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Systematic Review

Meta-Analysis of Dietary Supplementation with *Schizochytrium* sp. Microalgae in Dairy Goats: Milk Production, Milk Composition and Fatty Acid Profile in Milk

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Simple Summary

Improving the nutritional quality of goat milk through natural dietary strategies is of growing interest to both producers and consumers. This study synthesized findings from previously published research to evaluate the effects of supplementing dairy goat diets with the microalga *Schizochytrium* sp. The analysis demonstrated that dietary supplementation with *Schizochytrium* sp. increased milk production and improved the fatty acid composition of the milk, increasing total polyunsaturated fatty acids and total omega-3 fatty acids, while reducing total saturated fatty acids and the omega-6/omega-3 ratio. These findings support the use of *Schizochytrium* sp. as a natural supplement in dairy goat feed to produce milk with a modified fatty acid profile, although implications for human health were not evaluated. The modest milk yield response and reductions in milk fat and lactose do not establish an overall improvement in nutritional value or human health outcomes.

Abstract

This meta-analysis was conducted to comprehensively assess the effects of dietary supplementation with *Schizochytrium* sp. microalgae on milk yield, milk composition, and the fatty acid profile of milk in dairy goats. A systematic literature search was performed in the Scopus, Web of Science, ScienceDirect, and Google Scholar databases in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Following the eligibility and screening procedures, 16 peer-reviewed studies published in English between January 2015 and July 2026 were included in the quantitative synthesis. The pooled effects were estimated using random-effects models to accommodate the methodological and biological heterogeneity across the selected studies. In dairy goats, dietary supplementation with the microalga *Schizochytrium* sp. did not affect ($p > 0.05$) dry matter intake, but increased ($p < 0.05$) milk production and milk protein content. In contrast, a lower ($p < 0.001$) concentration of fat and lactose was observed in the milk of dairy goats supplemented with *Schizochytrium* sp. microalgae. Dietary supplementation

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with *Schizochytrium* sp. microalgae decreased ($p < 0.05$) the concentration of caproic, undecanoic, myristoleic, pentadecanoic, palmitoleic, heptadecanoic, margoleic, stearic, oleic, and arachidic fatty acids, total saturated fatty acids (SFAs), and the ω-6/ω-3 ratio in the milk of dairy goats. In contrast, dietary supplementation with *Schizochytrium* sp. microalgae increased ($p < 0.05$) the concentration of caprylic, capric, lauric, myristic, vaccenic, conjugated linoleic, eicosapentaenoic, behenic, docosahexaenoic, and nervonic fatty acids, total polyunsaturated fatty acids (PUFAs), and total ω-3 in the milk of dairy goats. In conclusion, dietary supplementation with *Schizochytrium* sp. microalgae was associated with a modest increase in milk production and changes in the milk fatty acid profile by increasing conjugated linoleic, eicosapentaenoic, docosahexaenoic, and total PUFAs, while simultaneously decreasing total SFAs and the ω-6/ω-3 ratio.

Keywords: marine microalgae; functional milk; polyunsaturated fatty acids; omega-3 fatty acids; dairy goats; goat milk

1. Introduction

Milk produced by ruminants is an important component of human nutrition because it provides a wide range of essential nutrients, including high-quality proteins, lipids, carbohydrates, vitamins, and minerals [1]. Among ruminant-derived dairy products, goat milk has attracted increasing scientific and commercial interest because of its distinctive nutritional characteristics and potential health benefits [2]. Goat milk production and consumption are particularly important in many developing regions, where goat farming can be more adaptable and economically viable than cattle production, thereby contributing to the availability of animal-derived nutrients for human populations [3]. Consequently, nutritional strategies aimed at improving goat milk production and composition have received considerable attention in animal nutrition research [4]. Lipid-rich feed ingredients, including fish oil [5], linseed oil [6], sunflower oil [7], and marine microalgae [8], have been evaluated as dietary strategies to modify milk fatty acid composition and increase the transfer of nutritionally relevant fatty acids to goat milk. Among marine microalgae, *Schizochytrium* sp. has received particular attention because of its high lipid content and abundance of docosahexaenoic acid (DHA), making it a concentrated dietary source of long-chain n-3 polyunsaturated fatty acids (PUFAs) for lactating ruminants [8–11]. Experimental studies in dairy goats have shown that dietary supplementation with *Schizochytrium* sp. can modify milk fatty acid composition, particularly by increasing DHA and other PUFAs [12–14]. Mavrommatis and Tsiplakou [8] reported that supplementation with 10 g/kg DM of *Schizochytrium* sp. increased milk PUFAs without reducing milk fat concentration, whereas supplementation at 20 and 30 g/kg DM induced milk fat depression. Zhu et al. [11] reported contrasting dose-dependent responses to *Schizochytrium* sp. supplementation, as 7 g/kg DM decreased the proportion of DHA by 37%, whereas supplementation at 12 and 16 g/kg DM increased DHA by 113 and 158%, respectively, compared with the control. More recent lipidomic analyses have provided additional evidence that *Schizochytrium* supplementation modifies the molecular lipid profile of goat milk, including the abundance and distribution of DHA- and docosapentaenoic acid (DPA)-containing lipid species [15,16].

The productive and milk lipid responses of dairy goats to dietary *Schizochytrium* sp. vary across experimental conditions [8,12,17]. Supplementation level represents an important source of variation because different inclusion rates have been associated with changes in feed intake, milk fat concentration, oxidative status, and milk fatty acid composition [8,18]. Dietary composition may further modulate these responses. Changes

in the forage-to-concentrate ratio in diets supplemented with *Schizochytrium* sp. have been associated with differences in milk fatty acid composition and oxidative status [19]. Furthermore, dietary *Schizochytrium* alters the abundance of ruminal microorganisms associated with fibrolysis, methanogenesis, and lipid metabolism, with responses varying according to supplementation level and dietary conditions [20,21]. At the quantitative level, substantial heterogeneity has also been detected among studies evaluating microalgae supplementation in dairy goats [17]. Meta-regression and subgroup analyses have identified factors including microalgal species, supplementation level, and animal breed as potential contributors to variation in productivity, milk composition, and fatty acid responses [4,17].

Previous meta-analyses have advanced the understanding of microalgae supplementation in lactating ruminants, but the effects of *Schizochytrium* sp. specifically in dairy goats have not yet been comprehensively quantified. Orzuna-Orzuna et al. [4] synthesized 20 studies involving lactating small ruminants supplemented with different microalgal sources, whereas Orzuna-Orzuna et al. [22] specifically evaluated *Schizochytrium* sp. but restricted the target population to dairy cows. More recently, Boukrouh et al. [17] evaluated microalgae supplementation specifically in dairy goats, but their database combined different microalgal taxa and included only studies published between 2015 and 2022. Although their meta-analysis comprised 17 peer-reviewed articles, only six specifically evaluated dietary *Schizochytrium* sp. in dairy goats [17]. In contrast, the present meta-analysis includes 16 peer-reviewed articles specifically evaluating *Schizochytrium* sp. supplementation in dairy goats. This intervention-specific dataset avoids pooling *Schizochytrium* sp. with microalgae differing in biochemical and fatty acid composition.

A quantitative meta-analytic approach is particularly valuable because it integrates evidence across independent experiments, accounts for differences in study precision, provides an overall estimate of the magnitude and direction of the intervention effect, and allows between-study heterogeneity to be formally quantified [23]. Compared with a narrative synthesis, meta-analysis therefore provides a more systematic and statistically explicit framework for assessing the consistency of responses across studies and for identifying variability that may not be readily apparent from individual experiments [24]. An updated host- and intervention-specific meta-analysis is therefore warranted to quantify the magnitude, direction, and consistency of responses associated with dietary *Schizochytrium* sp. Accordingly, the present meta-analysis aimed to evaluate the effects of *Schizochytrium* sp. supplementation on dry matter intake, milk yield, milk composition, and the milk fatty acid profile of dairy goats. We hypothesized that dietary *Schizochytrium* sp. would modify lactational responses and the nutritional characteristics of milk fat by increasing long-chain n-3 PUFAs and altering the relative proportions of saturated and unsaturated fatty acids.

