



Review article

Comprehensive review of benefits and risks from feeding fenugreek (*Trigonella foenum-graecum*) to bovines

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Abstract

Importance of the work: This work standardize fenugreek (*Trigonella foenum-graecum*) processing and dosage, ensuring consistent gains in metabolic efficiency and methane mitigation without compromising animal health or product quality. Establishing these precise details transforms a natural variable additive into a reliable, evidence-based supplementation for sustainable bovine production.

Objectives: To critically assess the benefits, limitations and practical conditions for the safe use of fenugreek in bovine production.

Materials and Methods: A systematic review was conducted using databases including Google Scholar, PubMed and Scopus for articles and reviews published between 1991 and 2025.

Results: Fenugreek consistently reduced enteric methane production (10.2–62.2%) and enhanced nutrient digestibility and energy efficiency by shifting rumen fermentation toward propionate. At the molecular level, it upregulated antioxidant capacity and energy production pathways. Compared to raw seeds, the germinated seeds significantly improved growth efficiency (up to 22.18% weight gain) and reproductive traits. These benefits were dose-sensitive, appearing at approximately 0.23 g/kg of body weight, whereas negligible doses (approximately 0.004 g/kg) failed to produce responses. Documented risks include compromised organoleptic quality of animal products and severe pathologies from high-volume intake, such as peripheral neuropathy, muscular hemorrhages and liver inflammation.

Main finding: Safe application of fenugreek requires strict adherence to processing methods and precise inclusion levels. Practical implementation should prioritize germinated seeds to maximize bioavailability; however, high-volume feeding of straw should be avoided to mitigate documented neurological perils and to maintain the organoleptic quality of meat and milk.

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Introduction

Fenugreek (*Trigonella foenum-graecum* L.) is a widely cultivated legume in Asia and Europe and is recognized globally for its diverse biological activities (Fig. 1). Its prominence stems from its rich profile of nutritional components and bioactive phytochemical, primarily attributed to its high content of steroidal saponins. This foundational understanding establishes fenugreek as more than just a culinary spice, setting the stage for its deep-rooted use in traditional medicine and modern nutraceutical practices.

Fenugreek is a nutrient-dense plant, boasting a comprehensive matrix of macronutrients and micronutrients that contributes to its versatility. Its composition includes substantial amounts of proteins, carbohydrates, lipids and essential fatty acids, complemented by a wealth of minerals, as well as crucial amino acids, including β carotene, ascorbic acid, dietary fiber and non-starch polysaccharides (Broca et al., 2004; Işikli and Karababa, 2005; Montgomery, 2009; Mathur and Choudhry, 2009; Naidu et al., 2011; Ahmad et al., 2016; Khan et al., 2018; El-Hamd et al., 2025; Rizzo et al., 2025). Beyond basic nutrition, fenugreek seeds are a hub of diverse secondary metabolites notably saponins, flavonoids and tannins which stimulate its therapeutic value (Naseri et al., 2013; Al-Maamari et al., 2016).

The extensive array of phytochemicals in fenugreek confers considerable therapeutic and physiological potential in both human and animal health. The phytochemicals in fenugreek validate its efficacy against diabetes, cancer, hyperlipidemia, inflammation, neurotoxicology, hepatotoxicity, oxidative stress, ulcers, wounds, bacterial and fungal infections, leg weakness and edema (Sauvaire et al., 1991; Nagulapalli Venkata et al., 2017; Wani and Kumar, 2018). Furthermore, its sapogenins are known to enhance biliary cholesterol synthesis, thereby stabilizing serum cholesterol levels (Sauvaire et al., 1991). For livestock, fenugreek inclusion in feed offers distinct benefits such as stimulating appetite, enhancing digestion, promoting milk production, bloat-free effect and restricting the anti-nutritional factors. Sprouting fenugreek reduces antinutritional factors such as phytic acid and oxalates (El-Hamd et al., 2025); however, fenugreek seeds stimulate the appetite in animals which accelerate the total dry matter and daily concentrated feed intake (Degirmencioglu et al., 2016). Furthermore, the phytochemicals in fenugreek accelerate digestion, the bloat-free effect, milk secretion, modulation of metabolism and overall enhancement of physiology upon consumption (Wina et al., 2005; Dixit et al., 2005; Cao and Yang, 2011; Degirmencioglu et al., 2016; Wani and Kumar, 2018; Niu et al., 2021; Sura et al., 2023). However, the application of fenugreek in animal diets, especially for bovine species, faces a critical limitation due to its distinctive aroma and flavor which can compromise the organoleptic quality of meat and milk (Moreno et al., 2023), restricting its widespread use despite the nutritional advantages.

