Research Article

Maximizing Goat Productivity: A Meta-Analysis of Methionine Supplementation Studies

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Abstract | Successful livestock farming of goats depends on understanding the impact of dietary supplementation for optimizing productivity. Methionine, an essential amino acid, plays a significant role in various metabolic processes, including protein synthesis and growth regulation, making it a potential candidate for enhancing productivity in goats. This meta-analysis aims to synthesize existing research to assess the efficacy of methionine supplementation in improving key parameters like dry matter intake (DMI), daily weight gain (DWG), feed conversion ratio (FCR), milk yield (MY), milk protein content (MP), and milk fat content (MF). The findings indicate significant effects of methionine supplementation on DMI, DWG, and FCR, suggesting increased intake, weight gain, and improved feed efficiency, respectively. In contrast, methionine supplementation showed non-significant effects on milk fat and protein contents, although trends towards positive outcomes were reported. These results emphasize the complexity of methionine's impact on milk composition and yield, highlighting the importance of considering various factors such as diet composition, management practices, and environmental conditions. In conclusion, while methionine supplementation holds promise in enhancing certain aspects of goat production, particularly growth and feed efficiency, further research is warranted to fully understand its effects on milk quality and yield. Addressing heterogeneity among studies and exploring interactions with other dietary components can provide valuable insights for optimizing methionine supplementation strategies in goat farming, ultimately contributing to improved productivity and profitability in the industry.

Received | March 19, 2024; **Accepted** | February 17, 2025; **Published** | July 15, 2025
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Citation | Yousaf, M.R., B. Ahmed, Y. Widiawati, A. Purnomoadi, F.A. Khan, N.S. Pandupuspitasari and A. Ali. 2025. Maximizing goat productivity: A meta-analysis of methionine supplementation studies. *Sarhad Journal of Agriculture,* 41(3): 991-997.
DOI | https://dx.doi.org/10.17582/journal.sja/2025.41.3.991.997
Keywords | Feed additive, Meta analysis, Livestock, Nutrition, Productivity

Introduction

Livestock farming, particularly of goats, plays a crucial role in meeting global demands for meat, milk, and other by-products (Akshit *et al.*, 2024; Modi *et al.*, 2024; Raheem *et al.*, 2024). Optimizing productivity in goat farming is of paramount importance for sustainable agricultural practices and ensuring food security (Roy and Rana, 2024; Yahya'Ey and Said, 2024). Central to achieving this goal is a deep understanding of the dietary factors that influence goat health, growth, and production efficiency (Afzal *et al*., 2022; Akshit *et al*., 2024; Battelli *et al*., 2024; Mellado *et al*., 2020; Roy and Rana, 2024).

Methionine, a key amino acid required for protein synthesis and a wide range of metabolic activities in livestock, is one such dietary supplement that has drawn recent attention (Tresia *et al*., 2024). Methionine also promotes milk production, growth performance, reproduction, and overall physiological functions (Chowdhury *et al*., 2024; Salilew-Wondim *et al*., 2024; Tresia *et al*., 2024; Yang *et al*., 2024).

Previous research generated useful insights on the impact of methionine supplementation on numerous parameters related to goat productivity (Chen *et al*., 2020; Montout *et al*., 2023; Wang *et al*., 2023). Interestingly, the existing literature portrays a diverse range of conclusions, often with contradictions regarding the efficacy of methionine supplementation. Some studies suggest significant improvements in growth rates, feed efficiency, and milk production, whereas others report negligible effects or even negative outcomes (Afzal *et al*., 2022; Chen *et al*., 2020; Giorgino *et al*., 2023; Mellado *et al*., 2020; Montout *et al*., 2023).

The disparity in research findings highlights the necessity for a comprehensive meta-analysis of the current literature to provide a more apparent understanding of the impact of methionine supplementation on goat production. A meta-analysis may assist to systematically review and analyze available studies to assess the efficacy of methionine supplementation throughout key parameters, such as dry matter intake (DMI), daily weight gain (DWG), feed conversion ratio (FCR), milk yield (MY), milk protein content (MP), and milk fat content (MF).