2. Materials and Methods

2.1. Literature Search

The research question was formulated according to the PICO framework (Population, Intervention, Comparison, and Outcome) proposed by Hooijmans et al. [25]. Within this framework, the target population (P) comprised dairy goats, whereas the intervention (I) corresponded to dietary supplementation with *Schizochytrium* sp. microalgae. The comparison (C) evaluated dairy goats receiving diets supplemented with *Schizochytrium* sp. against control groups of dairy goats fed equivalent diets without *Schizochytrium* sp. supplementation. The predefined outcomes (O) included treatment means for milk production, milk composition, and milk fatty acid profile. Eligible studies were identified through a systematic literature search conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [26]. Searches were performed in the Scopus, Web of Science, ScienceDirect, and Google Scholar databases to

identify peer-reviewed articles published in English between January 2015 and July 2026 (Figure 1). The search strategy reported for the four databases combined the following terms and Boolean operators: (goats OR dairy goats) AND (microalgae OR *Schizochytrium* sp.) AND (milk production OR milk yield OR milk composition OR milk quality OR milk fatty acid profile). The literature search was restricted to studies published between January 2015 and July 2026 to provide an up-to-date synthesis of the available scientific evidence. This timeframe was selected to focus on recent developments in experimental methodologies and research practices, while maintaining a clearly defined and consistent period for study selection. Although earlier studies may provide valuable information, they were excluded to ensure that the meta-analysis specifically reflected the most recent decade of research in the field.

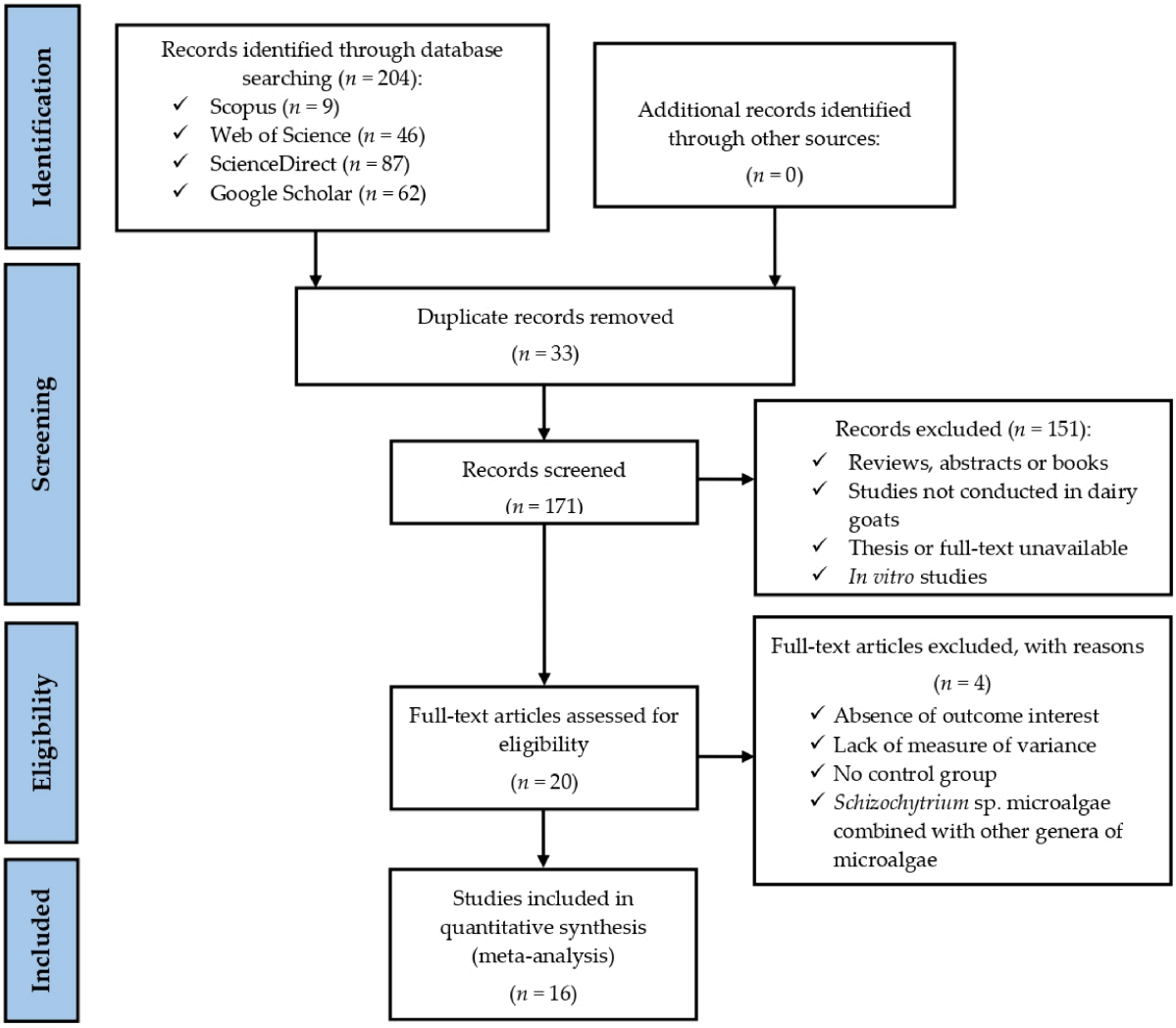

Figure 1. A PRISMA flow diagram detailing the literature search strategy and study selection for the meta-analysis.

2.2. Eligibility Criteria

The database assembled for the present meta-analysis comprised 16 peer-reviewed studies that satisfied all predefined eligibility criteria (Table A1). Only original articles published in English between January 2015 and July 2026 were considered for inclusion. Eligible studies were required to evaluate clinically healthy dairy goats, whereas experiments involving gastrointestinal parasitic or bacterial challenge models were excluded. Likewise, studies assessing *Schizochytrium* sp. in combination with other microalgal genera were

not considered to avoid potential confounding effects attributable to mixed supplementation strategies. A formal study-level risk-of-bias assessment was not documented in the present synthesis; this limits certainty in the pooled estimates and should be addressed in future updates. The literature search was restricted to January 2015–July 2026 to synthesize contemporary scientific evidence on *Schizochytrium* spp. supplementation in dairy goats within a clearly defined timeframe, while acknowledging that relevant earlier studies may have been excluded.

To be eligible, each study had to include a control group receiving a basal diet without *Schizochytrium* sp. supplementation and at least one experimental group supplemented with the microalga. In addition, studies were required to report the statistical information necessary for quantitative synthesis, including the number of experimental units (*n*), treatment means, and the standard error of the mean (SEM) for at least one of the predefined outcome variables related to milk yield, milk composition, or milk fatty acid profile. Consistent with the methodological recommendations of Borenstein et al. [27], secondary sources of information, including literature reviews, conference proceedings, undergraduate and postgraduate theses, and books, were excluded to minimize the risk of incorporating duplicate datasets into the meta-analysis.

2.3. Data Extraction

For each of the 16 studies included in the meta-analysis (Table A1), the n, treatment means, and SEM were extracted for all predefined outcome variables. These variables were grouped into two major categories: (1) productive traits, including dry matter intake, milk production, and the concentrations (g/100 g) of milk fat, protein, and lactose; and (2) milk fatty acid composition, comprising butyric, caproic, caprylic, capric, undecanoic, lauric, myristic, myristoleic, pentadecanoic, palmitic, palmitoleic, heptadecanoic, margaroleic, stearic, vaccenic, oleic, linoleic, conjugated linoleic, α-linolenic, arachidic, eicosapentaenoic, behenic, docosahexaenoic, nervonic, total SFAs, total MUFAs, total PUFAs, total omega-3, and total omega-6 fatty acids. In addition to the quantitative response variables, descriptive information was compiled from each study to characterize the experimental conditions. The extracted data included the first author and year of publication, days in milk at the beginning of the experiment, duration of the supplementation period, dietary inclusion level of *Schizochytrium* sp. (g/kg of diet), and forage proportion in the experimental diets (g/kg of diet).