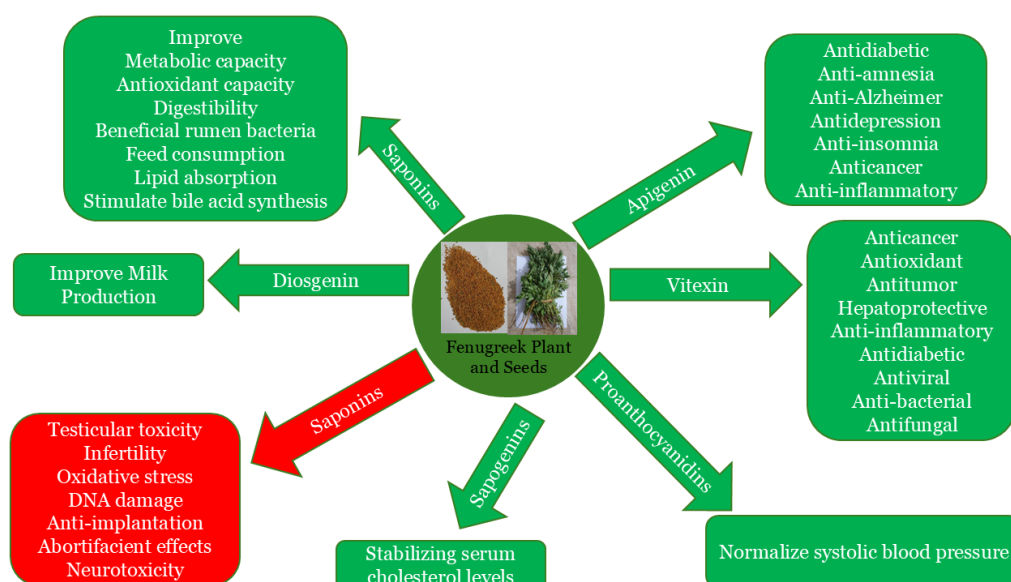


Fig. 1 Schematic representation of the components of fenugreek and their effects.

In addition to its therapeutic and nutritional importance, fenugreek plays roles in environmental and agricultural sustainability. *Rhizobium* spp. strains in fenugreek have potential for commercial amylase and cellulase production as the symbiotic *Rhizobium* bacteria in the root nodules of fenugreek utilize glucose, sucrose and starch as their solitary carbon source (Singh et al., 2008). In addition, fenugreek plant extract is considered to be a safe and sustainable pesticide (Perzada et al., 2025).

Besides the benefits from fenugreek applications, there are some aspects of this plant that are considered detrimental to animal health, since it contains mild concentrations of mycotoxins such as ochratoxin A, aflatoxins, deoxynivalenol, zearalenone, fumonisins and T2 toxins (Rizzo et al., 2025). Furthermore, the saponin in fenugreek is considered the root cause of numerous neurological and reproductive issues. For example, fenugreek straws were reported to induce peripheral neuropathy in beef cattle (Moreno et al., 2023), while the saponin present in fenugreek has been linked to various reproductive issues, such as testicular toxicity, infertility, oxidative stress, DNA damage and anti-implantation and abortifacient effects, as well as neurotoxicity that affects neurodevelopmental processes, neurobehavior and neuropathological disorders in human and animal offspring (Ouzir et al., 2016).

