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REVIEW

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Evaluating the potential of fermented concentrate feeds on lamb growth performance: A meta-analysis

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ABSTRACT. Fermented feeds (FFs) are known for high nutritional value and digestibility, but their impact on sheep growth performance remains inconsistent between studies. This meta-analysis systematically evaluates the effect of FFs on sheep growth. A comprehensive search was conducted using Google Scholar, ScienceDirect, and PubMed databases to identify relevant studies published between January 1990 and June 2024. Eleven studies comprising a total of 366 lambs met the established criteria. Growth parameters, including average daily gain (ADG), average daily feed intake (ADFI), and feed conversion ratio (FCR) were extracted and analysed using a random-effects model. Sensitivity and subgroup analyses were conducted to assess the stability of the results. FF supplementation as an energy source significantly improved ADG by 2.86 g/day (95% CI: 0.24–5.48, $P = 0.032$) but did not affect ADFI ($P > 0.05$). When used as a protein source, FF elevated ADFI (95% CI: 0.93–21.95, $P = 0.032$). Marked improvements in FCR were observed with both energy (standardised mean difference (SMD) = −3.95; $P < 0.001$) and protein-based FF (SMD= −5.02; $P < 0.001$). Microbial inoculants (*Lactobacillus/Bacillus* and Saccharomyces cerevisiae) positively affected ADG and FCR, although with significant heterogeneity ($I^2 > 75\%$), likely due to variations in substrates, strains, or feeding protocols. FFs used as either an energy or protein source can significantly improve lamb growth performance, particularly in terms of FCR and ADG, with microbial agents playing an important role.

Introduction

Feed resource limitations have recently become the primary constraint for the livestock industry, threatening future expansion opportunities due to increasing global demand for meat and milk (Chisoro et al., 2023). Addressing these limitations requires the adoption of efficient feed resources that will support food security (Piercy et al., 2022), sustainability in different production systems (Nath et al., 2023), and optimise animal performance. Recent studies reflect an increasing global interest in integrating circular and alternative feed sources, driven by increasing resource constraints and the urgency of achieving sustainability objectives (Palmonari et al., 2021; Vastolo et al., 2024). Among these strategies, the use of feed additives to target specific outcomes, such as growth, reproduction, health status, and product quality, has gained much attention (Cavallini et al., 2022; Abd El-Aziz et al., 2024; Jalal et al., 2024; Castillo et al., 2025). In parallel, fermentation is increasingly recognised for its contribution to feed preservation, safety, and nutritional improvement, supporting its broader integration into ruminant feeding strategies (Koakoski et al., 2024).

Feed fermentation is a biochemical process in which microorganisms decompose feed substrates for their growth and metabolite production, simultaneously degrading antinutritional factors and toxins (Dai et al., 2019). Globally, fermented feeds (FF) production predominantly utilises high-fibre feedstuffs and maize silage. However, the nutritional composition of these fermented products, particularly their crude protein and amino acid profiles, shows significant variability. This variation is primarily determined by the fermentation type, specific microbial inoculants, and enzymatic characteristics of the predominant microorganisms in the fermentation environment (Zentek and Goodarzi, 2020).

However, the nutritional quality of FF significantly depends on the microbial agents applied during fermentation (Irawan et al., 2021). Commonly employed microorganisms such as *Lactobacillus* species and the yeast *Saccharomyces cerevisiae* play dual roles in plant-based feed fermentation: they enhance silage digestibility through production of hydrolytic enzymes (amylases, proteases, and xylanases), while simultaneously reducing anti-nutritional factors (ANFs) (Wang et al., 2020a). However, their impact on growth performance at successive developmental stages remains debatable.

During the fattening phase of sheep production, the inclusion of concentrate is necessary to achieve optimal growth rates and desirable carcass quality. However, studies focusing on non-conventional silage types in sheep diets has produced inconsistent results, typically due to variability in substrate composition, fermentation technique, microbial starter cultures, and divergent research objectives. A major limitation of many non-conventional feeds is the lack of a complete and balanced nutrient profile, which can impair performance outcomes. FFs have been proposed as a means of addressing these nutritional deficiencies by improving the digestibility, palatability, and safety of unconventional feed resources (Su et al., 2020). Consequently, research interest has increasingly focused on FFs, which enable the utilisation of diverse agricultural by-products and potentially improve the overall nutritional quality of ruminant diets (Chavira, 2016; Abdelrahman et al., 2022; Wani et al., 2024). Despite these advantages, limited data exist on the impact of feed fermentation on sheep growth performance. While the fermentation of roughage has been extensively studied in ruminant nutrition, fermented concentrates remain relatively unexplored. Rumen microbial activity plays a key role in feed fermentation and nutrient utilisation; however, the specific effects of fermented concentrate feeds remain under-researched. Most existing studies have focused on fermented roughages, despite the distinct function of concentrates in ruminant diets. Therefore, further investigation is needed to clarify the nutritional and physiological impacts of fermented concentrates, particularly in relation to growth performance in sheep.

Even though individual studies have explored the effects of FFs on sheep performance, the existing literature is fragmented, methodologically heterogeneous, and often restricted to specific feed types (e.g., fermented roughage or silage). A systematic, and quantitative synthesis is lacking, particularly in the context of fermented concentrates and their impact on lamb growth performance.

Therefore, this meta-analysis aims to evaluate the effects of various non-conventional silage types or FFs on sheep growth performance and identify the most effective formulations for optimising sheep production systems. To our knowledge, this is the first quantitative meta-analysis specifically targeting fermented concentrate feeds in lambs, distinguishing it from prior reviews that either focused broadly on fermented forages and silages, included multiple ruminant species (cattle, goats, sheep) without isolating lamb-specific outcomes, or lacked statistical synthesis (i.e., only narrative reviews). Our study provides a structured, evidence-based evaluation of

how fermented concentrates, categorised by their nutritional role (protein vs. energy) and inclusion levels (additive vs. ingredient), impact lamb performance in individual production stages.

Material and methods

This meta-analysis was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, ensuring standardised reporting, methodological transparency, and replicability (Page et al., 2020).

Literature search

We conducted a comprehensive search to identify relevant studies using three major databases: PubMed (https://www.ncbi.nlm.nih.gov/pubmed; accessed June 14, 2024), ScienceDirect (https://www.sciencedirect.com; accessed June 14, 2024), and Google Scholar (https://scholar.google.com; accessed June 14, 2024). The search strategy involved a combination of the following terms and keywords: 'fermented feed', 'sheep', and 'performance'. The search was restricted to English-language publications, supplemented by manual screening of reference lists. Detailed information on the search methodology is provided in Table 1.

Selection processes

The study selection process involved rigorous screening by two independent investigators (M. Gao and B. Xie), who evaluated titles, abstracts, and full texts of retrieved studies. Additional potential trials were identified through manual examination of reference lists from eligible articles. Any discrepancies

Table 1. Search strategy

Search	Query	Items found
Google Scholar Search Strategy		
#1	Search: fermented, ensiled	24 800
#2	Search: sheep, lamb, kids, ram, ewe, goat, wethers	2 360
#1 AND #2		95
Science Direct Search Strategy		
#1	Search: fermented, ensiled	3 125
#2	Search: sheep, lamb, kids, ram, ewe, goat, wethers	127
#1 AND #2		23
PubMed Search Strategy		
#1	Search: fermented OR ensiled	126 049
#2	Search: ((((((sheep) OR lamb) OR kids) OR ram) OR OR goat) OR wethers	247 807
#1 AND #2		4 157