2.4. Statistical Analysis, Heterogeneity and Publication Bias

When standard deviations (SD) were unavailable, they were estimated from the reported standard errors of the mean (SEM) using the formula $SD = SEM \times \sqrt{n}$, where n represents the number of experimental replicates [27,28]. The effects of dietary *Schizochytrium* sp. supplementation in dairy goats were quantified using a three-level random-effects meta-analytic model implemented through the rma.mv() function of the metafor package in R software (version 4.4.2), following the methodological framework described by Viechtbauer [29]. Pooled effects were expressed as weighted mean differences (WMDs). To account for the non-independence of multiple effect sizes originating from the same study, a hierarchical random-effects structure was specified by nesting individual effect sizes within studies (random = ~1 | study_id/effect_id). Between-study and within-study variance components were estimated using restricted maximum likelihood (REML). This approach accommodated the clustering of effect sizes within studies while allowing individual comparisons to contribute to the pooled estimates. Potential sampling-error dependence associated with shared experimental groups or repeated measurements was considered separately when specifying the sampling variance–covariance structure.

The extent of variability among studies was evaluated through Cochran's Q statistic and the I^2 heterogeneity index [30]. Between-study heterogeneity was considered significant when the Q test indicated $p \leq 0.05$, and the I^2 value was >50% [27]. Potential publication bias was assessed using Begg's rank correlation test [31] and Egger's regression test [32], with statistical evidence of bias considered significant at $p \leq 0.05$. Meta-regression was not performed because the limited number of independent studies for individual outcomes did not support reliable moderator analyses; therefore, potential dose-, diet-, and breed-related effects remain unresolved.

3. Results

3.1. Milk Production and Composition

Dietary supplementation with the microalga *Schizochytrium* sp. did not affect ($p > 0.05$) dry matter intake (DMI) in dairy goats (Table 1). However, dietary supplementation with *Schizochytrium* sp. increased ($p < 0.05$) milk production (MP) and milk protein concentration in dairy goats. In contrast, lower ($p < 0.001$) fat and lactose concentrations were observed in the milk of dairy goats supplemented with *Schizochytrium* sp. (Table 1). Furthermore, Table 1 shows that no statistically significant between-study heterogeneity was detected using Cochran's Q test ($p > 0.05$; $I^2 < 50\%$), nor was there significant evidence of publication bias according to Egger's and Begg's tests ($p > 0.05$), for dry matter intake (DMI), milk production (MP), or milk fat, protein, and lactose concentrations in dairy goats. However, in the present meta-analysis, the results of the heterogeneity assessment and Egger's and Begg's tests for DMI should be interpreted with caution because this outcome was evaluated in only seven studies. The limited number of studies may reduce the statistical power of these tests to detect between-study heterogeneity, small-study effects, and potential publication bias.

Table 1. Milk production and milk composition of dairy goats supplemented with *Schizochytrium* sp. microalgae.

Item	N (NC)				Heterogeneity		Begg Test [2]	Egger Test [3]
		Control Means (SD)	WMD (95% CI)	WMD *p*-Value	I^2 (%)	Cochran's Q *p*-Value [1]	*p*-Value	*p*-Value
DMI, kg/d	7 (9)	2.33 (0.29)	0.028 (−0.096; 0.153)	0.656	0.00	0.999	0.389	0.310
MP, kg/d	11 (21)	1.76 (0.56)	0.058 (0.022; 0.095)	0.002	0.00	0.978	0.347	0.668
Milk composition, g/100 g								
Fat	13 (23)	3.40 (0.16)	−0.236 (−0.352; −0.120)	<0.001	46.80	0.066	0.647	0.794
Protein	11 (21)	3.14 (0.11)	0.082 (0.051; 0.114)	<0.001	0.00	0.998	0.762	0.382
Lactose	10 (20)	4.61 (0.15)	−0.156 (−0.246; −0.066)	<0.001	41.42	0.103	0.438	0.364

N: number of articles; NC: Number of comparisons between dairy goats supplemented with *Schizochytrium* sp. microalgae in diets and dairy goats in control treatments fed with diets without *Schizochytrium* sp. microalgae; SD: standard deviation; WMD: weighted mean differences between dairy goats supplemented with *Schizochytrium* sp. microalgae in diets and dairy goats in control treatments fed with diets without *Schizochytrium* sp. microalgae; CI: confidence interval of WMD; I^2: proportion of total variation in size effect estimates that is due to heterogeneity; [1]: *p*-value to Cochran's Q statistic; [2]: Begg's adjusted rank correlation; [3]: Egger's regression asymmetry test; DMI: dry matter intake; MP: milk production.

3.2. Fatty Acid Profile in Milk

Dietary supplementation with *Schizochytrium* sp. microalgae did not affect ($p > 0.05$) the milk concentration of butyric (C4:0), palmitic (C16:0), linoleic (C18:2 n-6 cis), α-linolenic (C18:3 n-3), and total MUFAs in the milk of dairy goats (Table 2). However, dietary supplementation with *Schizochytrium* sp. microalgae decreased ($p < 0.05$) the concentration

of caproic (C6:0), undecanoic (C11:0), myristoleic (C14:1), pentadecanoic (C15:0), palmitoleic (C16:1), heptadecanoic (C17:0), margoleic (C17:1), stearic (C18:0), oleic (C18:1 n-9 cis), arachidic (C20:0), total SFAs and the ω-6/ω-3 ratio in milk of dairy goats. In contrast, Table 2 shows that dietary supplementation with *Schizochytrium* sp. microalgae increased ($p < 0.05$) the concentration of caprylic (C8:0), capric (C10:0), lauric (C12:0), myristic (C14:0), vaccenic (C18:1 trans-11), conjugated linoleic acid (C18:2 cis-9, trans-11), eicosapentaenoic (C20:5 n-3), behenic (C22:0), docosahexaenoic (C22:6 n-3), nervonic (C24:1), total PUFAs and total ω-3 in the milk of dairy goats. On the other hand, Cochran's Q tests did not detect statistically significant heterogeneity ($p > 0.05$), although I^2 values indicated non-negligible variability for some outcomes, nor publication bias (Egger and Begg tests, $p > 0.05$) in any of the fatty acids of dairy goat milk (Table 2). Although no significant heterogeneity or publication bias was detected, these findings should be interpreted cautiously because most milk fatty acid outcomes were derived from only three to six studies. The small evidence base may limit the reliability and statistical power of heterogeneity assessments and of Egger's and Begg's tests, particularly for identifying between-study variability, small-study effects, and potential publication bias [27].

Table 2. Fatty acid profile (FAs) (% of total FAs) in milk from dairy goats supplemented with *Schizochytrium* sp. microalgae.