Despite the established nutritional benefits and diverse functional properties of fenugreek and the promising initial studies in livestock, there remains a clear gap regarding the systemic application and mechanistic understanding of its use specifically in bovine production systems. While general benefits, such as appetite stimulation and galactagogue effects, are known, the literature lacks a comprehensive synthesis of how fenugreek's complex phytochemistry influences specific bovine physiological pathways, rumen health and productivity parameters in a dose-dependent and sustainable manner. Furthermore, there has not been sufficient consolidated in the available literature of the necessary mitigation strategies for its negative organoleptic impact and the proper management of its potential antinutritional or toxic factors (such as its mycotoxin and high saponins levels leading to reproductive/neurological issues, particularly in high-volume feeding).

Therefore, this review aimed to systemically investigate the multifaceted nature of fenugreek, from its nutritional and phytochemical composition to its diverse biological functions, with a specific focus on its current and potential application in bovine nutrition and health. By critically appraising the existing scientific evidence, this work hoped to:

- 1) synthesize the proven benefits and mechanistic insights;
- 2) highlight the practical steps for its use and the challenges, particularly regarding the anti-quality effects on meat; and
- 3) clearly delineate the key areas where future research is urgently needed to fully and safely harness the potential of fenugreek in modern bovine agricultural systems.

Materials and Methods

This review article was compiled based on a comprehensive literature search across multiple scientific databases to ensure a broad and in-depth coverage of fenugreek's properties and applications. Key databases utilized for this extensive search included Google Scholar, PubMed, JSTOR, ResearchGate, Scopus and Web of Science, supplemented by cross-referencing from identified articles. The search applied keywords (fenugreek, *Trigonella foenum-graecum*, bovine, cattle, ruminant, growth, reproduction, methane, toxicity) in conjunction with Boolean operators. Initially, the search targeted articles published within the 2020–2025. However, due to the limited recent literature, the scope was expanded to include all relevant articles identified from 1991 to 2025. The selection process prioritized peer-reviewed research articles, reviews and theses. Articles were included if they reported on fenugreek's effect in ruminants (cattle, buffalo, sheep, heifers) and non-ruminants (dogs, rats), as well as relevant *in vivo* and *in vitro* studies. Articles focused solely on fenugreek production as a crop were excluded. The comprehensive search yielded 51 articles, of which 33 were included in the current review, with the 10 included articles on ruminants from 2021 to 2025.

Results and Discussion

Chemical composition and bioactive profile of fenugreek

Fenugreek is recognized for its rich and varied chemical composition, which greatly contributes to its diverse biological activities and nutritional value. A comparative analysis of key analytes across different parts and processing states of fenugreek highlights this variability, as detailed in Table 1.

Table 1 Local language terms for fenugreek and its pronunciation in various countries

Country	Fenugreek written in local language	Pronunciation (approximate)
Afghanistan	شنبليله	Shan-ba-lee-lah
Bangladesh	মথৈ	May-thee
Bhutan	མེན་པུ་	Men-dru
China	胡芦巴	Hoo-loo-bah
Egypt	حلبة	Hel-bah
Ethiopia	አብሽ	Ah-bish
France	Fenugrec	Fay-nyoo-grek
Germany	Bockshornklee	Boks-horn-klee
Greece	Τριγωνέλλα	Tree-go-nel-ah
India	मेथी	May-thee
Indonesia	Kelabat	Ke-la-bat
Italy	Fieno Greco	Fee-ay-no gre-co
Japan	コロハ	Ko-ro-ha
Malaysia	Halba	Hal-bah
Maldives	ހެލްބާ	Heel-bah
the Netherlands	Fenegriek	Fay-nuh-greek
Pakistan	میتھی	Maa-ee-tee
Russia	Пажитник	Pa-zheet-neek
South Africa	Fenugriek	Fen-ee-greek
Spain	Alholva	Al-ol-va
Sri Lanka	ඔලුවා	Oo-loo-haal
Tanzania	Hilba	Heel-bah
Thailand	หูลู่	Lûuk Sât
Turkey	Çemen	Che-men
Uzbekistan	Shambala	Sham-ba-la