Materials and Methods

Eligibility criteria, search strategy, and data extraction

We utilized databases of NCBI and Google Scholar to search for latest literature for the Methionine supplementation to goats, using keywords such as Methionine, goats, milk yield, and growth. Our criteria for choosing the relevant literature included: (1) full-text publications in English, (2) peer-reviewed journals, (3) indexed conference proceedings, (4) studies directly comparing control vs Methionine diets, (5) studies with host goats as host animal, and (6) studies with reports of milk yield, fat content, protein content, dry matter intake, feed conversion ratio, and daily weight gain. Initially, we identified 40 potential references based on the keywords we used on both of the search engines. After screening for relevancy to our criteria, 31 references were excluded for not meeting the inclusion criteria. Ultimately, we extracted data from 9 papers, ensuring adherence to the PRISMA-P guidelines throughout the process (Figure 1).

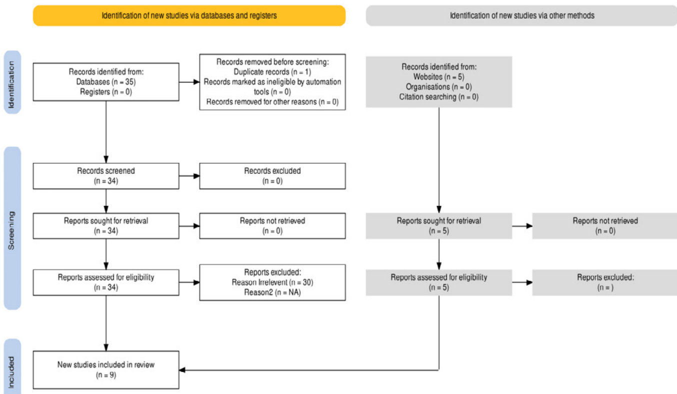

Figure 1: *Literature identification, screening and studies exclusion for meta-analysis following PRISMA-P guidelines.*

Data extraction

The data from finalized papers was extracted in Microsoft Excel which included the primary characteristic dry matter intake, daily weight gain, feed conversion ratio, milk yield per day, fat content, protein content in control group and treatment groups along with number of control and treatment group animals. All of the means and Standard Deviations of above data were extracted. In order to reduce the error and large disparity due to use of different units of measurements across the studies, the units of extracted data were homogenized.

The standard deviation where not reported, was calculated using standard error of mean using following mathematical formula.

$$SD = SEM \times \sqrt{n}$$

Meta-analysis using OPENMEE

A standard meta-analysis was used to compare the control and Methionine supplemented diets on selected parameters, using the Hedges' d effect size, which is capable of evaluating the impact of paired treatments and determining the effect size. The (E) in the Hedges'd is the pooled experimental group Methionine, whereas (C) is the pooled control group. The effect size (d) was calculated using the following formula:

$$d = \frac{X^E - X^C}{S_J} \quad \dots (2)$$

Where X^C represents the mean value of control and X^E denotes mean value of the experimental group. The measured parameter when in greater state, the effect size was positive, and vice versa. The S_J, is as follows, denotes small sample size correction factor:

$$J = 1 - \frac{3}{4(N^C + N^E - 2) - 1} \quad \dots (3)$$

S shows the pooled standard deviation, formulated as:

$$S = \sqrt{\frac{(N^E - 1)(S^E)^2 + (N^C - 1)(S^C)^2}{N^E + N^C - 2} \times J} \quad \dots (4)$$

Where S^E denotes the experimental group standard deviation and S^C dor SD of control group, and N^E denotes the experimental group's sample size and N^C denotes the control group's sample size. The following is a description of Hedges' d (V_d) variation:

$$V_d = \frac{N^C + N^E}{N^C N^E} + \frac{d^2}{2(N^C + N^E)} \quad \dots (5)$$

The cumulative effect size (d_{++}) was computed as follows:

$$d_{++} = \frac{\sum_{i=1}^{n} W_i d_1}{\sum_{i=1}^{n} W_i} \quad \dots (6)$$

Where W_i is the sampling variance's inverse: $W_i = 1/V_d$. The preciseness of the effect size, reported at 95% confidence interval (CI), represented by d++ ± (1.96 × SE), where SE (standard error) of cumulative effect size. If the computed effect size did not align a null effect size, the result was statistically significant.

Results and Discussion

Studies used for meta-analysis

After literature search, the total identified studies after screening and elimination of irrelevant studies provided a total of 9 studies for further analysis.

The literature in Table 1 was utilized for mil yield related parameters while Table 2 literature was used for growth related parameters.