Item	N (NC)				Heterogeneity		Begg Test [2]	Egger Test [3]
		Control Means (SD)	WMD (95% CI)	WMD *p*-Value	I^2 (%)	Cochran's Q *p*-Value [1]	*p*-Value	*p*-Value
Butyric (C4:0)	6 (12)	1.83 (0.69)	0.113 (−0.052; 0.277)	0.180	37.02	0.122	0.241	0.493
Caproic (C6:0)	5 (11)	1.84 (1.01)	−0.121 (−0.155; −0.086)	<0.001	0.00	0.441	0.098	0.124
Caprylic (C8:0)	6 (12)	4.06 (1.33)	0.201 (0.160; 0.242)	<0.001	0.00	0.625	0.076	0.145
Capric (C10:0)	6 (12)	10.11 (0.95)	0.970 (0.705; 1.235)	<0.001	19.69	0.250	0.777	0.400
Undecanoic (C11:0)	4 (8)	0.27 (0.06)	−0.179 (−0.281; −0.077)	<0.001	49.69	0.077	0.139	0.110
Lauric (C12:0)	5 (11)	4.63 (0.60)	0.431 (0.162; 0.700)	0.002	41.01	0.094	0.519	0.637
Myristic (C14:0)	5 (11)	10.56 (1.06)	0.434 (0.022; 0.845)	0.039	43.79	0.076	0.747	0.214
Myristoleic (C14:1)	4 (10)	0.32 (0.12)	−0.046 (−0.061; −0.030)	<0.001	0.00	0.678	0.850	0.959
Pentadecanoic (C15:0)	4 (9)	1.02 (0.14)	−0.129 (−0.183; −0.076)	<0.001	44.75	0.064	0.259	0.304
Palmitic (C16:0)	6 (12)	28.59 (3.71)	−0.273 (−1.190; 0.643)	0.559	44.40	0.065	0.336	0.865
Palmitoleic (C16:1)	4 (10)	0.91 (0.22)	−0.147 (−0.259; −0.034)	0.011	22.20	0.177	0.349	0.693
Heptadecanoic (C17:0)	4 (10)	0.63 (0.11)	−0.033 (−0.063; −0.003)	0.030	26.16	0.237	0.258	0.919
Margoleic (C17:1)	5 (11)	0.28 (0.08)	−0.123 (−0.174; −0.071)	<0.001	27.50	0.216	0.707	0.429
Stearic (C18:0)	6 (12)	7.30 (2.02)	−3.445 (−4.936; −1.954)	<0.001	23.94	0.240	0.420	0.218
Vaccenic (C18:1 trans-11)	3 (9)	1.81 (0.49)	0.428 (0.274; 0.583)	<0.001	6.17	0.384	0.454	0.128
Oleic (C18:1 n-9 cis)	6 (12)	18.63 (3.85)	−6.585 (−9.098; −4.072)	<0.001	44.78	0.109	0.998	0.739

Table 2. *Cont.*

Item	N (NC)				Heterogeneity		Begg Test [2]	Egger Test [3]
		Control Means (SD)	WMD (95% CI)	WMD *p*-Value	I^2 (%)	Cochran's Q *p*-Value [1]	*p*-Value	*p*-Value
Linoleic (C18:2 n-6 cis)	4 (10)	2.85 (0.86)	−0.259 (−0.755; 0.237)	0.306	20.30	0.463	0.411	0.500
Conjugated linoleic (C18:2 cis-9, trans-11)	3 (5)	0.88 (0.20)	2.907 (2.598; 3.216)	<0.001	0.00	0.597	0.179	0.425
α-linolenic (C18:3 n-3)	5 (11)	0.26 (0.11)	0.016 (−0.002; 0.034)	0.076	0.00	0.999	0.627	0.207
Arachidic (C20:0)	4 (8)	0.14 (0.05)	−0.018 (−0.027; −0.009)	<0.001	16.76	0.302	0.290	0.114
Eicosapentaenoic (C20:5 n-3)	4 (8)	0.10 (0.04)	0.044 (0.019; 0.070)	<0.001	10.42	0.288	0.281	0.186
Behenic (C22:0)	5 (11)	0.03 (0.01)	0.030 (0.013; 0.048)	<0.001	46.22	0.075	0.420	0.340
Docosahexaenoic (C22:6 n-3)	5 (11)	0.04 (0.01)	0.251 (0.150; 0.352)	<0.001	23.85	0.299	0.747	0.489
Nervonic (C24:1)	3 (9)	0.05 (0.02)	0.390 (0.239; 0.542)	<0.001	37.50	0.363	0.317	0.429
Total SFAs, %	4 (10)	71.88 (2.40)	−2.044 (−3.328; −0.760)	0.002	30.03	0.169	0.851	0.757
Total MUFAs, %	4 (10)	23.30 (2.03)	0.062 (−2.117; 2.241)	0.956	24.73	0.421	0.708	0.845
Total PUFAs, %	4 (10)	4.37 (0.65)	1.237 (0.950; 1.524)	<0.001	14.68	0.452	0.851	0.177
Total omega-3 (ω-3)	3 (9)	0.39 (0.08)	0.710 (0.299; 1.121)	<0.001	0.00	0.969	0.912	0.085
Total omega 6 (ω-6)	3 (9)	3.40 (1.00)	0.172 (−0.066; 0.409)	0.156	48.65	0.061	0.437	0.271
ω-6/ω-3 ratio	3 (9)	9.6 (2.08)	−5.272 (−5.796; −4.748)	<0.001	25.55	0.234	0.317	0.619

N: number of articles; NC: Number of comparisons between dairy goats supplemented with *Schizochytrium* sp. microalgae in diets and dairy goats in control treatments fed with diets without *Schizochytrium* sp. microalgae; SD: standard deviation; WMD: weighted mean differences between dairy goats supplemented with *Schizochytrium* sp. microalgae in diets and dairy goats in control treatments fed with diets without *Schizochytrium* sp. microalgae; CI: confidence interval of WMD; I^2: proportion of total variation in size effect estimates that is due to heterogeneity; [1]: *p*-value to Cochran's Q statistic; [2]: Begg's adjusted rank correlation; [3]: Egger's regression asymmetry test; SFAs: saturated fatty acids; MUFAs: monounsaturated fatty acids; PUFAs: polyunsaturated fatty acids.

4. Discussion

4.1. Milk Production and Composition

The present meta-analysis showed that dietary supplementation with *Schizochytrium* sp. did not affect DMI in dairy goats. This response is noteworthy because *Schizochytrium* is rich in long-chain PUFAs, particularly DHA, which can modify ruminal microbial populations involved in fiber degradation and biohydrogenation [19,20]. Consequently, changes in ruminal microbial ecology could potentially influence nutrient digestion and, indirectly, voluntary feed intake. However, the absence of an overall effect on DMI suggests that these ruminal modifications were insufficient to consistently alter feed intake across studies. This result agrees with Boukrouh et al. [17], who also reported no significant effect of microalgae supplementation on DMI in dairy goats.

Milk production increased following *Schizochytrium* sp. supplementation despite the absence of changes in DMI (pooled increase: 0.058 kg/day, approximately 58 g/day or 3.3% of the 1.76 kg/day control mean), indicating that the greater milk output was not

attributable to increased feed consumption. Although statistically significant, the absolute increase was modest and its economic importance depends on supplementation cost, milk price, and farm conditions. Instead, this response may reflect changes in nutrient digestion, availability, or partitioning toward milk synthesis. Microalgae provide protein, essential amino acids, minerals, vitamins, and lipids that can contribute nutrients to support lactation [33,34]. Moreover, Boukrouh et al. [17] reported improvements in crude protein and fiber digestibility in microalgae-supplemented goats, which could increase nutrient availability for milk synthesis. Nevertheless, because the present meta-analysis did not evaluate nutrient digestibility, metabolizable nutrient supply, or feed efficiency, the mechanisms underlying the increase in milk production cannot be established conclusively.

The positive effect of *Schizochytrium* sp. on milk production differs partially from previous meta-analytical evidence. Orzuna-Orzuna et al. [22] also reported increased milk production in dairy cows supplemented with *Schizochytrium* sp., but this response was accompanied by decreased DMI. Conversely, supplementation with different microalgae species increased both milk production and DMI in lactating small ruminants [4]. These contrasting intake responses indicate that increased milk production following microalgae supplementation does not necessarily depend on greater feed consumption. Differences among studies may be associated with animal species, microalgae type and dose, stage of lactation, basal diet, and supplementation period, factors previously identified as moderators of lactational responses to microalgae [4,17,35].