Basic nutritional components

Fenugreek seeds are particularly notable for their high contents of dry matter (DM) (91.11 %) and organic matter (OM) (87.88 %) (Rejil et al., 2008). In addition, they are important sources of metabolizable energy (2373.67 Kcal/kg) and crude protein (CP) (29.49 %). While the CP content in fenugreek plants varies with age (decreasing from 23.5% at age 1 wk to 17.7% at age 15 wk), the seeds maintain a consistently high protein level (Niu et al., 2021; Degirmencioglu et al., 2016; Rejil et al., 2008). Ether extract is present in fenugreek seeds (3.86%), with a slight increase following roasting (6.64%). Fiber components, such as neutral detergent fiber (NDF) and acid detergent fiber (ADF) show interesting trends; NDF increases greatly in the plant from age 11 wk (26.4%) to age 15 wk (37.7%), indicating maturation, while seeds contain a substantial amount of NDF (45.55% raw seeds and 45.20 roasted seeds) and ADF (11.50%) (Niu et al., 2021; Degirmencioglu et al., 2016; Rejil et al., 2008). The presence of steroidal saponins is also noteworthy, with higher concentrations in younger plants (1.13% at age 11 wk) than in older plants (0.95% at age 15 wk).

Broader nutritional profile and seed composition

Fenugreek has a rich and diverse nutritional profile across its different parts. Its leaves are particularly rich in essential micronutrients, containing an adequate amount of β carotene (19%), vitamin C (0.22%), dietary fiber, iron, calcium and zinc, whereas the fenugreek seeds are notable for their high dietary fiber (50–65%) and non-starch polysaccharides (Montgomery, 2009; Ahmad et al., 2016).

The endosperm of fenugreek seeds is rich in proteins (44%), consisting of globulin, lecithin and albumin, and a considerable amount of amino acids (10–30%), such as 4-hydroxyisoleucine and histidine, which have been reported to stimulate insulin activity (İşikli and Karababa, 2005; Mathur and Choudhry, 2009; Naidu et al., 2011). Additionally, the seeds account for 5.5–7.5% of the overall lipids which is primarily composed of 85% neutral lipids, 10% phospholipids and 5% glycolipids (Rizzo et al., 2025). In addition, fenugreek seeds contain total saponins (2.73%), phenolic compounds (1%), total tannins (0.38%), choline, oleic acid, linolenic acid, nicotinic acid and niacin in good proportions (Naseri et al., 2013). Studies have highlighted obtrusive variations in the total phenolic content, saponins, flavonoids and tannins among different accessions of fenugreek seeds (Al-Maamari et al., 2016).

Phytochemical profile

Beyond general nutritional parameters, fenugreek's functional properties are largely attributed to its rich phytochemical profile, particularly its phenolic compounds and fatty acid composition, as presented in Table 2 and Table 3, respectively. Table 2 indicates that the contents of various phenolic compounds vary between the fenugreek seed and plant components at different growth stages. For example, resveratrol, is significantly higher in fenugreek seeds (14.01 $\mu\text{g/g}$) than in the plant at any growth stage. Other important phenolics are also present in the seeds such as vitexin (1.80 $\mu\text{g/g}$), apigenin + genistein (0.17 $\mu\text{g/g}$) and ferulic acid (0.17 $\mu\text{g/g}$). The presence of phenolic compounds varies considerably with plant maturity, with some compounds, such as rutin, increasing considerably 0.20 $\mu\text{g/g}$ in seeds to 28.05 $\mu\text{g/g}$ in a plant aged 1 month.

