yield, meat color, hematological traits, serum proteins and lipids did not represent publication bias with P-value >0.05 (*Table 3*, *Table 4*, *Table 5*, *Table 6*, *Table 7*, *Table 8*).

Discussion

In this meta-analysis study, BSFL inclusion in feeding compared with basal feed as a control, and the findings demonstrated that BSFL was effective in terms of weight increase and feed efficiency. In a previous investigation, feeding BSFL at a ratio of 2:3 with basal diet improved the weight gain and feed efficiency of the chickens during the starting phase, contributing to improved growth performance [17]. According to other studies, utilizing BSFL at a ratio of 1:5 with basal diet improved average daily weight growth as well as final weight [12,15,18-20]. The recommended daily feed intake was stated to be highly elevated during the early period. The late period of broiler chicken growth was characterized by optimal growth, as indicated by adequate feeding efficiency and body weight measures. Due to the growth and development progress of broilers at an accelerated rate during the initial stage, it is thought to be the most crucial phase in the production process [21].

The nutrient composition of BSFL meal to rear chickens was found to be adequate and it can be regarded as a rich source of digestible amino acids and energy, resulting in a nutritious feed product for poultry. In investigations conducted to replace soybean meal with BSFL as a source of protein, BSFL showed favorable findings concerning growth performance [22]. Because of its higher protein concentration and preferable amino acid properties than many vegetable proteins, BSFL may be a desirable feed ingredient. However, the large substrate composition variations also affect its nutritional properties. A previous study reported a wide range in nutrient composition, including crude proteins (33-55%), calcium (2.4-5.8%), lysine (1.9-2.7%), and methionine (0.5-0.8%), because these larvae were raised on a variety of substrates, thereby such as organic material, vegetables and fruit wastes, chicken manure, and the pantry garbage [23].

Previous research linked increased feed efficiency to the benefits of diets high in medium-chain fatty acids (MCFA), which improve digestion and nutrient absorption. The conflicting results show that the chitin in BSFL, which is indigestible by monogastric animals and may reduce the digestibility of proteins, could be the reason why the feed efficiency has decreased. Because of this, the final weight of broiler chickens falls as the amount of BSFL in their diet rises, potentially endangering the output of intensive rearing techniques [24]. As a source of saturated fatty acid (SFAs), the BSFL mostly consisted of lauric acid (52.6%), myristic acid (8.54%), and palmitic acid (10.9%), and collectively contributed to 72% of the total fatty acid methyl ester (FAME). Lauric acid is one of the medium-chain fatty acids (MCFA), which are especially advantageous as dietary supplements and are widely recognized for their antimicrobial properties through disruption of cellular membranes [18]. It was reported that BSFL was composed of comparatively rare polyunsaturated fatty acids (PUFAs), which were mostly reflected by α-linoleic acid (7.8% of PUFAs) and linoleic acid (89.9% of PUFAs) [25]. The substantial fatty acid content of BSFL generally degrades the fat composition of the meat, which is visible as contemporary consumers shift concerning more nutritious meat and meat-related products. This is undoubtedly an area that continues to demand investigation. To determine whether the fatty acid profile of BSFL fat may be improved through substrate composition, a study should be done as the fatty acid properties of BSFL fat may fluctuate significantly depending on the rearing substrate applied [26,27].

In the previous study, diets including 10% and 15% BSFL meal instead of soybean meal and soybean oil did not have an adverse effect on the weight of breast muscles or their percentage of the overall weight of the growing broiler carcass [15,18,19]. Despite certain outliers that demonstrated a linear effect, such as C12:0, C15:0, and C18-PUFAs, the increasing BSFL fat in chicken diets primarily reveals a linear response in terms of summarised fatty acids and a quadratic response in the case of individual SFAs and unsaturated fatty acid (UFAs) [28]. It is notable to highlight that the significant amount of BSFL fat (60 and 90 g/kg) in broiler diets led to a beneficial rise in the content of PUFA in the breast meat, especially as a result of increased linolenic acid (C18:2). In contrast, oleic acid decreased monounsaturated fatty acid (MUFA) levels (C18:1). In the end, the higher UFA level and lower SFAs point to a positive impact for consumers [29]. A dose-dependent decrease in BSFL fat in the hens' meals, however, should not be linked to the elevated linolenic acid concentration. It should be highlighted that although feed intake did not rise in birds fed more BSFL fat, FAs in tissues might be synthesised. Furthermore, it is widely known that elevated PUFAs reduce 9-desaturase activity, which in turn inhibits MUFA production in the liver [30]. However, another study found that the proportion of pectoral muscles increased while the proportion of quadricep muscles drastically decreased in broiler-fed dietary regimens with 5% BSFL, a significantly lower proportion of BSFL meal [31].