Milk protein concentration increased following *Schizochytrium* sp. supplementation, contrasting with the lack of a significant effect on milk protein concentration previously reported in dairy cows supplemented with *Schizochytrium* sp. [22]. In dairy goats, Boukrouh et al. [17] found that supplementation with different microalgal species increased milk protein yield, although milk protein concentration was not significantly affected. Microalgae can provide protein and essential amino acids, including methionine and lysine [33,34], and improvements in protein digestibility may increase amino acid availability for mammary protein synthesis [17]. Greater amino acid availability could therefore partly explain the increase in milk protein concentration observed in the present meta-analysis. However, this mechanism remains speculative because microbial protein synthesis, duodenal amino acid flow, plasma amino acid concentrations, and mammary amino acid uptake were not consistently reported in the included studies.

Milk fat concentration decreased following *Schizochytrium* sp. supplementation, consistent with previous meta-analytical evidence in dairy cows and small ruminants [4,22] and with experimental studies in goats supplemented with DHA-rich marine microalgae [8,12]. This response may be related to alterations in ruminal biohydrogenation induced by the high supply of long-chain PUFAs from marine microalgae. These fatty acids can modify ruminal microbial populations and shift biohydrogenation pathways, promoting the accumulation of specific trans fatty acid intermediates with antilipogenic activity [36–38]. Once available to the mammary gland, these intermediates can inhibit pathways involved in de novo fatty acid synthesis, thereby reducing milk fat synthesis and concentration [38]. The changes in milk fatty acid composition observed in the present meta-analysis are consistent with this mechanism. However, direct evidence of changes in ruminal biohydrogenation intermediates and mammary lipogenic activity was not consistently available across the included studies.

Milk lactose concentration decreased following *Schizochytrium* sp. supplementation despite the simultaneous increase in milk production. Because lactose is a major osmotic regulator of milk secretion, this combination of responses suggests that the lower lactose concentration did not impair overall mammary secretory activity. The reduction could partly reflect dilution associated with greater milk output or changes in glucose partitioning

among mammary metabolic pathways. Boukrouh et al. [17] reported increased blood glucose and lactose yield in microalgae-supplemented goats without a corresponding increase in milk production, further indicating that the relationships among systemic glucose availability, lactose synthesis, and milk secretion are complex. Consequently, the mechanism responsible for the lower lactose concentration cannot be established from the variables available in the present meta-analysis.

Overall, the effects of *Schizochytrium* sp. on milk production and composition suggest modifications in nutrient utilization and mammary metabolism rather than responses driven by increased feed intake. Nevertheless, the mechanisms underlying the increases in milk production and protein concentration and the reductions in milk fat and lactose require further investigation through direct measurements of nutrient digestibility, metabolizable nutrient supply, and mammary. Although I^2 was 0% for DMI, milk yield, and milk protein, moderate heterogeneity estimates for milk fat and lactose (46.80% and 41.42%, respectively) warrant caution when interpreting consistency across studies. Interpretation is also limited by the absence of a documented formal risk-of-bias appraisal and the small number of studies for several fatty acid outcomes.

4.2. Fatty Acid Profile in Milk

Dietary supplementation with *Schizochytrium* sp. markedly modified the fatty acid profile of goat milk, decreasing total SFAs while increasing total PUFAs and n-3 fatty acids and reducing the n-6/n-3 ratio. These responses are consistent with the lipid composition of *Schizochytrium*, which is particularly rich in long-chain n-3 PUFAs, especially DHA [39]. Similar changes have been reported in previous meta-analyses evaluating microalgae supplementation in small ruminants, dairy goats, and dairy cows [4,17,22,35]. In dairy goats, Boukrouh et al. [17] similarly reported lower C18:0 and C18:1 cis-9 and higher EPA, DHA, PUFAs, and n-3 fatty acids following microalgae supplementation.

The increases in C8:0, C10:0, C12:0, and C14:0 suggest that mammary de novo synthesized fatty acids may respond differently to *Schizochytrium* supplementation among ruminant species. Several short- and medium-chain fatty acids decreased in dairy cows supplemented with *Schizochytrium* sp. [22], whereas increases were reported in a previous meta-analysis of microalgae supplementation in lactating small ruminants [4]. Because acetate and β-hydroxybutyrate are major carbon precursors for mammary de novo fatty acid synthesis [40], differences in precursor supply or regulation of mammary lipogenesis may contribute to these contrasting responses. Nevertheless, the available data do not allow these mechanisms to be distinguished.

The reduction in total SFAs occurred despite increases in C8:0, C10:0, C12:0, and C14:0, indicating that *Schizochytrium* sp. differentially affected individual SFAs rather than uniformly reducing their concentration in milk. In contrast, C6:0, C15:0, C17:0, C18:0, and C20:0 decreased, with the reduction in C18:0 being particularly pronounced. This distinction is physiologically relevant because short- and medium-chain fatty acids are synthesized predominantly de novo in mammary epithelial cells, whereas C18 fatty acids originate mainly from circulating preformed fatty acids derived from dietary lipids, ruminal biohydrogenation, and adipose tissue mobilization [40]. Thus, the contrasting responses among individual SFAs may reflect concurrent effects of supplementation on ruminal lipid metabolism and mammary fatty acid synthesis.

The marked decrease in C18:0, together with the increase in vaccenic acid (C18:1 trans-11), is consistent with altered terminal ruminal biohydrogenation. Unsaturated C18 fatty acids undergo sequential microbial transformations in the rumen, with C18:0 representing a major end product, whereas microalgae long-chain PUFAs can interfere with biohydrogenation and promote the accumulation of trans-C18:1 intermediates [37,41]. For

example, in dairy goats, *Schizochytrium* supplementation has been associated with reduced abundance of *Butyrivibrio proteoclasticus*, a bacterium involved in the terminal stages of biohydrogenation [20]. Therefore, reduced terminal hydrogenation provides a plausible explanation for the simultaneous decrease in C18:0 and accumulation of vaccenic acid, although ruminal biohydrogenation was not directly evaluated in all studies included in the present meta-analysis.

The parallel increase in cis-9, trans-11 CLA is also consistent with greater availability of vaccenic acid. In ruminants, a substantial proportion of cis-9, trans-11 CLA in milk is synthesized endogenously through mammary Δ9-desaturation of C18:1 trans-11 [37,40]. Greater ruminal escape and mammary availability of vaccenic acid could therefore contribute to the CLA enrichment observed in the present meta-analysis. Conversely, the reduction in C18:1 cis-9 may partly reflect the lower availability of C18:0, because stearic acid is an important substrate for mammary synthesis of oleic acid through the same Δ9-desaturase pathway [8,40]. Together, these responses indicate that *Schizochytrium* supplementation may modify both the ruminal supply of C18 intermediates and their subsequent mammary metabolism. The apparent discrepancies between the pooled estimates for individual fatty acids and broader fatty acid categories can be attributed to differences in the number of studies and comparisons included in each analysis. Specifically, CLA was evaluated in three studies and five comparisons, whereas PUFA included four studies and ten comparisons. Similarly, oleic and stearic acids were evaluated in six studies and twelve comparisons each, compared with four studies and ten comparisons for MUFA. Therefore, these independently calculated pooled estimates are not directly comparable or necessarily additive, as they represent different datasets and statistical weights rather than identical sets of observations.

The decreases in C15:0 and C17:0 may also reflect changes in ruminal microbial lipid metabolism. Odd-chain fatty acids in ruminant milk are substantially derived from ruminal bacterial lipids, although endogenous synthesis also contributes [42]. Because DHA-rich microalgae can alter the ruminal bacterial community in goats [19,20,41], changes in microbial populations or metabolism provide a plausible explanation for the lower concentrations of these fatty acids. However, the relative contribution of microbial and endogenous pathways cannot be determined from the variables available in the present meta-analysis.