Table 2 Key analytes in fenugreek plants at ages 11 wk and 15 wk and in raw and roasted fenugreek seeds.

Analyte	Plant (age 11 wk)	Plant (age 15 wk)	Fenugreek seeds	Raw fenugreek seeds	Roasted fenugreek seeds
Dry matter (%)	-	-	91.11	-	-
Organic matter (%)	89	89	87.88	96.85	96.69
Metabolizable energy (Kcal/kg)	-	-	2373.67	-	-
Crude protein (%)	23.5	17.7	29.49	22.73	22.35
Ether extract (%)	-	-	3.86	5.38	6.64
Crude fiber (%)	-	-	-	9.56	9.74
Neutral detergent fiber (%)	26.4	37.7	14.44	45.55	45.20
Acid detergent fiber (%)	26.4	37.7	11.50	-	-
Acid detergent lignin (%)	-	-	2.61	-	-
Cellulose %	-	-	6.20	-	-
Nitrogen free extract (%)	-	-	48.33	50.28	52.22
Crude ash (%)	-	-	3.23	-	-
Total ash (%)	-	-	-	3.15	3.31
Steroidal saponin (%)	1.13	0.95	-	-	-
Reference	(Niu et al., 2021)	(Niu et al., 2021)	(Degirmencioglu et al., 2016)	(Rejil et al., 2008)	(Rejil et al., 2008)

Fatty acid composition

Table 3 provides a detailed breakdown of the fatty acid composition, revealing fenugreek seeds as a rich source of essential fatty acids. Methyl linoleate (C18:2) is the most abundant fatty acid in seeds (38.3%), followed by methyl linolenate (C18:3n3) (19.3%) and methyl palmitate (C16:0) (16.2%). Notably, the portion of methyl linolenate (C18:3n3) greatly increases as the plant matures, reaching 50.6% at age 1 month, indicating a shift in the lipid profile during growth. Collectively, these diverse chemical constituents underscore fenugreek's potential as a valuable dietary component and source of various bioactive compounds for health and animal nutrition.

Health-promoting bioactive compounds and medicinal value

Beyond basic nutrition, fenugreek seeds are a powerhouse of diverse phytochemicals. Steroidal saponin is the richest phytochemical among various bioactive compounds present in the fenugreek seeds extract (Kaviarasan et al., 2007). Some other major bioactive components are flavonoids, polyphenols, proanthocyanidins, alkaloids and tannins.

These diverse phytochemicals cumulatively facilitate a range of physiological activities, including promotion of digestion, enhancement of milk secretion, modulation of metabolism and overall enhancement of animal physiology upon consumption (Wina et al., 2005; Dixit et al., 2005; Wani and Kumar, 2018; Niu et al., 2021; Sura et al., 2023).

Table 3 Contents of phenolic compounds in fenugreek seeds and plants at various growth stages (Sura et al., 2023).

Phenolic compound	Fenugreek seeds	Fenugreek plant age 1 wk	Fenugreek plant age 2 wk	Fenugreek plant age 1 mth
Apigenin + Genistein	0.17	0.34	0.02	0.39
Caffeic acid	0.02	0.01	0.01	0.08
Catechin	0.003	0.003	ND	ND
Chlorogenic acid	0.04	ND	ND	ND
Epi-catechin	0.01	0.01	ND	ND
Epicatechin gallate	0.01	ND	ND	ND
Epigallocatechin	0.13	0.15	<LOQ	ND
Ferulic acid	0.17	ND	ND	2.24
Gallic acid	0.30	ND	ND	ND
Iso-vitexin	0.78	0.13	0.01	0.03
Sinapic acid	0.09	ND	0.18	ND
Resveratrol	14.01	0.28	<LOQ	0.03
Rutin	0.20	0.12	0.36	28.05
Vitexin	1.80	ND	ND	ND

ND = not detected; LOQ = Limit of quantification.