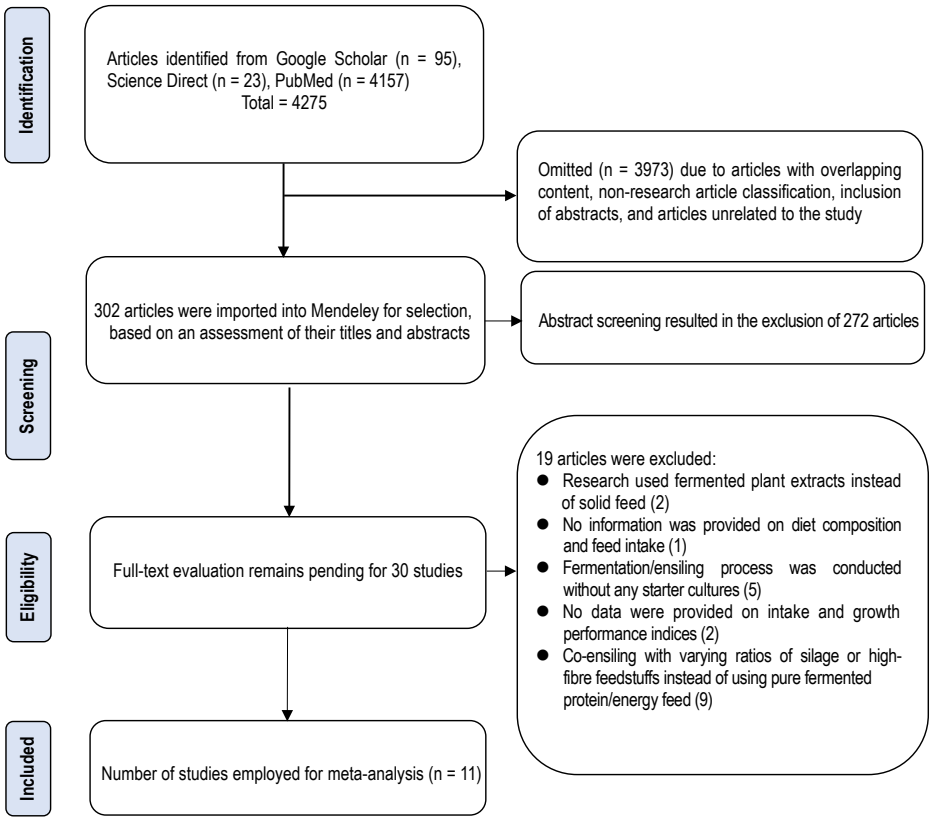

Figure 1. PRISMA protocol-based article selection scheme

in study selection were resolved through consultation with a third investigator (A. Irawan). The final data extraction for meta-analysis was performed by M. Gao and B. Xie, following established protocols (Xu et al., 2020).

Inclusion and exclusion criteria

Studies were deemed eligible based on the following inclusion criteria: 1) used commercially bred sheep (e.g., Dorper × Small-tailed Han Sheep); 2) maintained comparable energy and protein levels (±5%) between control and treatment groups; 3) employed randomised controlled trial designs; 4) applied FF with defined purposes; and 5) explicitly reported sheep growth stages. The exclusion criteria comprised: 1) probiotic supplementation without feed fermentation; 2) used fermented plant extracts instead of solid feeds; 3) incomplete dietary composition data; 4) fermentation or ensiling process performed without any starter cultures; 5) absent intake data or growth performance metrics; 6) protein feeds fermented with varying ratios of silage or high-fibre feedstuffs, without separate protein evaluation; 7) sheep growth not assessed by production stages.

Data extraction

The following information was extracted from each included study: author details (first author, year, country), journal of publication, ethical approval status, experimental design, experimental unit (sample size of selected groups, number of replications, and number of experimental groups), genetic background, gender, growth stage (weaned, growing, or fattening), FF fermentation procedure, initial age, experimental period, FF intake level, control diet composition, treatment supplement details, initial body weight (BW, kg), final BW (kg), and mean production performance parameters (average daily gain [ADG]/g/day, average daily feed intake [ADFI]/g/day, and feed conversion ratio [FCR]/kg/kg), along with their corresponding standard deviation (SD) or standard error of the mean (SEM). The analysis aimed to evaluate the effects of varying concentrations to determine the overall FF impact on growth performance. Data pre-processing showed that FF levels varied considerably, ranging from 0.539 to 1000 g/kg. Based on concentration thresholds, supplements were categorised as fermented feed ingredients when exceeding 20 g/kg and as fermented feed additives when below 20 g/kg (Xu et al., 2020). For studies testing multiple concentrations above 20 g/kg, protein or energy source supplements included cottonseed meal, rapeseed meal, concentrate mixture, olive cake, cardboard-based protein-enriched FF, distiller's grains, brewers' grains, and triticale grain. In contrast, supplements administered at levels ≤ 20 g/kg consisted of soybean meal and wheat bran.

Estimation of within-group standard deviation

The within-group standard deviation (SD) for each study was calculated using three methods. First, the within-group SD was determined from the within-group standard error of the mean (SEM) following the methodology described by Wan et al (2014). Second, if neither the within-group SD nor the SEM was reported in the study, the corresponding authors were contacted via email to request this information. Third, for cases where the within-group SD was derived from SEM, the pooled SD was calculated by multiplying the SEM by the square root of the sample size. The statistical significance and direction of effects were evaluated by examining whether the 95% confidence interval (CI) of the pooled estimate included zero, with zero inclusion indicating no significant difference. The significance and direction of all individual study results were determined based on the original study findings. This comprehensive approach demonstrated both robustness and practical applicability.

Study quality assessment

The risk of bias in the studies was evaluated using the Cochrane quality assessment methodology for systematic reviews and meta-analyses. The assessment examined five specific bias indicators: (i) b randomisation procedure bias, (ii) methodological/procedural bias, (iii) statistical approach bias, (iv) deviations from control experiment bias, (v) and missing outcome data bias. Each indicator was categorised as: 'high risk', 'low risk', or 'no risk' of bias through independent evaluation by three examiners, with results subsequently pooled. Studies demonstrating high risk of bias for all criteria were excluded from the analysis. The results of the risk of bias evaluation are presented in Figure 2B, comprising weighted bar plots and a traffic light diagram to visualise methodological quality across studies. Publication bias was assessed using visual funnel plot asymmetry (Figure 2A) and quantitative analysis using Egger's regression test (Egger et al., 1997). This approach provided both graphical and statistical evidence for evaluating potential bias in the dataset.

Statistical meta-analysis

The meta-analysis was conducted in RStudio (R version 2024.4.2 + 764; R Core Team, 2024) using the 'meta' (Schwarzer, 2007) and 'metafor'

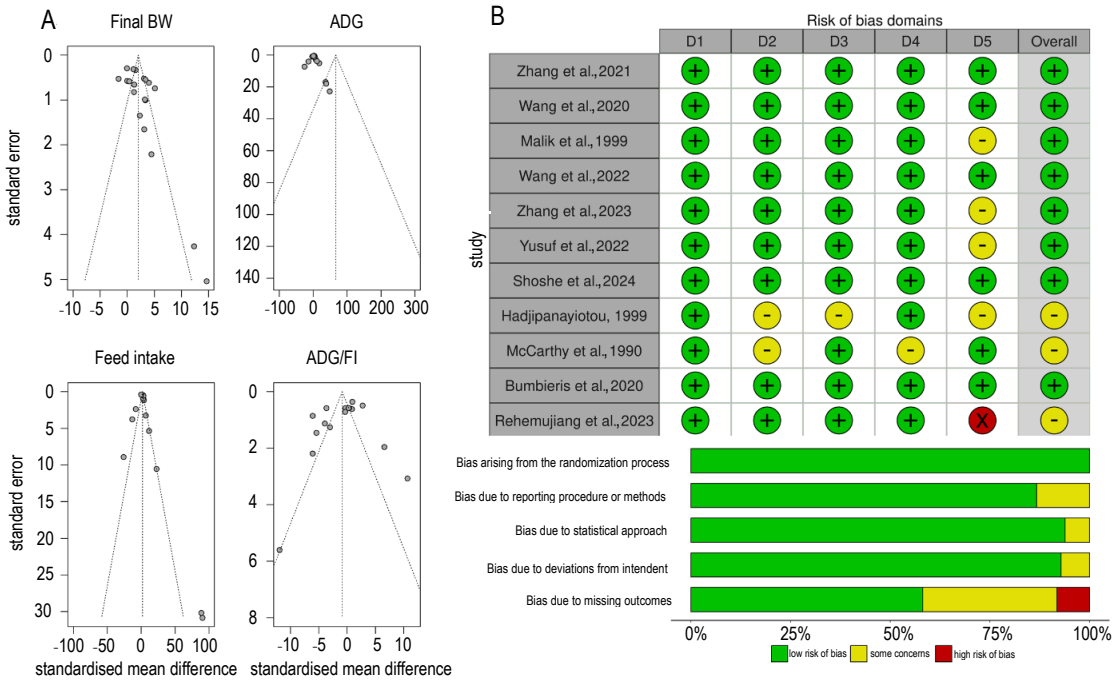

Figure 2. Risks of bias assessment. (A) Funnel plot and (B) traffic light plots and weighted bar plots summarising the risk of bias assessment between studies included in the meta-analysis (green indicates low risk of bias, yellow indicates unclear risk of bias, red indicates high risk)
BW – body weight, ADG – average daily gain, FI – feed intake