Table 1: *Selected studies for parameters including milk yield, protein content, fat content.*

Author	Year	Journal	Sum of goats	Parameters	Amount
Erick Alonso-Mélendez	2016	Journal of Dairy Research	36	Milk Yield, Protein content, Fat content	1g, 2g, 3g
Ahmed AK Salama	2001	Journal of Dairy Research	22	Milk Yield, Protein content, Fat content	1g
Krista Lauren Jacobsen	2015	ProQuest	12	Milk Yield, Protein content, Fat content	2.3g, 2.3g
Mohmmad A. Al-Qaisi	2014	Archives Animal Breeding	32	Milk Yield, Protein content, Fat content	2.5g, 5g
Adriana Flores	2008	Italian Journal of Animal Science	16	Milk Yield, Protein content, Fat content	2.5g, 5g

Table 2: *Selected studies for growth related data such as dry matter intake DMI, daily weight gain DWG, and feed conversion Ratio FCR.*

Author	Year	Journal	Sum of goats	Parameters	Amount
Dong Chen	2020	Journal of Animal Physiology and Animal Nutrition	54	Dry matter intake, daily weight gain, feed conversion ratio	0.4g, 0.8g, 1.7g
Laura Montout	2023	Veterinary Sciences	36	Dry matter intake, daily weight gain, feed conversion ratio	3.5g, 11.5g
Wennan Wang	2023	Animals	36	Dry matter intake, daily weight gain, feed conversion ratio	1g, 2g, 3g
Erick Alonso Mélendez	2016	Journal of Dairy Research	36	Dry matter intake, daily weight gain, feed conversion ratio	1g, 2g, 3g
Mohmmad A. Al-Qaisi	2014	Archives Animal Breeding	32	Dry matter intake, daily weight gain, feed conversion ratio	2.5g, 5g
M. Souri	2010	Animal Science	20	Dry matter intake, daily weight gain, feed conversion ratio	2.5g, 2.5g

DMI

The meta-analysis using OpenMEE software with the continuous random-effects model via the DerSimonian-Laird approach, concented on the impact of a Methionine intervention. The analysis includes data from 6 studies with the weights assigned to each study in the meta-analysis, with substantial weights allocated to studies by Wennan Wang in 2023. The meta-analysis results from the Continuous Random-Effects Model reveal a significant and substantial overall effect size (Hedges' d) of 8.995, with a 95% confidence interval of (3.076, 14.914). The standard error is 3.020, and the p-value is 0.003, indicating statistical significance between the control and treatment groups. Notable heterogeneity is observed across studies, as evidenced by an I^2 value of 96.069%. This suggests substantial variability in effect sizes among the studies. Based on 5 included studies, the forest plot (Figure 2) graphically depicts the outcomes of a meta-analysis examining the effects of a Methionine intervention. The forest plot highlights the variety within the dataset as well as the importance of the overall effect, providing a visual aid for understanding the meta-analysis results.

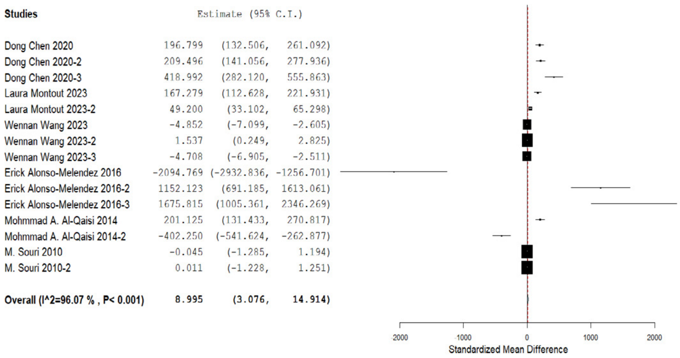

Figure 2: *The forest plot depicts effect of dietary Methionine supplementation on dry matter intake (DMI). The forest plot displays the effect sizes and confidence intervals from each study. Larger squares represent studies with greater weight. Overall, the plot reveals a significant positive effect (Hedges' d = 8.995, 95% CI: 3.076 to 14.914, p = 0.003). Notably, studies by Laura Montout (2023-2), Wennan Wang (2023-2, 2023-3), and M. Souri (2010, 2010-2) carry the most weight in contributing to the observed effect.*

DWG

The meta-analysis results for daily weight gain (DWG) via the Continuous Random-Effects Model reveal a significant overall effect size (Hedges' d) of 2.075, with a 95% confidence interval of (0.236, 3.914) and the p-value of 0.027, indicating statistical significance. A substantial heterogeneity is observed across studies, as evidenced by I^2 value of 92.65%. This suggests considerable variability in effect sizes among the studies. The results for daily weight gain influenced by methionine supplementation across different studies are displayed in a forest plot (Figure 3). This forest plot provides a visual aid for analyzing the variability within the examined dataset as well as the statistical significance of the overall effect (Hedges' d = 2.075, 95% CI: 0.236 to 3.914, p = 0.027), indicating a meaningful difference between control and experimental groups in DWG outcomes. Notable contributors to the effect size include studies by Laura Montout (2023, 2023-2), Wennan Wang (2023, 2023-2, 2023-3), Erick Alonso-Melendez (2016, 2016-2, 2016-3), reflecting their substantial weight in the meta-analysis.