The increases in EPA (C20:5 n-3) and DHA (C22:6 n-3) represent particularly relevant changes in the milk fatty acid profile. *Schizochytrium* is a rich dietary source of DHA, and although DHA undergoes extensive ruminal metabolism, a fraction can escape biohydrogenation and become available for intestinal absorption and subsequent mammary uptake [11]. Experimental studies have shown that DHA biohydrogenation involves several conjugated and trans C22 intermediates, demonstrating the complexity of its ruminal metabolism [43,44]. Consequently, the extent of milk DHA enrichment depends not only on dietary supply but also on the fraction that remains available for post-ruminal absorption and transfer to the mammary gland.

Recent lipidomic evidence provides additional support for the incorporation of *Schizochytrium*-derived long-chain n-3 PUFAs into goat milk. Wang et al. [16] identified 638 lipid molecular species and showed that *Schizochytrium* preferentially enriched DHA- and DPA-containing lipids. Increases in DHA-containing triacylglycerols and glycerophospholipids further demonstrate that supplementation modifies the molecular distribution of long-chain n-3 PUFAs within milk lipids [16]. These findings complement the increase in milk DHA detected in the present meta-analysis and indicate that the response extends beyond changes in total fatty acid proportions.

The increases in C22:0 and C24:1 indicate that *Schizochytrium* supplementation also affected less abundant long-chain fatty acids. However, the metabolic pathways respon-

sible for these responses remain uncertain, and the available evidence does not support attributing them directly to DHA metabolism. The increase in C24:1 is consistent with that previously reported in lactating small ruminants receiving microalgae [4], but further studies are required to determine whether changes in elongation, desaturation, ruminal metabolism, or preformed fatty acid supply are responsible.

The increase in total PUFAs and n-3 fatty acids, together with the reduction in total SFAs, indicates an overall shift in goat milk lipid composition following *Schizochytrium* sp. supplementation. Boukrouh et al. [17] similarly reported increased EPA, DHA, PUFAs, and n-3 fatty acids in microalgae-supplemented goats, whereas a recent meta-analysis in dairy cows identified microalgae species and inclusion level as important sources of variation and specifically associated *Schizochytrium* supplementation with increased milk DHA [35]. The nutritional relevance of the present findings is therefore most appropriately characterized as enrichment of goat milk with long-chain n-3 PUFAs and modification of its fatty acid composition, without inferring direct human-health effects from changes in individual fatty acid classes.

The reduction in the n-6/n-3 ratio was primarily driven by enrichment of the n-3 fraction, as total n-6 remained unchanged while EPA, DHA, and total n-3 increased. Thus, this response reflects a greater contribution of n-3 fatty acids to milk lipids rather than depletion of n-6 fatty acids. The observed EPA and DHA enrichment describes milk composition only; potential effects of consuming this milk on human cardiovascular outcomes were not assessed.

Overall, dietary *Schizochytrium* sp. supplementation produced a coherent modification of the goat milk fatty acid profile characterized by lower total SFAs and greater PUFAs and n-3 fatty acids. The reductions in C18:0 and C18:1 cis-9, increases in vaccenic acid and cis-9, trans-11 CLA, and enrichment of EPA and DHA are consistent with altered ruminal lipid metabolism and greater transfer of long-chain n-3 PUFAs into milk. Despite moderate heterogeneity (I^2 values close to 40% and 50%) in some individual responses, the available pooled evidence suggests that *Schizochytrium* sp. may enrich goat milk with long-chain n-3 PUFAs while modifying the relative proportions of several saturated and unsaturated fatty acids.

5. Limitations of the Meta-Analysis

Several limitations should be considered when interpreting the present meta-analysis. Although 16 peer-reviewed studies were included, the evidence base was limited for several outcomes. DMI was evaluated in seven studies, whereas most individual fatty acids and fatty acid classes were derived from only three to six studies. Consequently, pooled estimates for these outcomes should be interpreted cautiously because the small number of available studies may limit their precision and generalizability. The limited number of studies also reduces the statistical power of Begg's and Egger's tests; therefore, the absence of significant asymmetry should not be interpreted as definitive evidence that publication bias or small-study effects were absent. In addition, differences among studies in *Schizochytrium* inclusion level, basal diet, forage proportion, stage of lactation, supplementation period, and breed could contribute to variability in treatment responses, but the available number of studies was insufficient to robustly evaluate these factors through meta-regression. Furthermore, detailed information on control diet composition and the DHA concentration of the microalgal products was inconsistently reported across the original studies, preventing their systematic evaluation as potential moderators of treatment responses. Future studies should therefore further characterize dose-dependent responses and determine how dietary and animal-related factors influence the effects of *Schizochytrium* supplementation on milk production, composition, and fatty acid profile. Finally, a formal assessment of study-level

risk of bias was not conducted in the present meta-analysis. Although risk-of-bias evaluation is widely recognized as an important component of systematic evidence synthesis, it is not universally mandated across meta-analyses in animal science and animal nutrition research. Furthermore, substantial heterogeneity in experimental designs, methodological procedures, and reporting standards among animal-production studies may complicate the consistent application of a single standardized assessment framework. Nevertheless, the absence of a structured risk-of-bias evaluation represents a methodological limitation, as potential sources of systematic bias and their influence on the pooled effect estimates could not be comprehensively assessed. Consequently, this limitation introduces uncertainty regarding the internal validity and robustness of the synthesized evidence and should be considered when interpreting the findings. Because numerous fatty acid outcomes were tested without a documented multiplicity adjustment, some statistically significant findings may represent false-positive results and should be interpreted as exploratory.

6. Conclusions

Dietary supplementation with *Schizochytrium* sp. modestly increased milk production (WMD = 0.058 kg/day) and increased milk protein concentration and modified the fatty acid profile of dairy goat milk without affecting dry matter intake. Although *Schizochytrium* sp. supplementation decreased milk fat and lactose concentrations, it increased the proportions of conjugated linoleic acid, eicosapentaenoic acid, docosahexaenoic acid, total polyunsaturated fatty acids, and total omega-3 fatty acids, while reducing total saturated fatty acids and the omega-6/omega-3 ratio. These findings suggest that *Schizochytrium* sp. supplementation may enrich dairy goat milk with long-chain omega-3 polyunsaturated fatty acids, although estimates for several individual fatty acids were derived from only three to six studies. These changes should not be interpreted as demonstrating an overall improvement in milk nutritional value or benefits to human health, which were not directly assessed.

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Abbreviations

The following abbreviations are used in this manuscript:

DMI	Dry matter intake
MP	Milk production
C4:0	Butyric
C6:0	Caproic
C8:0	Caprylic
C10:0	Capric
C12:0	Lauric
C14:0	Myristic
C14:1	Myristoleic
C15:0	Pentadecanoic
C16:0	Palmitic
C16:1	Palmitoleic
C17:0	Heptadecanoic
C17:1	Margoleic
C18:0	Stearic
C18:1 trans-11	Vaccenic
C18:1 n-9 cis	Oleic
C18:2 n-6 cis	Linoleic
C18:2 cis-9, trans-11	Conjugated linoleic
C18:3 n-3	α-linolenic
C20:0	Arachidic
C20:5 n-3	Eicosapentaenoic
C22:0	Behenic
C22:6 n-3	Docosahexaenoic
C24:1	Nervonic
SFA	Saturated fatty acids
MUFA	Monounsaturated fatty acids
PUFA	Polyunsaturated fatty acids
WMD	Weighted mean differences
CI	Confidence intervals
CLA	Conjugated linoleic acid
EPA	Eicosapentaenoic acid
DHA	Docosahexaenoic acid

Appendix A

Table A1. Description of the studies included in the meta-analysis database.