(Viechtbauer, 2010) packages. A random-effects model was applied to estimate pooled effect sizes, following a methodological approach similar to previous meta-analyses in the field (Irawan et al., 2022; Putra et al., 2024). Between-study heterogeneity was assessed using Cochran's Q statistic and I^2 statistic (Higgins and Thompson, 2002), with the DerSimonian-Laird estimator quantifying between-study variance as a percentage of total variability. Effect sizes were calculated as SMDs using Hedges' *g* with associated variances, weighted by the inverse of each study's squared standard error. Results were illustrated as forest plots with a 95% confidence interval (CI), including only outcomes reported in ≥ 3 studies with sufficient statistical power. The random-effects model was selected due to substantial heterogeneity among the included studies, which varied in sheep breeds, growth stages, diet formulations, types of fermented substrates, microbial inoculants, and feeding durations. These variations introduced true between-study differences beyond simple *d* sampling error. Preliminary analysis confirmed substantial heterogeneity with I^2 values exceeding 75% for key performance outcomes such as ADG, FCR, and ADFI. The random-effects model provided more conservative and generalizable effect estimates by accounting for both within-study variability and between-study heterogeneity for diverse experimental conditions examined.

Results

A total of 4 275 studies were initially screened, of which 11 works, encompassing data on 366 sheep, met the inclusion criteria and were retained for meta-analysis (Figure 1). The included studies were as follows: McCarthy et al. (1990), Hadjipanayiotou (1999), Malik et al. (1999), Bumbieris et al. (2020), Wang et al. (2020b), Zhang et al. (2020), Wang et al. (2022), Yusuf et al. (2022), Rehemujiang et al. (2023), Zhang et al. (2023), and Shoshe et al. (2024). Among these, one focused on lactating sheep, two on weaning lambs, two on fattening sheep, and six on growing lambs. The average initial body weights were 25.1 kg for growing lambs, 17.2 kg for weaning lambs, 25.0 kg for fattening sheep, and 69.9 kg for lactating sheep (Table 2). Fermentation conditions for the included studies are presented in Table 3. The inclusion rates for protein and energy sources were 0.054% and 57% for weaning lambs, 0.3% ~ 10% and 25% ~ 100% for growing lambs, and 2% to 30% for fattening sheep, respectively. The meta-analysis revealed no significant publication bias for any parameters except for final BW and ADG ($P > 0.10$) (Table 4). Funnel plot symmetry (Figure 1A) indicated that trim-and-fill analysis was not required. The effects of FFs, including subgroup analyses on the SMD for all performance traits and sheep classifications, are

Table 2. Characteristics of included studies evaluating the effects of fermented feeds (FFs) on lamb growth performance

Study	Country	Treatment supplement	Inclusion level, g/kg of diet	Growth stage	Sample size	Breed	Initial BW, kg	Duration/final BW, kg	ADG, g/day	ADFI, g/day	Feed conversion, kg/kg
Bumbieris et al. (2020)	Brazil	Control diet	0	Weaning	6	Texel × Santa Inês	19.83	42 days/28.3	200	838	4.19
		Fermented triticale grain 1	570	Weaning	6	Texel × Santa Inês	20.22	42 days/28.9	210	980.7	4.67
		Fermented triticale grain 2	570	Weaning	6	Texel × Santa Inês	19.58	42 days/28.18	200	894	4.47
		Fermented triticale grain 3	570	Weaning	6	Texel × Santa Inês	20.55	42 days/29.75	220	957	4.35
Hadjipanayiotou (1999)	Cyprus	Control diet	0	Lactating (49–86 DIM)	23	Chios ewes	62.3	61 days/67.6	88	2700	N.A.
		Fermented olive cake	N.A.	Lactating (49–86 DIM)	23	Chios ewes	62.2	61 days/67.1	79	2710	N.A.
Malik et al. (1999)	Kuwait	Control diet	0	Growing	5	Fat-tailed Naeemi (Awassi)	N.A.	112 days/N.A.	279	1291	5.1
		FCBPEF	250	Growing	5	Fat-tailed Naeemi (Awassi)	N.A.	112 days/N.A.	224	1373	6.7
		FCBPEF	500	Growing	5	Fat-tailed Naeemi (Awassi)	N.A.	112 days/N.A.	146	1040	7.7
		FCBPEF	750	Growing	5	Fat-tailed Naeemi (Awassi)	N.A.	112 days/N.A.	83	882	11.3
McCarthy et al. (1990)	USA	Control diet	0	Growing	4	Suffolk × Hampshire × Dorset crosses	35.9	56 days/50.6	240	1900	7.8
		Fermented brewers' grains	351	Growing	4	Suffolk × Hampshire × Dorset crosses	36.2	56 days/51.6	270	1600	5.7
		Fermented brewers' grains	351	Growing	12	Suffolk × Hampshire × Dorset crosses	N.A.	10 days/N.A.	N.A.	720	N.A.
Rehemujiang et al. (2023)	China	Control diet	0	Growing	17	Hu sheep	22.7	80 days/39.7	192.1	970.1	5.4
		Fermented cottonseed meal	100	Growing	17	Hu sheep	22.3	80 days/42	210.1	1140	5.1
		Fermented rapeseed meal	100	Growing	17	Hu sheep	22.4	80 days/43.2	226	1110	4.9
Shoshe et al. (2024)	Bangladesh	Control diet	0	Growing	4	N.A.	6.85	120 days/12.26	45.13	333.9	7.63
		Fermented concentrate mixture	1000	Growing	4	N.A.	6.05	120 days/14.55	70.9	497.2	7.5
Wang et al. (2020b)	China	Control diet	0	Growing	18	Dorper × Mongolian Sheep	34.87	60 days/45.36	171	1575	9.24
		Fermented wheat bran	3	Growing	18	Dorper × Mongolian Sheep	34.93	60 days/46.23	185	1691	9.15
		Fermented wheat bran	3	Growing	18	Dorper × Mongolian Sheep	34.61	60 days/46.22	193	1699	8.77
Wang et al. (2022)	China	Control diet	0	Weaning	6	Dorper × Small-tailed Han Sheep	11.35	28 days/17.28	214.88	815	3.84

Table 2. continued on the next page

Table 2. continued

Study	Country	Treatment supplement	Inclusion level, g/kg of diet	Growth stage	Sample size	Breed	Initial, BW, kg	Duration/final, BW, kg	ADG, g/day	ADFI g/day	Feed conversion, kg/kg
		Fermented wheat bran	0.539	Weaning	6	Dorper × Small-tailed Han Sheep	11.41	28 days/19.09	273.93	815.4	2.99
Yusuf et al. (2022)	Somalia	Control diet	0	Growing	17	Hu lambs	22.82	80 days/39.81	212.29	1190	5.61
		Fermented cottonseed meal	100	Growing	17	Hu lambs	23.47	80 days/41.24	222.19	1320	5.94
		Fermented rapeseed meal	100	Growing	17	Hu lambs	22.92	80 days/41.67	234.37	1340	5.72
Zhang et al. (2020)	China	Control diet	0	Fattening	15	Australia Aries×Hu Sheep	22.63	84 days/37	234	1391	5.94
		Fermented soybean meal	20	Fattening	15	Australia Aries×Hu Sheep	22.65	84 days/39.26	277	1453	5.24
		Fermented wheat bran[5]	20	Fattening	15	Australia Aries×Hu Sheep	22.61	84 days/38.58	266	1428	5.37
		Fermented wheat bran[6]	20	Fattening	15	Australia Aries×Hu Sheep	22.58	84 days/38.18	268	1514	5.64
Zhang et al. (2023)	China	Control diet	0	Fattening	10	ASM	30.1	90 days/42.15	119.86	2205	N.A.
		Fermented distiller's grains	300	Fattening	10	ASM	29.1	90 days/40.34	123.18	2295	N.A.