Certain constituents of fenugreek have proven their medicinal value. Proanthocyanidins in fenugreek are accountable for the normalization of systolic blood pressure (Baba et al., 2018; Amini et al., 2023). Vitexin, which is a widespread polyphenol, shows extensive biological activities such as anticancer, antioxidant, antitumor, hepatoprotective, anti-inflammatory, antidiabetic, antiviral and anti-bacterial/antifungal activities (Sura et al., 2023). Similarly, Apigenin, as a phytoestrogen, is therapeutically promising for diabetes, amnesia, Alzheimer, depression, insomnia, cancer and inflammation (Sura et al., 2023). Further, the synergistic action of phenolics and polyunsaturated fatty acids in fenugreek is responsible for reducing hypertension and obesity in humans (Sura et al., 2023).

These diverse chemical constituents collectively underscore fenugreek's potential as a valuable dietary component and source of various bioactive compounds for health and animal nutrition.

Pathway analysis of whole blood transcriptome

Beyond physiological or production parameters, transcriptomics approaches offer robust, molecular-level investigations into the deeper impacts of fenugreek seed extract. In bovine nutrition, analyzing the whole blood transcriptome provides a powerful, non-invasive window into systemic health and overall body metabolism, as gene expression in blood cells reflects physiological changes across the body. It is critical for evaluating novel phytobiotics, such as fenugreek, as it offers mechanistic insights into the beneficial effects of these additives on animal health and performance.

Principles and value of gene set enrichment analysis

Gene set enrichment analysis (GSEA) is sophisticated computational method that examines the entire set of differentially expressed genes within the context of predefined biological pathways, rather than just focusing on individual genes. In addition, it provides functional insights into entire metabolic and cellular processes that are coherently regulated due to dietary intervention, offering a clearer picture of the functional consequences of the supplement on the animal's biology (Taiwo et al., 2022).

Molecular mechanism of action: Functional pathways altered

GSEA of whole blood transcriptome in heifers supplemented with fenugreek seed extract as a rich source of steroidal

saponins revealed significant improvement in metabolic and antioxidant capacities (Taiwo et al., 2022). Specifically, the fenugreek seed extracts supplementation led to the upregulation of the pathways critical for enhanced immunity and metabolic status of heifers, demonstrating positive enrichment of the gene sets related to the ISG15 antiviral mechanism, suggesting an improved antiviral immune status and better ability of initiating defense against pathogens (Taiwo et al., 2022). Furthermore, pathways central to the energy metabolism were upregulated, including the citric acid cycle, respiratory electron transport and ATP synthesis (Taiwo et al., 2022). The improved energy generation aligned with increased blood glucose concentration. However, the enhance metabolic status was also supported by upregulation for the pathways of metabolism of proteins, indicating an improved amino acid status which has been attributed to the defaunating effect of saponins in the rumen, leading to increased microbial protein flow (Taiwo et al., 2022).

Furthermore, the fenugreek seed extract downregulates the erythrocyte gas exchange pathways such as transport of oxygen and carbon dioxide, which is the key molecular indicator of reduced oxidative stress, as erythrocytes are highly susceptible to oxidative damage, with this highlighting the potent antioxidant capacity conferred by fenugreek saponins (Taiwo et al., 2022).

Effects on rumen fermentation and microbiome

Supplementation using fenugreek has a positive impact on the rumen microbiome and fermentation, due to beneficial alterations in methane production, nutrient disappearance and volatile fatty acid (VFA) profiles, in both *in vivo* and *in vitro* studies. The effectiveness of fenugreek is influenced by its form, the degree of processing (raw or germinated) and the species (Niu et al., 2021; Dey et al., 2015; Rejil et al., 2008; Dixit et al., 2005).

Consistent Beneficial Effects

Fenugreek has a consistently positive influence on key fermentation parameters across different forms, dosages and species, as detailed below.

Reduced methane production

Fenugreek displays a consistent anti-methanogenic effect.