This study demonstrated that proteins' water-holding capacity (WHC) increases as they shift beyond their isoelectric point because they absorb excess water [32]. Since well-hydrated meat absorbs light more intensely and has a different pH value in different muscle parts, an increase in WHC can therefore have an impact on the color of the meat. In the present study reported a slight correlation between the aforementioned associations and drip loss independently. Nonetheless, the broilers fed BSFL meal had an elevated L* (lightness) contribution and b* (yellowness). The carcasses of broiler chickens fed BSFL meal had slightly higher levels of L*, b* and a* (redness). Reduced soybean meal gluten levels in meals containing insect meal may lead to lower yellowness and redness due to the buildup of pigments from the BSFL meal [17,18,33].

The physiological parameters reviewed in this study demonstrated that the animals' health state was unaffected by the BSFL diet. Furthermore, routine blood parameters measured for this investigation fell within the standard physiological range. The hematology profile of broiler chickens and turkeys fed BSFL did not alter significantly [10,18]. A prior study found that serum samples containing BSFL fat had lower levels of high density lipoprotein cholesterol (HDL-C) and total cholesterol. In contrast, BSFL fat had no effect on triglycerides, uric acid, alanine aminotransferase (ALT), or aspartate aminotransferase (AST) [34]. This outcome can be explicated through BSFL's high lauric acid concentration. An increase in HDL content was linked to increased ApoA1 secretion brought on by MCFA use. The main protein component of HDL particles is apolipoprotein A1 (ApoA1). HDL-C development is significantly influenced by ApoA-I. 70% of ApoA-I is produced in the liver, making it the main organ responsible for both its synthesis and excretion. An increase in HDL levels in the blood can result from elevated ApoA-I levels [31]. When compared to the control group, the erythrocyte level and H/L ratio of the chickens fed BSFL showed a favorable effect [35]. On the other hand, leukocyte counts were within normal limits, suggesting that the broiler chickens' immune systems were unaffected by the feeding regimen [24]. Elevated serum AST, ALT, and gamma-glutamyl transferase (GGT) activities serve as indications of liver necrosis and are typically linked to liver injury. The finding that AST or ALT activity was unaffected implies that BSFL feeding may not be harmful to the health of the liver or the hepatopancreas [22]. Mean creatinine levels did not exhibit any negative effects, suggesting that BSFL meal had a comparable impact on renal physiology [19,36,37]. When the broiler chickens and mirror carps were fed BSFL meal instead of soybean meal, their haematological characteristics were unaffected, thereby, confirming the nutritional sufficiency of BSFL. The increased phosphorus bioavailability in BSFL meal may cause of the elevated blood phosphorus concentrations detected in chickens fed with BSFL diet [19,25]. Similarly, supplementing broilers with BSFL raised their blood albumin and total protein levels. Since MCFA are more ketogenic than long-chain fatty acids (LCFA), the body can produce more proteins. Furthermore, because MCFA offers a sufficient energy source, less protein is used as an energy source, which raises the concentration of protein [38]. The conclusions drawn from the earlier studies are placed in context by the wide range of results found in the previously described studies. This heterogeneity may also be related to the composition of the BSFL meal that was utilized, which can be influenced by the life stage of the insect (adult, larva, or pupa), the substrate used for insect rearing, the defatting process, and the growth season during which the chickens were fed.

Conclusion

Out of 1878 studies, 21 studies covering the years 2016-2024 on the nutritional benefits of BSFL meal for broiler chickens were reviewed using meta-analysis. The study's findings demonstrated that feeding broiler chickens BSFL meals improved the chickens' weight gain, feed efficiency, carcass percentage, muscles in the breast and thighs, cooking loss, drip loss, and the lightness and yellowness of their meat. Meanwhile, favorable results were also reported for serum glucose, erythrocytes, liver and renal physiology, and electrolyte properties.

Declarations

Availability of Data and Materials: All the generated data are included in the manuscript.

Acknowledgements: We express our gratitude to the Dean of the Faculty of Health, Medicine, and Life Sciences at Universitas Airlangga and the Dean of the Faculty of Science at Eskişehir Osmangazi Üniversitesi for providing facilities for the present study.

Competing Interests: The authors declared that there is no competing interest.

Declaration of Generative Artificial Intelligence (AI): The article and/or tables and figures were not written/created by AI and AI-assisted technologies.

Author Contributions: SC, HÇ, and MTEP: Conceptualization, methodology, and data curation. AP and FF: Data extraction and editing. MTEP: Performed data analysis and edited the visualization and validation of tables and figures. SC, HÇ, and MTEP: Drafted, revised, and submitted the manuscript. All authors read and approved the final manuscript.

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