Enzyme–bacterial additive: A multi-strain microbial blend consisting of *Lactobacillus curvatus, Lactobacillus acidophilus, Lactobacillus plantarum, Latobacillus buchneri, Lactobacillus lactis, Pediococcus acidilactici, and Enterococcus faecium* at concentrations of 10^9 colony-forming units (CFU, per g) combined with a 4% cellulase-based enzyme complex; 0.5% natural matter urea, 1.5% natural matter sodium benzoate, FCBPEF – fermented cardboard-based protein-enriched feed; *Lactobacillus* spp.; Yeast – *Saccharomyces cerevisiae;* N.A. – not applicable; DIM – days in milk; ASM – Australian white sheep × Suffolk sheep × Mongolian sheep; BW – body weight

Table 3. Fermenting conditions of included studies

Study	Time[1]	Temperature	Starter cultures
Bumbieris et al. (2020)	N.A.	N.A.	Fermented triticale grain 1: enzymebacterial additive (*Lactobacillus curvatus*, *Lactobacillus acidophilus*, *Lactobacillus plantarum*, *Latobacillus buchneri*, *Lactobacillus lactis*, *Pediococcus acidilactici*, and *Enterococcus faecium* at concentrations of 10^9 colony-forming units (CFU, per g) together with a 4% cellulase-based enzyme complex.
	N.A.	N.A.	Fermented triticale grain 2: 0.5% natural matter urea
	N.A.	N.A.	Fermented triticale grain 3: 1.5% natural matter sodium benzoate
Hadjipanayiotou (1999)	3–4 months	N.A.	Fermented olive cake: N.A.
Malik et al. (1999)	21 days	37 °C	FCBPEF: *Phanerochaete chrysosporium* NRRL 6370 and *Pleurotus ostreatus* NRRL 2366
McCarthy et al. (1990)	N.A.	N.A.	Fermented brewers' grains: N.A.
Rehemujiang et al. (2023)	60 h	32 °C	Fermented cottonseed meal: *Bacillus clausi*i and *Saccharomyces cariocanus*
	60 h	28 °C	Fermented rapeseed meal: *Bacillus clausi*i and *Saccharomyces cariocanus*
Shoshe et al. (2024)	5 days	N.A.	Fermented concentrate mixture: Yeast (*Saccharomyces cariocanus*)
Wang et al. (2020)	48 h	35 °C	Fermented wheat bran: *Bacillus subtilis* (CGMCC No. 1.0892) and *Saccharomyces cerevisiae* (CGMCC No. 2.119).
Wang et al. (2022b)	48 h	35 °C	Fermented wheat bran: *Bacillus subtilis* (CGMCC No. 1.0892) and *Saccharomyces cerevisiae* (CGMCC No. 2.119)
Yusuf et al. (2022)	60 h	32 °C	Fermented cottonseed meal: *Bacillus clausi*i and *Saccharomyces cariocanus*
	60 h	28 °C	Fermented rapeseed meal: *Bacillus clausi*i and *Saccharomyces cariocanus*
Zhang et al. (2020)	30 days	N.A.	Fermented soybean meal: *Lactobacillus* spp.
	30 days	N.A.	Fermented wheat bran 1: *Lactobacillus* spp.
	30 days	N.A.	Fermented wheat bran 2: Yeast - *Saccharomyces cariocanus*
Zhang et al. (2023)	N.A.	N.A.	Fermented distiller's grains: *Saccharomyces cariocanus*

N.A. – not applicable

summarised in Table 4. The quality assessment of the studies is presented in Figure 1B. Regarding potential biases related to bias arising from randomisation process (D1), bias due to procedure or method (D2), bias due to statistical approach (D3), bias due to missing outcome (D4), and bias due to deviation from expected value (D5), all studies demonstrated a low risk of bias.

Effects of FF on average daily gain

The SMD for the FF effect (the pooled estimates) on the increase in lambs' ADG was 66.55 g/day (95% CI: −17.27–150.3) with high heterogeneity (I^2 = 91.8%, Q statistic P < 0.001). This indicates that lambs fed FFs gained an additional 66.55 g/day compared to those on a basal diet. Subgroup demonstrated differential effects by FF composition: energy-source FFs showed a small but significant ADG improvement of 2.86 g/day (95% CI: 0.24–5.48, P = 0.032) although heterogeneity remained high (I^2 = 85%). The use of FFs as a protein source resulted in a non-significant pooled SMD of 337.3 g/day (95% CI: −75.63–750.2, P = 0.109), with very high heterogeneity among studies (I^2 = 97%).

The analysis of maize brewers' grains resulted in an SMD of 1.24 with a wide 95% CI (−0.37 to 2.86), suggesting a potentially positive effect on ADG, but with a high degree of variability and limited confidence in this estimate (Figure 2A). In contrast, cottonseed meal showed a significant positive effect with an SMD of 3.35 (95% CI 2.27–4.43), indicating a strong and reliable improvement in ADG following its inclusion (Figure 2A). Conversely, dried distillers' grains demonstrated a negative effect (SMD −1.59, 95% CI: −2.62 to −0.56), suggesting a significant adverse effect on ADG; the relatively narrow CI reflects high estimate precision. Olive cake supplementation appeared to exert a modest positive effect (SMD 0.86), although the wide 95% CI (−0.09 to 1.81) indicates considerable variability and limited confidence in the estimate. The randomeffects model demonstrated significant heterogeneity (I^2 = 87% (61–95%), possibly due to variations in olive cake quality or in experimental protocols.

Both canola and soybean meal exerted substantial positive effects on ADG, with SMDs of 5.10 (95% CI: 3.65–6.55) and 4.44 (95% CI: 0.10–8.78), respectively. An exceptionally high SMD of 12.33

