Curcumin Supplementation in Ruminants: Effects on Growth Performance, Rumen Health, Oxidative Stress, Immunity, and Inflammatory Responses

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Abstract
This review reviews the effects of adding curcumin to ruminant diets, a natural polyphenol extracted from turmeric (Curcuma longa). Literature suggests that it may improve growth performance and feed conversion efficiency, modulate rumen fermentations and microbiome, and reduce oxidative stress by elevating antioxidant enzymes such as SOD, catalase, and glutathione peroxidase. It also exhibits immunological and anti-inflammatory effects, as it reduces the inflammatory cytokines IL-1β, IL-6, and TNF-α, increases IL-10, and affects immunoglobulins and acute phase proteins. Curcumin is relatively safe within 2000 mg/kg feed and has been used in calves up to 320 mg/day, but its bioavailability is low and undergoes extensive metabolism, necessitating higher doses or nanoformulations. Gaps remain about the optimal dosage, methane emission, mechanisms of action, and interactions with nutrients, especially in sheep and goats. Curcumin therefore appears to be a promising supplement for ruminant health and productivity, with independent standardized studies needed.

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1. Introduction

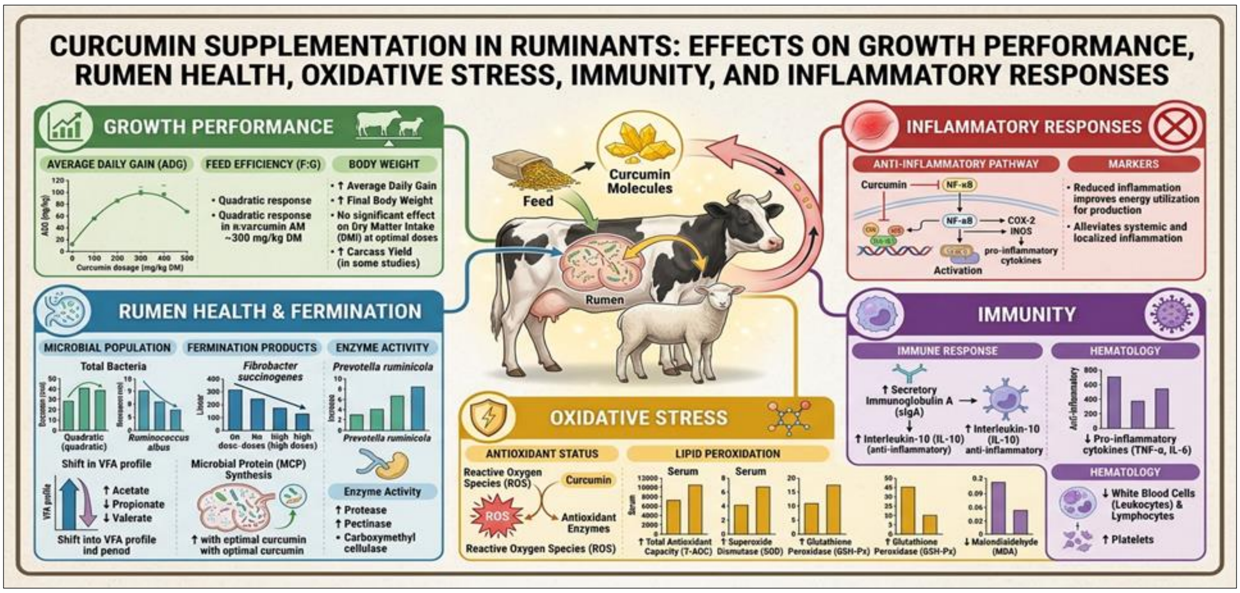
Acid stress, pharmaceutical residues, and pathogenic microflora challenge livestock health, compromise animal welfare, adversely affect productivity, increase greenhouse gas emissions, and pose an exorbitant financial burden on producers (Rene Bible, 2013) [25]. These challenges often prompt extensive usage of feed additives, such as growth promoters, cellular immunostimulants, ionophore anticoccidials, and in-feed antibiotics, which have generated some success, but attracted increasing concerns over safety, residual effects, warning periods, and public acceptances (Mantovani *et al*., 2022) [20]. The ubiquitous and abundany curcumin is such a feed supplement receiving attention, and national authorities and researchers are catching up (Anas *et al*.2024) [3].