Reference	Days in Milk	Supplementation Period, Days	Dose of *Schizochytrium* sp., g/kg DM	Forage in Diet, g/kg
Bernard et al. [45]	61	28	37.1	450
Beyzi and Dallı [10]	51	28	20	400
Bodnár et al. [46]	161	45	4.8	715
Delavaud et al. [47]	61	28	15	450
Fougère and Bernard [48]	61	28	15	450
Fougère et al. [12]	61	28	37.1	450
Fougère et al. [49]	61	28	15	450
Gebereyowhans et al. [9]	91	70	6.4, 10.8, 15.2	830
Martin et al. [50]	19	28	15	450
Mavrommatis et al. [18]	150	60	10, 20, 30	500
Mavrommatis and Tsiplakou [8]	150	74	10, 20, 30	500
Mavrommatis et al. [19]	150	74	10, 20, 30	500

Table A1. *Cont.*

Reference	Days in Milk	Supplementation Period, Days	Dose of *Schizochytrium* sp., g/kg DM	Forage in Diet, g/kg
Pajor et al. [13]	71	31	7.4	713
Pajor et al. [14]	NR	35	4.9	715
Wang et al. [16]	NR	28	100	NR
Zhu et al. [11]	NR	65	7, 12, 16	320

NR: not reported.

References

1. Altomonte, I.; Salari, F.; Licitra, R.; Martini, M. Use of microalgae in ruminant nutrition and implications on milk quality—A review. *Livest. Sci.* **2018**, *214*, 25–35. [CrossRef]
2. Mishra, S.; Kannaujia, S.; Dipt, A.; Singh, S.; Meena, S.; Duary, R.K.; Meena, K.K. Exploring the multifaceted potential of goat milk: Nutritional, processing, and commercial applications. *Int. Dairy J.* **2026**, *172*, 106447. [CrossRef]
3. Bandara, A.L.J.; Johnson, S.R.E.; Lankanatha, H.K.D.M.P.; Guruge, T.P.S.R.; Jayasinghe, K.L.A.M.; Abeysiriwardana, P.C.; Kuruppu, I.V. Exploring the commercial viability of goat milk from a developing country perspective: Implications for consumer preferences, market dynamics, and food security. *Small Rumin. Res.* **2025**, *250*, 107559. [CrossRef]
4. Orzuna-Orzuna, J.F.; Chay-Canul, A.J.; Lara-Bueno, A. Performance, milk fatty acid profile and oxidative status of lactating small ruminants supplemented with microalgae: A meta-analysis. *Small Rumin. Res.* **2023**, *226*, 107031. [CrossRef]
5. Thanh, L.P.; Loor, J.J.; Mai, D.T.T.; Hang, T.T.T. Effect of fish oil and linseed oil on intake, milk yield and milk fatty acid profile in goats. *Animals* **2023**, *13*, 2174. [CrossRef]
6. Kholif, A.E.; Morsy, T.A.; Abdo, M.M. Crushed flaxseed versus flaxseed oil in the diets of Nubian goats: Effect on feed intake, digestion, ruminal fermentation, blood chemistry, milk production, milk composition and milk fatty acid profile. *Anim. Feed Sci. Technol.* **2018**, *244*, 66–75. [CrossRef]
7. Darabighane, B.; Ghavipanje, N.; Robles Jimenez, L.E.; González-Ronquillo, M.; Vargas-Bello-Pérez, E. Meta-analysis of dietary sunflower oil supplementation for dairy goats: Performance, milk composition, and milk fatty acid profile. *Chil. J. Agric. Anim. Sci.* **2024**, *40*, 266–282. [CrossRef]
8. Mavrommatis, A.; Tsiplakou, E. The impact of the dietary supplementation level with *Schizochytrium* sp. on milk chemical composition and fatty acid profile 2020, of both blood plasma and milk of goats. *Small Rumin. Res.* **2020**, *193*, 106252. [CrossRef]
9. Gebereyowhans, S.; Quan, Z.H.; Zhang, S.; Pang, X.; Workelul, K.; Lu, J.; Lv, J. Inclusion of microalgae in the caprine diet improves nutritional profile of milk and its Camembert cheese. *Int. J. Dairy Technol.* **2023**, *76*, 801–812. [CrossRef]
10. Beyzi, S.B.; Dallı, C.Ç. Changes in the rumen and milk fatty acid profile and milk composition in response to fish and microalgae oils supplementation to diet alone or combination in dairy goats. *Trop. Anim. Health Prod.* **2023**, *55*, 407. [CrossRef]
11. Zhu, H.; Wang, X.; Zhang, W.; Zhang, Y.; Zhang, S.; Pang, X.; Lu, J.; Lv, J. Dietary *Schizochytrium* microalgae affect the fatty acid profile of goat milk: Quantification of docosahexaenoic acid (DHA) and its distribution at sn-2 position. *Foods* **2022**, *11*, 2087. [CrossRef]
12. Fougère, H.; Delavaud, C.; Bernard, L. Diets supplemented with starch and corn oil, marine algae, or hydrogenated palm oil differentially modulate milk fat secretion and composition in cows and goats: A comparative study. *J. Dairy Sci.* **2018**, *101*, 8429–8445. [CrossRef]
13. Pajor, F.; Egerszegi, I.; Steiber, O.; Bodnár, Á.; Póti, P. Effect of marine algae supplementation on the fatty acid profile of milk of dairy goats kept indoor and on pasture. *J. Anim. Feed Sci.* **2019**, *28*, 169–176. [CrossRef]
14. Pajor, F.; Egerszegi, I.; Szűcs, Á.; Póti, P.; Bodnár, Á. Effect of marine algae supplementation on somatic cell count, prevalence of udder pathogens, and fatty acid profile of dairy goats' milk. *Animals* **2021**, *11*, 1097. [CrossRef]
15. Ran, S.; Zhu, Y.; Wang, J.; Li, D.; Chen, X.; Lü, X.; Xiang, J.; Chen, H.; Wei, F. Lipidomics analysis of the effect of feeding *Schizochytrium* spp. on the fatty acid and lipid profiles of goat milk. *Food Sci.* **2023**, *44*, 227–234. [CrossRef]
16. Wang, J.; Ran, S.; Lv, X.; Wang, D.; Chen, H.; Wei, F. Comprehensive lipidomics analysis reveals the effects in goat milk from different ω-3 PUFA dietary supplementation by UPLC Q-TOF-MS/MS. *Food Chem. X* **2025**, *28*, 102581. [CrossRef]
17. Boukrouh, S.; Mnaouer, I.; Mendes de Souza, P.; Hornick, J.-L.; Nilahyane, A.; El Amiri, B.; Hirich, A. Microalgae supplementation improves goat milk composition and fatty acid profile: A meta-analysis and meta-regression. *Arch. Anim. Breed.* **2025**, *68*, 223–238. [CrossRef]
18. Mavrommatis, A.; Chronopoulou, E.G.; Sotirakoglou, K.; Labrou, N.E.; Zervas, G.; Tsiplakou, E. The impact of the dietary supplementation level with *Schizochytrium* sp. on the oxidative capacity of both goats' organism and milk. *Livest. Sci.* **2018**, *218*, 37–43. [CrossRef]