Table 4. Meta-analysis results

Outcomes	Subgroup	N	SMD (95% CI)	*P*-value	I^2	Q	Egger's test	Begg's test
Final BW	Overall	20	2.03 (1.14–2.93)	<0.001	88.2	<0.001	0.028	0.027
	Lactobacillus/ Bacillus	16	2.02 (1.18–2.85)	<0.001	87			
	SC	4	5.76 (−1.72–13.25)	>0.05	89			
	Energy source	10	1.67 (0.87–2.48)	<0.01	75			
	Protein source	4	2.66 (−0.49–5.82)	>0.05	96			
	TMR	6	1.89 (0.08–3.71)	<0.01	90			
ADG	Overall	21	66.55 (−17.27–150.3)	0.119	91.8	<0.001	0.034	0.009
	Lactobacillus/ Bacillus	14	110.1 (−32.87–253.2)	0.131	93			
	PC	3	−7.02 (−32.17–18.13)	0.584	94			
	SC	4	6.90 (0.55–13.25)	0.033	81			
	Energy source	8	2.86 (0.24–5.48)	0.032	85			
	Protein source	5	337.3 (−75.63–750.2)	0.109	97			
	TMR	8	−1.49 (−7.70–4.71)	0.636	89			
Feed Intake	Overall	14	1.94 (−2.94–6.80)	0.435	88	<0.001	0.601	0.25
	Lactobacillus/ Bacillus	8	2.78 (1.23–4.33)	<0.001	87			
	PC	3	−5.71 (−14.98–3.55)	0.227	94			
	SC	3	59.97 (10.97–108.97)	0.016	74			
	Energy source	7	4.29 (−6.42–15.02)	0.432	86			
	Protein source	1	11.44 (0.93–21.95)	0.032	NA			
	TMR	6	−0.84 (−7.51–5.83)	0.805	90			
FI/ADG	Overall	19	−0.864 (−3.26–1.54)	0.480	91.8	<0.001	0.299	0.649
	Lactobacillus/ Bacillus	13	−1.94 (−3.84–0.04)	0.045	93			
	PC	3	12.12 (3.09–21.15)	0.008	71			
	SC	3	−2.47 (−5.93–0.99)	0.161	72			
	Energy source	7	−3.95 (-6.19–1.71)	<0.001	79			
	Protein source	3	−5.02 (-7.50–2.55)	<0.001	77			
	TMR	9	2.62 (0.33–4.91)	<0.001	84			
Carcass	Overall	4	2.59 (0.86–4.31)	0.003	87.2	<0.001	0.311	0.497
DMD	Overall	5	9.78 (−2.67–22.23)	0.123	90.2	<0.001	0.064	0.142
N Intake	Overall	6	3.46 (−1.34; 8.25)	0.158	89.4	<0.001	0.344	0.188
Faeces N excreted	Overall	6	−0.47 (−4.82–3.88)	0.833	94.6	<0.001	0.419	0.573
Urine N excreted	Overall	6	1.09 (−2.39–4.57)	0.539	90.9	<0.001	0.521	0.573
N retention	Overall	6	1.61 (−0.21–3.43)	0.083	84.9	<0.001	0.336	0.348
Blood protein	Overall	8	1.73 (−0.80–4.27)	0.178	90.5	<0.001	0.237	0.322
Albumin	Overall	7	1.15 (−0.02–2.33)	0.054	75.8	<0.001	0.286	0.177
Triglycerides	Overall	8	0.70 (−1.78–3.17)	0.581	89.1	<0.001	0.35	0.458
Cholesterol	Overall	5	0.30 (−1.75–1.15)	0.683	89.8	<0.001	0.587	0.327

N – number of comparisons; SMD – standardised mean differences; 95% CI – 95% confidence interval (lower – upper); I^2 – within-studies heterogeneity used in meta-analysis; Q – *P*-value for Q statistic; BW – body weight; ADG – average daily gain; DMD – dry matter digestibility; *Saccharomyces cerevisiae*; PC – *Phanerochaete chrysosporium* ; TMR – total mixed ration.

(95% CI: 3.97–20.69) was observed for sugarcane bagasse, also indicating a strong effect; however, the wide CI and the inapplicability of the random effects model suggest that these results should be interpreted with caution and require further investigation. The total mixed ration showed an SMD of 3.60 (95% CI: 2.62–4.57) with moderate heterogeneity ($I^2 = 68\%$ (0–91%), indicating a significant positive effect. In contrast, triticale grain and wheat bran had smaller effect sizes, with SMDs of 0.16 (95% CI:

−0.49–0.82) and 2.45 (95% CI: 1.37–3.53), respectively. While triticale grain showed minimal heterogeneity (I^2 = 0%; 0–90%), wheat bran displayed moderate between-study variation (I^2 = 14% (0–82%), indicating more consistent results for triticale grain.

Regarding the fermentation inoculants (Figure 2B), *Lactobacillus/Bacillus* showed a significant positive effect with an SMD of 2.02 (95% CI: 1.18–2.85) and considerable heterogeneity (I^2 = 87%; 80–91%), suggesting variability in the effectiveness of these probiotics in individual studies. *Saccharomyces cerevisiae* showed a wide range of potential effects with an SMD of 5.76 (95% CI: −1.73–13.25), as the confidence interval included both positive and negative values. This finding reflects a high uncertainty and heterogeneity (I^2 = 89%; 74–95%), which requires further research to clarify its effects. The overall effect (z = 4.45, $P < 0.01$) confirmed the statistical significance of the observed effects within subgroups. However, subgroup analysis detected significant differences for feed additives and substrates ($P < 0.01$) but not for probiotics ($P = 0.33$), potentially due to limited study number or more consistent effects within probiotic subgroups.

Fermentation inoculants, particularly *Lactobacillus/Bacillus*, demonstrated significant positive effects on animal performance. However, the high heterogeneity indicates substantial variation between studies. There is a need for standardised experimental protocols and larger sample sizes to reduce variability and improve the reliability of conclusions. Future research should address these areas to improve understanding of the effects of these substances and optimise their use in practical applications.

FF effect on average daily feed intake

The analysis of different FFs on lambs, based on the pooled estimates, showed no significant effect (SMD =1.94 g/day, 95% CI: 2.94 to 6.8, P = 0.435), with high between-study heterogeneity (I^2= 88%, Q statistic $P < 0.001$). Subgroup analysis showed that lambs receiving fermented energy feed supplements showed no significant improvements compared to a basal diet was 4.29 g/day (95% CI: −6.42 to 15.02, $P = 0.432$), and a high heterogeneity was also observed between studies (I^2 = 86%). In contrast, lambs fed fermented protein sources demonstrated a significant positive effect (SMD = 11.44 g/day (95% CI: 0.93–21.95, $P = 0.032$), with no heterogeneity detected (I^2 = 0.00%).

Feed intake effects differed markedly between feed ingredients (Figure 3). Brewers' grain maize had a negative, non-significant effect (SMD = −11.51, 95% CI: −36.87 to 13.86), with extensive variation between studies (I^2 = 88%), possibly due to differences in study design, population, or intervention. However, soybean meal, sugarcane bagasse, and wheat bran positively affected sheep feed intake. Soybean meal analysis resulted in an SMD of 11.44 (95% CI: 0.93 to 21.95), with the confidence interval not including zero, indicating a likely beneficial effect. Sugarcane bagasse and wheat bran supplementation also produced SMDs of 88.46 (95% CI: 29.28 to 147.63) and 3.88 (95% CI: 2.44 to 5.32), respectively. On the other hand, the total mixed showed no statistically meaningful effect (SMD = −0.84, 95% CI: −7.50 to 5.83), with the high between-study variation (I^2 = 90%), suggesting inconsistent experimental conditions.

Among microbial inoculants, both *Lactobacillus/Bacillus* and *Saccharomyces cerevisiae* positively affected feed intake. *Lactobacillus/Bacillus* administration resulted in an SMD of 2.78 with a 95% CI of 1.23–4.33, while SMD for *Saccharomyces cerevisiae* was 59.97 (95% CI: 10.97–108.97), indicating a significant positive effect, and suggesting that these may effectively improve feed intake (Figure 4). In contrast, *Phanerochaete chrysosporium* + *Pleurotus ostreatus* did not seem to exert a statistically significant effect, (SMD = −5.71, 95% CI: −14.98–3.55) and the high heterogeneity (I^2 = 94%) indicated high result variation. The inconsistent heterogeneity between subgroups suggest non-uniform effects of fermented feed materials and inoculant. The high I^2 values imply that outcomes may depend on study design, population characteristics, and specific fermentation processes. The test for overall effect (z = 0.78, $P = 0.44$) for all subgroups combined did not provide significant results. Moreover, considerable subgroup differences ($P = 0.01$) indicate that specific materials and inoculants can exert distinct effects. Future studies should adopt standardised methodologies to minimise variability.