2. Bioavailability and Pharmacokinetics of Curcumin in Ruminants

Curcumin is a polyphenol widely studied for its biological activities, such as anti-inflammatory properties in ruminants (dos Santos *et al*., 2026). It is mainly extracted from turmeric (Curcuma longa), a rhizome belonging to the Zingiberaceae family. Recent literature presents some evidence for curcumin-induced modulation of immune responses in ruminants following both natural and induced stresses (Grabarczyk *et al*., 2026) [14]. Therefore, the pharmacokinetics of curcumin and its metabolites in ruminants needs to be reviewed in order to understand better the relevance of the biological responses observed (Harigae *et al*., 2016) [15].

In the literature, the are a large number of surveys on VRP and its variants, among them Braekers *et al*. (2016) who presented a review of the classification of VRP, Goel and Maini (2017) presented a survey on solution methodologies on VRP and Kumar and Panneerselvam (2012), Han and Wang (2018) review the variants of VRP. A MDVRP survey has been conducted by Sharma and Monika in Sharma and Monika (2015). This article by Prodhon and Prins (2014) present a survey on LRP and the recent contribution before 2014 and one other concerns the variant and extensions (Drexl and Schneider, 2015). A survey on DVRP has been done in Ritzinger *et al*. (2016). A systematic review on SVRP has also been conducted in this article Berhan *et al*.

The absorption and biological fate of orally administered curcumin depend on structural characteristics and are variable among different animal species (Hunter *et al*.2026) [17]. The absence of a carboxyl or hydroxyl group in the curcumin structure limits the modifications that it can undergo and, consequently, the generation of a wide range of metabolites (Chu *et al*.2025) [8]. Ruminants are known to produce certain metabolites, and the transformation of curcumin in the rumen may influence the biological responses observed as well as the design of related studies (Rene Bible, 2013) [25]. Curcumin bioavailability remains a challenge, prompting the exploration of approaches to enhance it. Techniques such as nanoemulsification, microencapsulation, liposomes, phospholipid complexes, complexation with cyclodextrins, and polymeric nanoparticles have been used to improve curcumin delivery for mammalian species. In ruminants, however, there are no scientific reports regarding the use of carrier delivery systems to facilitate curcumin oral bioavailability (Castello-Guillen *et al*.2026) [6].



3. Effects on Growth Performance and Feed Efficiency

Epidemiological and experimental studies indicate that curcumin may support growth performance in ruminants by enhancing feed efficiency and, possibly, average daily gain (ADG) (Rene Bible, 2013) [25]. Several interventions to improve feed efficiency in ruminants have been documented. In growing-finishing pigs, curcumin supplementation improved growth performance (Karthikeyan *et al*.2026) [18]. Curcumin also increased average daily gain and feed conversion rate and decreased feed intake in birds. Similar results were obtained in nursery pigs (Trudeau *et al*., 2023).

4. Impacts on Rumen Health and Fermentation Dynamics

Curcumin influences fermentation and ruminal microbial ecology in ruminants (Rene Bible, 2013) [25]. Fermentation mediates energy, nitrogen, vitamin synthesis, and detoxification, vital for nutrient supply. Acetate, propionate, and butyrate serve as carbon sources; ammonia, peptide, and amino acids as nitrogen (Ahmed *et al*., 2023) [2]. Rumen activities convert fibrous feeds to short chain fatty acids, forming 70–80% nutrient energy. Carbohydrate, nitrogen fractions, and rumen health affect fermentation, echoing curcumin effects on feed intake, conversion, gut health, and ruminal fermentation (Zhang *et al*., 2025) [31].