19. Mavrommatis, A.; Sotirakoglou, K.; Kamilaris, C.; Tsiplakou, E. Effects of inclusion of *Schizochytrium* spp. and forage-to-concentrate ratios on goats' milk quality and oxidative status. *Foods* **2021**, *10*, 1322. [CrossRef]
20. Mavrommatis, A.; Sotirakoglou, K.; Skliros, D.; Flemetakis, E.; Tsiplakou, E. Dose and time response of dietary supplementation with *Schizochytrium* sp. on the abundances of several microorganisms in the rumen liquid of dairy goats. *Livest. Sci.* **2021**, *247*, 104489. [CrossRef]
21. Mavrommatis, A.; Skliros, D.; Simoni, M.; Righi, F.; Flemetakis, E.; Tsiplakou, E. Alterations in the rumen particle-associated microbiota of goats in response to dietary supplementation levels of *Schizochytrium* spp. *Sustainability* **2021**, *13*, 607. [CrossRef]
22. Orzuna-Orzuna, J.F.; Godina-Rodríguez, J.E.; Garay-Martínez, J.R.; Reséndiz-González, G.; Joaquín-Cancino, S.; Lara-Bueno, A. Milk yield, composition, and fatty acid profile in milk of dairy cows supplemented with microalgae *Schizochytrium* sp.: A meta-analysis. *Agriculture* **2024**, *14*, 1119. [CrossRef]
23. Haidich, A.B. Meta-analysis in medical research. *Hippokratia* **2010**, *14*, 29–37.
24. Gurevitch, J.; Koricheva, J.; Nakagawa, S.; Stewart, G. Meta-analysis and the science of research synthesis. *Nature* **2018**, *555*, 175–182. [CrossRef]
25. Hooijmans, C.R.; de Vries, R.B.M.; Ritskes-Hoitinga, M.; Rovers, M.M.; Leeflang, M.M.; IntHout, J.; Wever, K.E.; Hooft, L.; de Beer, H.; Kuijpers, T.; et al. Facilitating healthcare decisions by assessing the certainty in the evidence from preclinical animal studies. *PLoS ONE* **2018**, *13*, e0187271. [CrossRef]
26. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ* **2009**, *339*, b2535. [CrossRef]
27. Borenstein, M.; Hedges, L.V.; Higgins, J.P.T.; Rothstein, H.R. *Introduction to Meta-Analysis*, 1st ed.; John Wiley & Sons, Ltd.: Chichester, UK, 2009; p. 413. [CrossRef]
28. DerSimonian, R.; Laird, N. Meta-analysis in clinical trials. *Control. Clin. Trials* **1986**, *7*, 177–188. [CrossRef]
29. Viechtbauer, W. Conducting meta-analyses in R with the metafor package. *J. Stat. Softw.* **2010**, *36*, 1–48. [CrossRef]
30. Koricheva, J.; Gurevitch, J.; Mengersen, K. *Handbook of Meta-Analysis in Ecology and Evolution*; Princeton University Press: Princeton, NJ, USA, 2013. [CrossRef]
31. Begg, C.B.; Mazumdar, M. Operating characteristics of a rank correlation test for publication bias. *Biometrics* **1994**, *50*, 1088–1101. [CrossRef]
32. Egger, M.; Smith, G.D.; Schneider, M.; Minder, C. Bias in meta-analysis detected by a simple, graphical test. *BMJ* **1997**, *315*, 629–634. [CrossRef]
33. Madeira, M.S.; Cardoso, C.; Lopes, P.A.; Coelho, D.; Afonso, C.; Bandarra, N.M.; Prates, J.A.M. Microalgae as feed ingredients for livestock production and meat quality: A review. *Livest. Sci.* **2017**, *205*, 111–121. [CrossRef]
34. Saadaoui, I.; Rasheed, R.; Aguilar, A.; Cherif, M.; Al Jabri, H.; Sayadi, S.; Manning, S.R. Microalgal-based feed: Promising alternative feedstocks for livestock and poultry production. *J. Anim. Sci. Biotechnol.* **2021**, *12*, 76. [CrossRef]
35. Boukrouh, S.; Karouach, F.; El Aayadi, S.; El Amiri, B.; Hornick, J.-L.; Nilahyane, A.; Hirich, A. A systematic review and meta-analysis of the effects of inclusion of microalgae in dairy cows' diets on nutrient digestibility, fermentation parameters, blood metabolites, milk production, and fatty acid profiles. *Arch. Anim. Breed.* **2026**, *69*, 101–115. [CrossRef]
36. Bauman, D.E.; Griinari, J.M. Regulation and nutritional manipulation of milk fat: Low-fat milk syndrome. *Livest. Prod. Sci.* **2001**, *70*, 15–29. [CrossRef]
37. Shingfield, K.J.; Bernard, L.; Leroux, C.; Chilliard, Y. Role of trans fatty acids in the nutritional regulation of mammary lipogenesis in ruminants. *Animal* **2010**, *4*, 1140–1166. [CrossRef]
38. Dewanckele, L.; Toral, P.G.; Vlaeminck, B.; Fievez, V. Invited review: Role of rumen biohydrogenation intermediates and rumen microbes in diet-induced milk fat depression: An update. *J. Dairy Sci.* **2020**, *103*, 7655–7681. [CrossRef]
39. Chi, G.; Xu, Y.; Cao, X.; Li, Z.; Cao, M.; Chisti, Y.; He, H. Production of polyunsaturated fatty acids by *Schizochytrium* (Aurantiochytrium) spp. *Biotechnol. Adv.* **2022**, *55*, 107897. [CrossRef]
40. Bauman, D.E.; Harvatine, K.J.; Lock, A.L. Nutrigenomics, rumen-derived bioactive fatty acids, and the regulation of milk fat synthesis. *Annu. Rev. Nutr.* **2011**, *31*, 299–319. [CrossRef]
41. Dewanckele, L.; Vlaeminck, B.; Hernandez-Sanabria, E.; Ruiz-González, A.; Debruyne, S.; Jeyanathan, J.; Fievez, V. Rumen biohydrogenation and microbial community changes upon early life supplementation of 22:6 n-3 enriched microalgae to goats. *Front. Microbiol.* **2018**, *9*, 573. [CrossRef]
42. Vlaeminck, B.; Fievez, V.; Tamminga, S.; Dewhurst, R.J.; van Vuuren, A.; De Brabander, D.; Demeyer, D. Milk odd- and branched-chain fatty acids in relation to the rumen fermentation pattern. *J. Dairy Sci.* **2006**, *89*, 3954–3964. [CrossRef]
43. Aldai, N.; Delmonte, P.; Alves, S.P.; Bessa, R.J.B.; Kramer, J.K.G. Evidence for the initial steps of DHA biohydrogenation by mixed ruminal microorganisms from sheep involves formation of conjugated fatty acids. *J. Agric. Food Chem.* **2018**, *66*, 842–855. [CrossRef]
44. Innes, J.K.; Calder, P.C. The differential effects of eicosapentaenoic acid and docosahexaenoic acid on cardiovascular risk factors: An updated systematic review of randomized controlled trials. *Front. Nutr.* **2024**, *11*, 1423228. [CrossRef]

45. Bernard, L.; Fougère, H.; Larsen, T.; Pires, J. Short communication: Diets supplemented with starch and corn oil, marine algae, or hydrogenated palm oil differently affect selected metabolite concentrations in cow and goat milk. *J. Dairy Sci.* **2020**, *103*, 5647–5653. [CrossRef]
46. Bodnár, Á.; Egerszegi, I.; Póti, P.; Kuchtik, J.; Pajor, F. Influence of marine algae (*Schizochytrium* sp.) supplementation, ripening and vacuum packaging on goat cheese composition and fatty acid profile. *Small Rumin. Res.* **2023**, *226*, 107058. [CrossRef]
47. Delavaud, C.; Fougère, H.; Bertrand-Michel, J.; Bernard, L. Milk fat depression and plasma lipids in dairy cows and goats. *Animal* **2022**, *16*, 100635. [CrossRef]
48. Fougère, H.; Bernard, L. Effect of diets supplemented with starch and corn oil, marine algae, or hydrogenated palm oil on mammary lipogenic gene expression in cows and goats: A comparative study. *J. Dairy Sci.* **2019**, *102*, 768–779. [CrossRef]
49. Fougère, H.; Delavaud, C.; Le Faouder, P.; Bertrand-Michel, J.; Bernard, L. Triacylglycerols and polar lipids in cow and goat milk are differentially affected by various lipid supplemented diets. *Eur. J. Lipid Sci. Technol.* **2021**, *123*, 2100009. [CrossRef]
50. Martin, C.; Coppa, M.; Fougère, H.; Bougouin, A.; Baumont, R.; Eugène, M.; Bernard, L. Diets supplemented with corn oil and wheat starch, marine algae, or hydrogenated palm oil modulate methane emissions similarly in dairy goats and cows, but not feeding behavior. *Anim. Feed Sci. Technol.* **2021**, *272*, 114783. [CrossRef]

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