FF effect on feed conversion ratio

The pooled estimates for lambs' feed conversion ratio (F/G) supplemented with FFs showed no significant improvement (SMD = −0.864, 95% CI: −3.26 to 1.54, $P = 0.48$), with high heterogeneity observed between studies (I^2 = 91.8%, Q statistic $P < 0.001$). However, subgroup analyses revealed significant positive effects for both fermented-energy sources (SMD = −3.95, 95% CI: −6.19 to −1.71, $P < 0.001$) and fermented protein-source feeds (SMD = 5.02, 95% CI: −7.5 to −2.55, $P < 0.001$), though the latter showed high heterogeneity (I^2 = 77%).

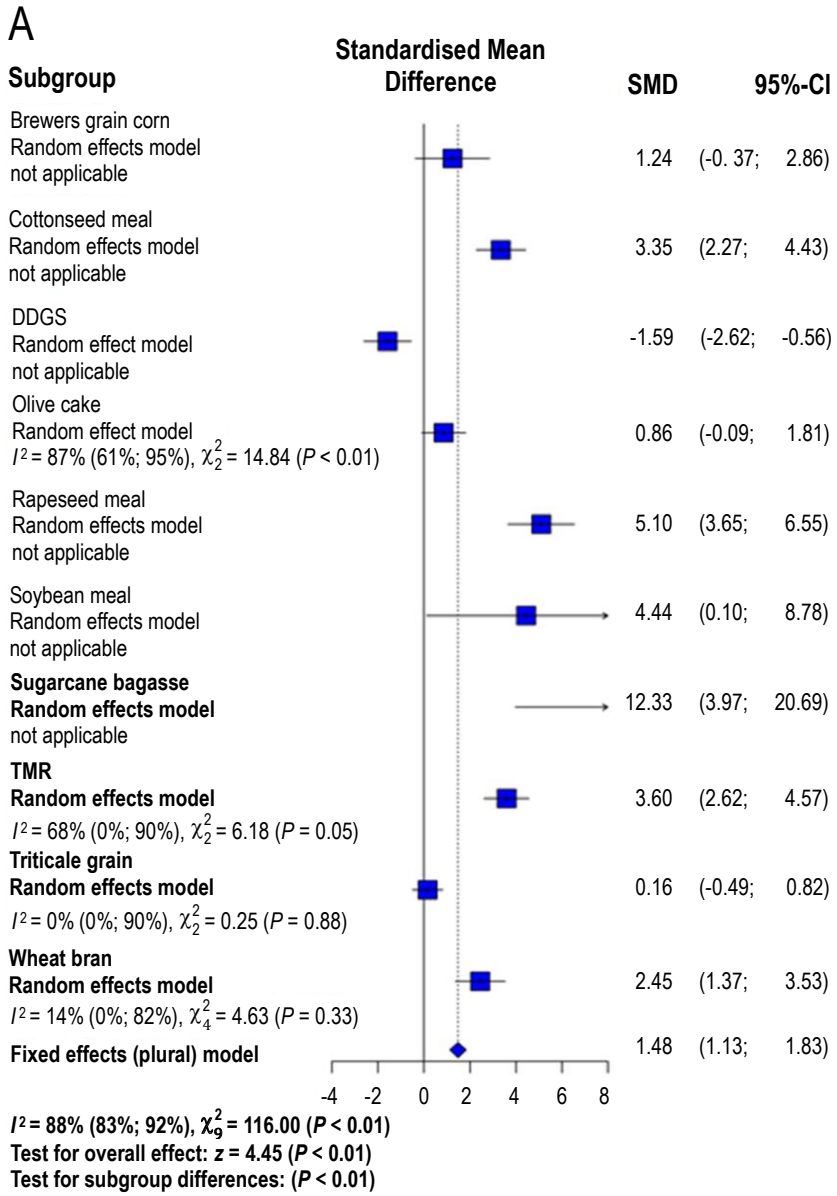

Figure 3. Forest plot of meta-analysis of fermented feed subgroups based on feed materials and inoculants used on final body weight of sheep
SMD – standardised mean differences, TMR – total mixed ration, DDGS – distillers' dried grains solids, I^2 – within-studies heterogeneity used in meta-analysis

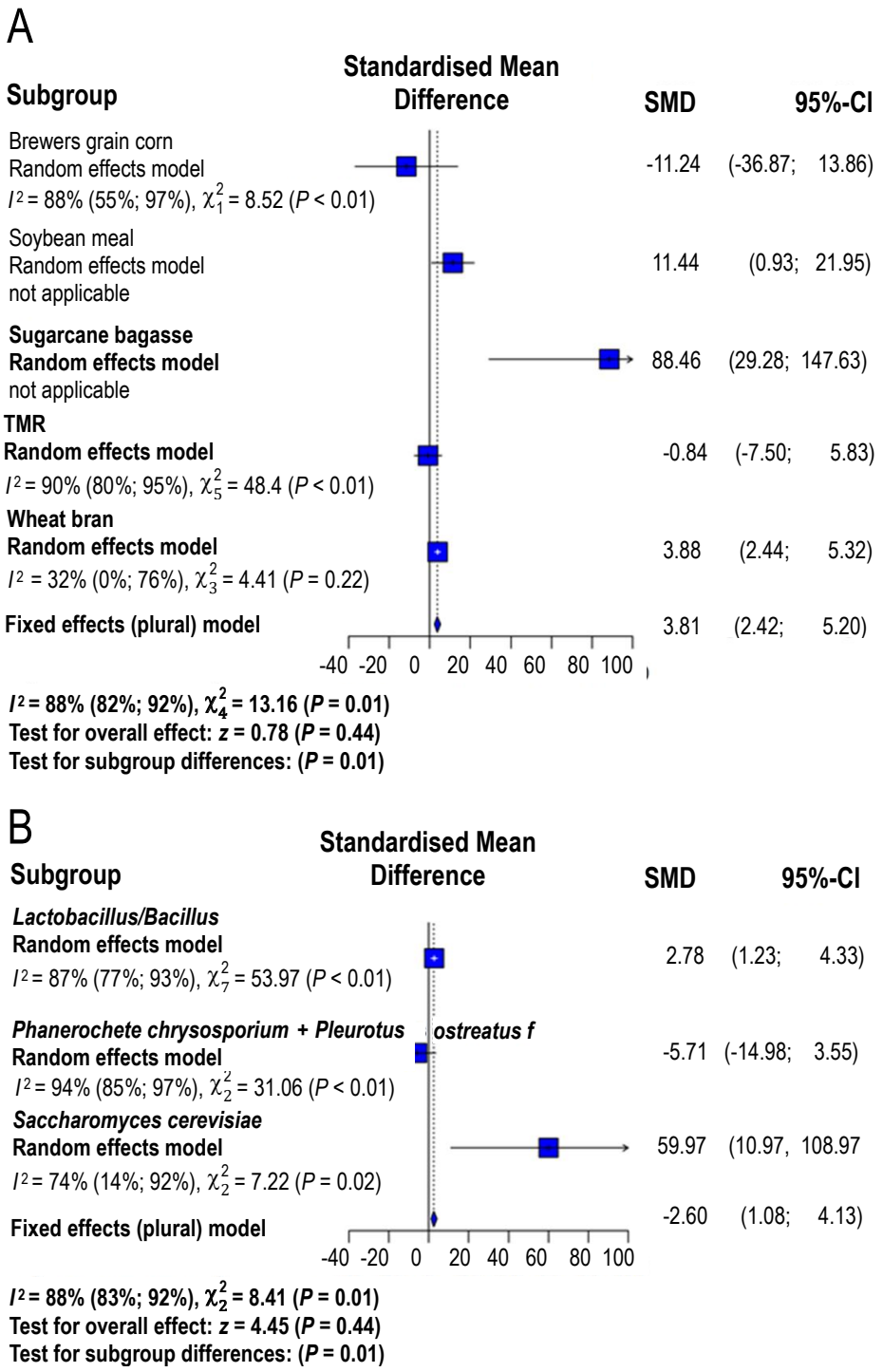

Figure 4. Forest plot of meta-analysis of fermented feed subgroups based on feed materials and inoculants used on feed intake of small ruminants

SMD – standardised mean differences; TMR – total mixed ration, I^2 – within-studies heterogeneity used in meta-analysis;

The funnel plot analysis for AFI/ADG (Figure 2A) displayed asymmetry, potentially indicating publication bias. This asymmetry suggests that smaller studies with non-significant or negative results may be underrepresented, possibly leading to an overestimation of treatment effects in the meta-analysis.