Curcumin varies in composition and formulation; physiological diversity among mammals influences bioavailability, efficacy, toxicity, and pharmacokinetics. Extra-hepatic circulation, biotransformation, and excretion occur. Presence in headspace and enrichment scales post-feeding indicate ruminant saliva protraction and extra-hepatic circulation; biofortification improves distribution, and metabolism can elevate pharmacological activity.

5. Modulation of Oxidative Stress and Antioxidant Enzymes

Oxidative stress arises from an imbalance between the production of free radicals and the animal’s ability to neutralize their damaging effects via antioxidant systems (Thi Cat Tuong *et al*., 2023) [27]. The associated redox status is a critical factor that influences homeostasis by affecting both the metabolic level of cells and the integrity of cellular structures. Ruminants, like all animals, are highly susceptible to oxidative stress due to their constant exposure to exogenous stimuli (including feed), their metabolic processes (e.g., fermentation), and their reproductive cycles (vascularized placenta, delivery, lactation) and subsequent physiological conditions (e.g., growth, fattening, reproduction) (Ponnampalam *et al*., 2022) [23]. Growing ruminants—both young and fattening animals—as well as lactating dairy ruminants represent critical production periods in which substantial physiological changes occur. Hormonal variations raise metabolic rates and, consequently, free radical production, leading to potential oxidative stress. Immune pathology and infectious pressure exacerbate oxidative stress in all ruminants. Poor management practices (feeding; milking, drinking, and feeding frequency; stall conditions; walking distances; etc.) compound preexisting oxidative stresses and increase the risk of critical welfare conditions and production losses (Wang *et al*., 2023) [29].

6. Immunomodulatory Effects and Inflammatory Markers

The precise immunomodulatory role of curcumin in ruminants, as reflected in several biomarkers, remains inadequately understood. The findings of the 11 eligible studies demonstrate distinct modifications in pro-inflammatory cytokines (IL-1β, IL-6, TNF-α), humoral responses (IgA, IgM, IgG), and acute-phase proteins (CRP, Haptoglobin) following administration of curcumin in various challenge models (dos Santos *et al*., 2026) [13]. Despite considerable intertrial variability, a trend of reduction in these inflammatory indicators is noted, indicating a potential dampening of inflammatory processes (Naghsh *et al*., 2023) [22]. In pre-clinical studies of different species, including rodents, comparable concentrations of curcumin have elicited marked modulation of the cellular immune response, suppression of humoral aspects, and attenuation of inflammatory reactions following challenges of variable nature (B. Pickich *et al*., 2019) [5]. When extrapolated to ruminants, these observations provide a plausible explanation for the observed enhancements in performance under inflammatory conditions (Dhakal *et al*.2026) [12].

7. Safety, Dosage, and Practical Considerations

Curcumin has been proposed as a feed additive for ruminants to improve production efficiency and mitigate the adverse effects of environmental stressors. Analytical methods have established a maximum safe limit of 2,000 mg/kg of feed (Chin *et al*., 2014) [7]. Available information suggests good tolerance within this range, and no adverse effects have been observed in calves supplemented with 320 mg/day (Wu *et al*., 2023). However, interactions with minerals or antibiotics have been reported (Rene Bible, 2013) [25].

Formulations of curcumin remain less stable than other feed additives. Curcumin cannot be legally used in feedstuffs labeled as ‘organic,’ since regulation prohibits the use of coloring agents in certified products. Product stability, palatability, and incorporation logistics should thus be assessed for routine farm-level use. An estimated cost of €5/month per animal is incurred at a feeding rate of 200 mg/animal/day (Abozaid *et al*.2026) [1] (Dakanalis *et al*.2026) [9].