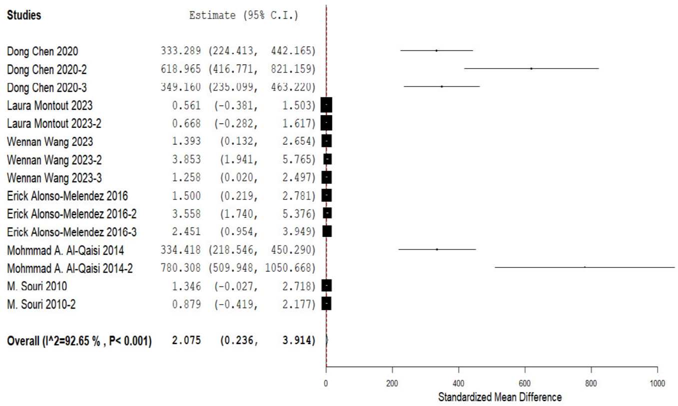

Figure 3: *Effect of Methionine on daily weight gain in goats. The standard deviations (SMDs) of each trial are indicated by the error bars, and the lines connecting each square box represent the upper and lower 95% confidence intervals (CIs) for the effect size.*

FCR

The meta-analysis for feed conversion ratio (FCR) by using the Continuous Random-Effects Model and DerSimonian-Laird as the random effects revealed a significant overall effect size (Hedges' d) of -1.708 with a 95% confidence interval (-3.309, -0.107), a significant p value of 0.037, and I^2 value of 91.863%. These results point to a sizable and statistically significant intervention impact, while there is a great deal of variation among the studies. The forest plot (Figure 4) presents the findings of a meta-analysis that compared control and experimental groups in 6 selected studies to investigate the impact of methionine supplementation on feed conversion ratio (FCR). An individual study is represented by each horizontal line, which shows the effect size estimate and its confidence interval. Overall, methionine supplementation has a statistically significant overall effect on lowering FCR.

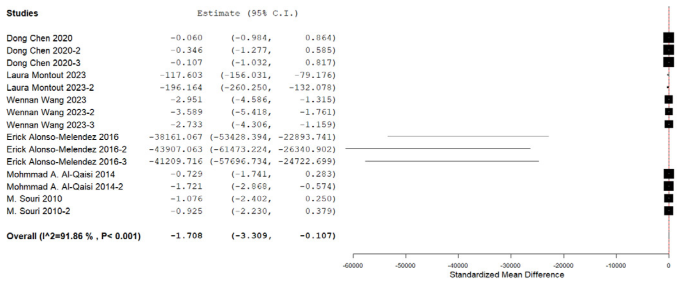

Figure 4: *The forest plot for effect of Methionine on feed conversion ratio in goats showing Dietary Methionine intervention have significant effect on feed conversion ratio.*

DMI

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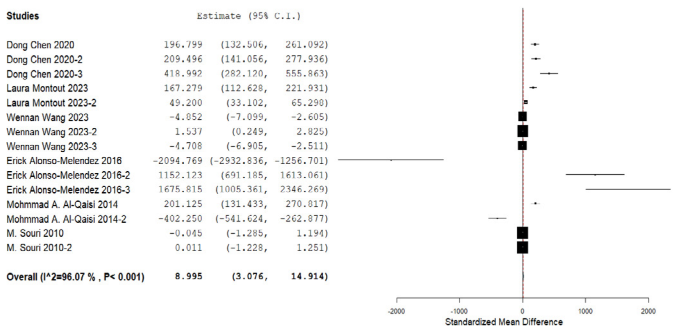