Discussion

Soybean meal and wheat bran, frequently used as by-products in lamb feed, contain several ANFs, including trypsin inhibitors, soybean antigenic proteins, and phytic acid. These ANFs negatively affect feed efficiency, gut microbiota, and induce

intestinal inflammation and diarrhoea, ultimately impairing productivity and animal health (Zhang et al., 2020). Fermentation is a cost-effective and practical approach for feed preservation, maintaining nutrient content and improving feed quality. However, there is limited research focusing on the impact of incorporating FF into lamb diets, particularly regarding its effects on feed efficiency during successive growth stages. Solid-state fermentation is a traditional technique employed to improve nutrient availability in the feed, as well as preserve physical attributes such as colour, aroma, and flavour (Flores-Hernández et al., 2019).

The present meta-analysis indicates that FFs improve ADG and F/G while showing minimal or no effect on ADFI. These findings suggest that the observed improvements in performance are likely linked to increased nutrient availability and/or utilisation efficiency. FF ingredients improved the performance of weaned and growing lambs but did not affect finishing lambs. We hypothesise that this may stem from the more developed digestive systems and stable gut microbiome characteristic of finishing lambs. In contrast, FF additives increased performance during all growth stages and seemed advantageous for weaners, growing lambs, and finishing lambs.

Mechanisms of FF effects on growth performance

Fermentation improves feed quality through several mechanisms. The process increases protein digestibility by breaking down complex proteins into smaller peptides and reducing harmful impact of anti-nutritional factors including trypsin inhibitors (Gao et al., 2020). In common feed ingredients like soybean meal and wheat bran, processes occurring in FF degrade problematic compounds (e.g., trypsin inhibitors, phytic acid, and antigenic proteins), thereby improving protein absorption and alleviating gut inflammation (Gao et al., 2020; Zhang et al., 2020). Additionally, the biochemical transformations during fermentation result in the synthesis of beneficial small peptides and short-chain fatty acids, increased starch digestibility, and enzymatic activity, which jointly elevate feed efficiency (Feizi et al., 2024). Moreover, lactic acid produced during fermentation improves palatability, potentially increasing voluntary intake in certain formulations. Furthermore, FF creates an acidic environment that supports beneficial microbes, such as *Lactobacillus* and *Saccharomyces cerevisiae*, while suppressing pathogens like *E. coli* and *Clostridium perfringens*. This modulation contributes to improved gut health, nutrient absorption, and reduced incidence of diarrhoea (Ban and Guan, 2021; Hafez et al., 2022; Wu et al., 2022). Fermented feed mediates its growth-promoting effects in lambs through distinct yet interrelated physiological mechanisms. The intervention induces significant morphological adaptations in intestinal architecture, characterised by increased villus height, and the villus height-to-crypt depth ratio, which expands the absorptive surface area and increases nutrient uptake. These structural improvements correlate with elevated short-chain fatty acid production and reduced population of coliform bacteria (Ibrahim et al., 2020). Simultaneously, FF stimulates immune function, by promoting lymphocyte proliferation, increasing immunoglobulin levels, and cytokine release, contributing to better resilience and growth performance in lambs (Chen et al., 2021; Qiu et al., 2023; Zhang et al., 2024). Although the impact of FFs on average daily feed intake remains uncertain due to the limited number of relevant studies, ADFI appears to be positively associated with FF palatability. High levels of lactic acid can enhance feed palatability but the presence of biogenic amines, elevated concentrations of acetic acid, ethanol, pentanol, and anti-nutritional factors may reduce it (Scherer et al., 2015; Halmemies-Beauchet-Filleau et al., 2018; Bandla et al., 2023). An uncontrolled, incomplete, and suboptimal fermentation process can also result in nutrient loss and growth retardation (Malherbe et al., 2007). For instance, L-lysine can be decarboxylated into cadaverine, a toxic and bitter compound that diminishes palatability and growth performance. Furthermore, the efficiency of fibre degradation during fermentation depends on multiple structural factors like lignin content and composition, ferulic acid cross-linking, cellulose crystallinity and polymerisation, or hemicellulose composition (Li et al., 2013; Wu et al., 2013; Zhang et al., 2013).

Indicators such as serum protein, albumin, and triglyceride levels have been inconsistently reported in the literature. While some studies (e.g., Chen et al., 2021, or Zhang et al., 2020) have observed improved immune and metabolic status in animals fed FFs, the data from studies included in the present quantitative synthesis were insufficiently uniform to allow for subgroup meta-analysis. Nonetheless, numerical trends in blood protein and albumin levels (SMD = 1.73 and 1.15, respectively) suggest potential physiological relevance, albeit not reaching statistical significance due to high heterogeneity and a limited number of studies. Previous research

(e.g., Rehemujiang et al., 2023; Feizi et al., 2024) have demonstrated that FFs can modify rumen microbial populations, increase VFA concentrations, and nitrogen utilisation. These physiological responses are likely key contributors to the observed improvements in FCR and ADG, which relate to earlier discussed findings on microbial inoculants and fermentation substrates. Gut morphology, including the villus height/crypt depth ratio, microbial diversity, and reductions in enteric pathogens are widely recognised factors in supporting animal performance. For instance, Qiu et al. (2023) demonstrated that fermented *Pennisetum giganteum* improved gut microflora balance and immunity in goats under heat stress. Moreover, FFs have shown potential to mitigate climate-related stressors, such as heat stress, and increase livestock immunity (Qiu et al., 2023). At the same time, it should be noted that, despite the environmental advantages of circular feeding systems, they may also pose food safety or nutritional risks if not properly managed, particularly when using fermented by-products (Gasparini et al., 2024).

Identification of heterogeneity sources and subgroup analyses

Subgroup and sensitivity analyses revealed multiple sources of significant heterogeneity in the study outcomes. The primary contributing factors included variations in microbial strains, fermentation quality parameters, substrate composition, environmental conditions, and rearing technologies. The sensitivity analysis of feed-to-gain ratios showed that excluded data contributed significantly to the observed heterogeneity, primarily due to marked deviations between individual study estimates and the pooled effect size. However, while these variations were significant, they did not affect either the direction or statistical significance of the results. The absence of within-subgroup heterogeneity and the divergence between subgroups support the validity of our classification for the intended use of FF.

Furthermore, this suggests that the impact of FF ingredients is primarily influenced by the type of alternative nutrient source, whether protein or energy, rather than the specific substrate used. The effects of fermentation appear to be consistent within each category of ingredients. For example, energy sources, such as maize and other grains tend to influence growth performance in a similar manner. Additionally, the effects of FF ingredients and feed additives caused comparable effects on the growth performance of weaned lambs. FF ingredients used as alternative protein sources increased average daily gain of growing lambs compared to alternative energy sources. However, these components did not exert significant effects on finishing lambs. These results indicate that matching the category of an ingredient with its intended nutritional function is essential for accurately predicting outcomes in feeding strategies.