8. Comparative Perspectives: Curcumin versus Conventional Mitigants

The exploration of curcumin as a dietary supplement for livestock is of increasing importance in agricultural science, owing to tightening restrictions on the use of antibiotic feed additives. Within livestock species, the majority of the metrological database and research input is available only for pigs (Rene Bible, 2013) [25]. Curcumin supplementation consistently favoured growth performance and feed efficiency in pigs, and encouraging or equivocal results have been observed in poultry and cattle (Medras & Al-Khalaifah, 2026) [21].

The curcumin molecule is known to exhibit a wide range of biological activities, including antioxidant, anti-inflammatory, antibacterial, antifungal, antiviral, antiprotozoal, anthelmintic, and anticoccidial effects. Preliminary work in pigs, poultry and fish has confirmed similar promising characteristics of curcumin. Ruminants are known to possess a considerably different gut microbiome from other livestock species, and the possibility of formulating ruminant-specific curcumin products has yet to be fully explored (De *et al*.2024)(Teli *et al*.2026) [26].

9. Knowledge Gaps and Future Research Directions

Determining the influence of curcumin on rumen activity and fermentation dynamics remains a relatively unexplored area ruminant research. Studies investigating curcumin’s potential to regulate methane emissions must adopt consistent methodology, particularly given the need to assess multiple endpoints such as hydrogen production, methyl-coenzyme M reductase gene abundance, and microbial community profiles (Rene Bible, 2013) [25]. Studies comparing female ruminant species would advance the understanding of curcumin’s effects on growth and immunity (Thi Cat Tuong *et al*., 2023). It is unclear whether the recommended curcumin dosage of 50 mg/kg feed intake is optimal for dairy cattle; further work should clarify the potential benefits of increasing curcumin supply and explore dosing recommendations for goats and sheep (Rehman *et al*., 2026) [24]. Fundamental investigations into curcumin’s mechanisms of action in ruminants are essential. *in vivo* studies so far have largely emphasized antioxidant and anti-inflammatory activities; additional studies considering metabolic pathways associated with ruminal amino acid and carbohydrate metabolism are warranted (Laurindo *et al*.2023) [19] (Hashem *et al*., 2024) [16]. Investigating curcumin-micronutrient interactions could shed light on competing transport, activation, and inactivation processes spanning the gastrointestinal tract and influence digestibility and delivery to tissues (Damo *et al*.2026) [10]. Research on curcumin-nutrition interactions could examine effects on ration components, such as concentrate-to-forage ratios or specific feed ingredients, or evaluate how curcumin affects nutrient metabolism and subsequent performance responses. The majority of the research conducted to date has been commissioned by commercial laboratories pursuing patent protection, highlighting the potential for independent research to inform practical industry applications (Angell & Streicher, 2026) [4] (Zhou *et al*., 2026) [32].

10. Conclusion

Curcumin supplements have gained popularity as feed additives in ruminant production systems. Evidence from studies in cattle, goats, and sheep suggests that curcumin positively influences growth performance–daily gain, feed intake, feed conversion efficiency, and profitability. Curcumin affects gastro-intestinal health and rumen fermentation by modulating microbiome composition and activity. The product also lowers markers of systemic oxidation and enhances the activity of key antioxidant enzymes, including superoxide dismutase, catalase, and glutathione peroxidase. Curcumin additionally has immunomodulatory effects, influencing both innate and acquired responses, depending on dose and exposure duration. Pro-inflammatory pathways (NF-κB, IL-1β, IL-6, TNF-α) are downregulated, while activity of the anti-inflammatory cytokine (IL-10) is boosted. Curcumin's effects on oxidative balance and immunity suggest potential for improving resilience to enteric and other diseases while reducing environmental impacts.

Curcumin is the bioactive polyphenolic compound present in turmeric. It has low bioavailability, rapid excretion, and undergoes extensive first-pass metabolism in ruminant species, leading to high doses (15–500 mg/kg) and specific carriers (sodium curcuminate, nanoemulsions) for increasing efficacy and associated productivity and health benefits. These modes of action, the main matrices used, current knowledge of pharmacokinetics and -dynamics, and future experimentation to advance application in ruminants are now considered.

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