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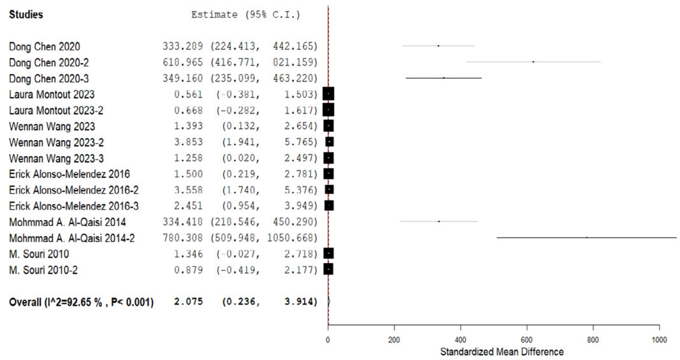

Figure 6: *Effect of Methionine on daily weight gain in goats. The standard deviations (SMDs) of each trial are indicated by the error bars, and the lines connecting each square box represent the upper and lower 95% confidence intervals (CIs) for the effect size.*

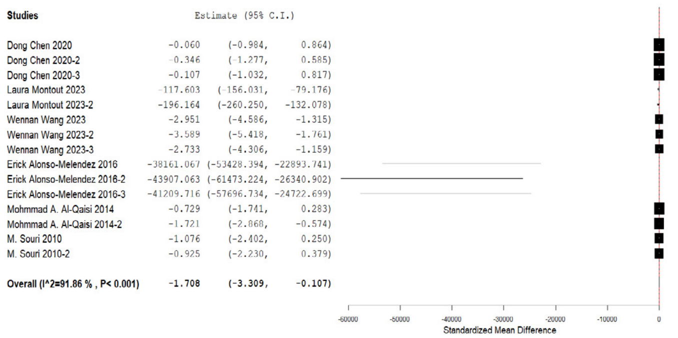

Figure 7: *The forest plot for effect of Methionine on feed conversion ratio in goats showing Dietary Methionine intervention have significant effect on feed conversion ratio.*

FCR

The meta-analysis for feed conversion ratio (FCR) by using the Continuous Random-Effects Model and DerSimonian-Laird as the random effects revealed a significant overall effect size (Hedges' d) of -1.708 with a 95% confidence interval (-3.309, -0.107), a significant p value of 0.037, and I^2 value of 91.863%. These results point to a sizable and statistically significant intervention impact, while there is a great deal of variation among the studies. The forest plot (Figure 7) presents the findings of a meta-analysis that compared control and experimental groups in 6 selected studies to investigate the impact of methionine supplementation on feed conversion ratio (FCR). An individual study is represented by each horizontal line, which shows the effect size estimate and its confidence interval. Overall, methionine supplementation has a statistically significant overall effect on lowering FCR.

Conclusions and Recommendations

In conclusion, the meta-analysis on Methionine supplementation in goats reveals significant findings across parameters. Methionine intervention significantly impacted dry matter intake (DMI), daily weight gain (DWG), and feed conversion ratio (FCR), as evidenced by substantial effect sizes and statistically significant p-values. However, notable heterogeneity indicates variability in effect sizes. Methionine supplementation led to increased DMI and DWG, and as a result improved FCR, suggesting its beneficial dietary intervention for enhancing goat productivity. These findings were consistent across multiple studies, further reinforcing the robustness of the observed effects. However, the effects of Methionine supplementation on milk fat content, milk protein content, and milk yield were not statistically significant. While there were trends suggesting positive impacts on milk fat content and milk yield, the results did not meet conventional levels of statistical significance due to limited available studies. However, further research can elucidate its effects on milk composition and yield more comprehensively.

Acknowledgement

The authors are grateful to all the reviewers who put their efforts for science. Also, a much needed appreciation to BRIN Indonesia, and UNDIP Semarang for providing their valuable resourced.

Novelty Statement

This meta-analysis looked at the different variations in milk composition results and gave new information about how adding methionine to goat food affects their productivity, focusing on changes in dry matter intake, daily weight gain, and feed conversion ratio.

Author's Contribution

Muhammad Rizwan Yousaf, Yeni Widiawati, Agung Purnomoadi, Faheem Ahmed Khan and Nuruliarizki Shinta Pandupuspitasari: Conceptualized the meta-analysis.
Muhammad Rizwan Yousaf, Bilal Ahmed, Yeni Widiawati and Agung Purnomoadi: Screened the literature and extracted data.
Muhammad Rizwan Yousaf and Bilal Ahmed: Analyzed the data and wrote the paper.
Faheem Ahmed Khan, Nuruliarizki Shinta Pandupuspitasari and Azhar Ali: Helped revise the manuscript.
All authors read and approved the final manuscript.

Data availability

The data that support the findings of this study are available as supplementary files.

Conflict of nterest

The authors have declared no conflict of interest.

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