The present meta-analysis identified significant variability in substrate types, inclusion levels, fermentation duration, inoculant strains and concentrations, and environmental conditions. These methodological inconsistencies limit comparability between studies and contribute to the high heterogeneity observed in performance outcomes. To address this, we recommend that future studies should adopt more standardised reporting practices for FF production. They should include detailed descriptions of microbial inoculants (species, strain, colony-forming units; CFU/g), fermentation conditions (duration, temperature, pH, moisture content), nutrient composition pre- and post-fermentation (e.g., CP, fibre, ANF levels), and quality control indicators (e.g., lactic acid concentration, microbial load, biogenic amine levels). The implementation of standardised protocols would improve scientific reproducibility and help formulate FF-based diets with predictable performance outcomes. Future work should prioritise systematic strain selection based on enzymatic profiles (e.g., protease, cellulase, and amylase production), comparative trials of microbial consortia vs. single-strain fermentation, as well as optimisation of fermentation protocols, including moisture content, incubation time, and substrate pre-treatment. In addition, application of uniform quality control metrics, such as lactic acid levels, pH, and microbial counts would help ensure consistent fermentation outcomes. Biological sources of heterogeneity include differences in sheep breed, age, physiological stage (weaning vs. finishing), health status, and baseline diet composition. Nutritional and methodological variation can arise from different fermentation substrates (e.g., cottonseed vs. olive cake), inoculants (e.g., *Lactobacillus* vs. *Saccharomyces*), and feed inclusion levels (ranging from <1% to 100%). Environmental and management conditions such as geographic region, climate, housing, and feeding protocols, may also differently affect FF efficacy in individual studies.

Study limitations

This meta-analysis examined the effects of supplementing lamb diets either partially or re-

placing completely with FF ingredients and 20 g/kg of FF additives to control for variability. However, the optimal concentration of FF has not yet been determined. The effects of fermented protein-source and energy-source feeds on weaned lambs and finishing lambs were not evaluated due to the limited number of available studies in these categories. Additionally, the analysis used pooled SD as the within-group SD, which may have been influenced by the number of groups and the SEM. Pooled SD is derived from the square root of a pooled variance estimator, a technique used to estimate the variance across multiple populations. For future research, it is recommended to conduct preliminary tests to verify whether the 95% confidence interval of the pooled estimate aligns with both the significance and effect direction reported in individual studies. As such, estimating within-group SD using this approach is considered robust and suitable for ruminant nutrition trials that report SEM without providing SD directly. It is advisable to identify the most suitable distribution types and select descriptive statistics accordingly. For instance, the mean and standard deviation are appropriate for normally distributed data, while the median and quartiles are more suitable for skewed distributions (Wan et al., 2014). Consequently, incorporating within-group standard deviation in animal nutrition studies can more precisely reflect variability and demonstrate individual adaptive responses to interventions.

The lack of comprehensive reporting of these parameters in studies limits the ability to draw definitive meta-analytical conclusions regarding physiological mechanisms. Although this restriction was applied to ensure consistency in data extraction and interpretation, it may have excluded valuable non-English studies, which could slightly influence the broader applicability of our findings. To enable a more integrated understanding of performance outcomes, future research should systematically include such parameters. FF production can be economically viable, particularly when based on agricultural by-products such as cottonseed meal, wheat bran, or sugarcane bagasse, which are low-cost but limited in nutritive value due to anti-nutritional factors. Fermentation improves their digestibility and value, potentially lowering the cost per unit of weight gain compared to conventional protein or energy sources. Several studies included in the current analysis used FFs derived from agricultural by-products, and reported significant improvements in FCR and ADG, which translated into measurable economic benefits (Rehemujiang et al., 2023; Zhang et al., 2021; Yusuf et al., 2022). Moreover, using on-farm or local fermentation systems can reduce feed transportation and storage costs, especially in regions where conventional concentrate feeds are expensive or limited. The microbial agents employed in these processes (e.g., *Lactobacillus spp.*, *Bacillus* spp., and *Saccharomyces cerevisiae*) are not only widely accessible but also cost-effective, especially when produced in bulk. Nevertheless, it is important to note that FF production requires careful control of fermentation parameters (temperature, moisture, pH), adequate labour input, and consistent quality monitoring to prevent feed quality deterioration or toxin formation. The economic feasibility of FF use is context-dependent and varies based on local feedstuff availability, infrastructure, and production scale. Soybean meal and wheat bran fermented at inclusion levels of ≤20 g/kg showed good performance in finishing lambs without adverse effects (Zhang et al., 2021). Cottonseed and rapeseed meals fermented and included at 100 g/kg resulted in improved performance in growing lambs (Rehemujiang et al., 2023; Yusuf et al., 2022). Several studies included in our dataset (Zhang et al., 2021; Yusuf et al., 2022) briefly reported effects on carcass traits, nutrient digestibility, or nitrogen retention. However, consistent and comprehensive data on health indicators (oxidative stress, immunity, and disease resistance), long-term gut health and microbiome stability, or meat quality traits (tenderness, fatty acid profile, and shelf-life) were not available in a standardised form. This limitation precluded robust meta-analytical assessment. Future studies, in addition to short-term growth metrics, should also incorporate longitudinal health assessments and detailed meat quality analyses, ideally accompanied by post-slaughter histological and biochemical evaluations.

While the current meta-analysis focused on evaluating biological performance (ADG, ADFI, and FCR), we recognise that the inclusion of FFs in farming systems ultimately depends on economic viability, i.e., whether the production benefits (e.g., increased weight gain, and feed efficiency) justify the associated costs, including infrastructure, microbial inoculants, labour requirements, and quality control measures. Several studies in the present dataset have indicated that FF formulations derived from low-value agricultural by-products, such as cottonseed meal, wheat bran, or distiller's grains, can significantly improve growth parameters without markedly increasing feed costs (Rehemujiang et al., 2023; Shoshe et al., 2024). Nevertheless, these studies did

commercial feasibility. Future research is advised to incorporate comprehensive cost-benefit analyses. Such analyses should evaluate the cost of raw material vs. conventional feed expenses, fermentation systems, labour and energy requirements, potential savings from improved feed conversion and reduced health interventions, as well as added value from higher carcass yield or meat quality. Incorporating these data will be essential for developing decision-support tools for farmers, feed companies, and policymakers in FF adoption strategies. Four studies were excluded from the present analysis during the quality assessment process based on the Cochrane risk of bias. They were consistently rated as 'high risk' in all or most of the five domains assessed: randomisation, methodology, statistical analysis, outcome reporting, and consistency. The excluded studies often lacked essential methodological details, such as clear descriptions of experimental design or complete performance parameters, which limited their reliability and comparability with the retained dataset. Although these exclusions reduced the total number of studies, they likely strengthened the internal validity of the meta-analysis by minimising the influence of poorly controlled trials. Importantly, sensitivity analyses confirmed the stability of both the direction and statistical significance of pooled results, indicating that excluding high-risk studies did not bias the outcomes. A potential limitation arises from the possible underrepresentation of small-scale studies or null findings in the published literature, leading to overestimating positive effects in meta-analyses. However, sensitivity analyses showed stable effect directions even after removing influential studies, suggesting that our key findings concerning FF improvements of FCR and ADG are robust despite the potential publication bias. It should be noted that while certain performance outcomes (e.g., ADFI and carcass traits) did not show significant evidence of publication bias, variability in outcome reporting between studies limited comprehensive bias correction.

Moreover, a recent study using Instagram demonstrated the effectiveness of social media in disseminating complex scientific concepts (Lamanna et al., 2025). This illustrates the potential of digital communication tools to raise awareness of innovative feeding strategies, such as fermented feeds, and engage a broader audience, including farmers, stakeholders, and the general public. Such initiatives can complement influencer-driven outreach and support knowledge exchange in specialised sectors like small ruminant nutrition.

Conclusions

The inclusion of fermented feed (FF) as an energy source significantly improved average daily gain (ADG) in lambs compared to the basal diet, though no significant effect on average daily feed intake (ADFI) was observed. Conversely, lambs receiving FF as a protein source demonstrated an increase in ADFI. Additionally, both FF formulations, whether used as energy or protein sources, resulted in significant FCR improvements, indicating overall better lamb performance. This study confirms the beneficial effects of FF supplementation on growth performance in ruminants. In parallel, it is important to emphasise the value of disseminating scientific results through accessible digital platforms such as Twitter (X), Facebook, Instagram, and LinkedIn. These channels allow researchers to share simplified, evidence-based messages with broader audiences, counteract myths or misconceptions surrounding feed technologies, promote sustainable and science-informed livestock feeding practices, and engage directly with stakeholders including farmers, students, consumers, and policymakers in real time.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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