In vitro (whole plant forage)

The *in vitro* ruminal incubation (conducted over time intervals of 6 hr, 12 hr, 24 hr and 48 hr) of the fenugreek whole

plant collected at ages 11 wk and 15 wk significantly reduced (15–62%) methane production (measured in milliliters of CH₄ per gram) compared to an alfalfa or an alfalfa fenugreek mixture (Niu et al., 2021).

In vivo (seed powder)

A study in crossbred steers demonstrated that feeding 100 g/d of raw or roasted ground fenugreek seeds powder (approximately 2% of diet) significantly reduced methane production (10.2–23.6%) by decreasing protozoal population (42.25–68.38%) in rumen liquor (Rejil et al., 2008). Notably, in that study, roasting the seeds did not provide additional benefit in methane production over the raw form.

Improved digestibility and nutrient utilization

In vitro (forage / extract)

The *in vitro* ruminal incubation of fenugreek collected at age 11 wk significantly increased the DM and NDF disappearance percentages compared to alfalfa (Niu et al., 2021). Similarly, fenugreek leaf extract improved the truly degradable DM content in buffaloes (Dey et al., 2015).

In vivo (germinated seeds)

The form of fenugreek seed inclusion in the diet determines the effect. For example, 50 g/d of germinated fenugreek seeds fed to Freisen heifers provided significantly higher nutrient digestibility and feeding values than the soaked and dried forms (El-Hamd et al., 2025).

Beneficial VFA profile shift

Fenugreek promotes a VFA profile more favorable for energy efficiency, as detailed below.

In vitro

The *in vitro* ruminal incubation of fenugreek collected at ages 11 wk and 15 wk significantly increased the propionate percentage, while reducing the acetate-to-propionate ratio compared to the control (Niu et al., 2021).

In vivo

Steers fed roasted ground fenugreek seeds significantly increased total VFA (TVFA) concentrations compared to those fed on raw fenugreek seeds or the control (Rejil et al., 2008). Similarly, heifers fed all supplemented forms (dry, soaked or germinated) had significantly increased TVFA levels compared to the control (El-Hamd et al., 2025), where increased TVFA was attributed to efficient energy production.

Overall, fenugreek serves as a reliable anti-methanogenic agent, consistently shifting the rumen environment toward energy-efficient propionate production and enhanced nutrient disappearance. However, while these benefits were stable across cattle and buffalo, the magnitude of methane reduction and digestibility was strictly modified by the harvest age of the plant and the processing method of the seeds. Thus, although the direction of the fermentation shift was consistent, the quantitative outcomes remained subject to the specific dietary inclusion strategy and the physiological state of the animals.

Negative or mixed effects

Ammonia fluctuation and ruminal pH

Fenugreek's impact on nitrogen metabolism shows a conflict between *in vitro* and *in vivo* findings, likely due to methodological differences (closed versus open) and feed interaction.

In vitro

Fenugreek harvested at age 15 wk produced a reduction in ammonia concentration at 6 hr, 12 hr and 24 hr of incubation (Niu et al., 2021).

In vivo

Friesian heifers, fed on supplementation with dry, soaked or germinated fenugreek seeds exhibited significant increases in both ammonia-N and pH in the rumen fluid compared to the control group (El-Hamd et al., 2025). In that study, while increased ammonia-N could suggest more protein degradation, the increase in pH (6.00–6.34) remained within the optimal range for microbial activity.

Microbial population response

Fenugreek demonstrates a selective action on microbial groups.

Positive shifts

Fenugreek led to a consistent increase in markers for protein synthesis (microbial nitrogen) and resulted in a significant reduction (defaunation) of the protozoal population (Niu et al., 2021; Rejil et al., 2008).

No Broad Effect

Despite the targeted protozoal reduction, *in vivo* study showed no significant impact on the population of total anaerobic and proteolytic bacteria (Rejil et al., 2008).

Methanogen Fluctuations

Although overall methane was reduced, the *in vitro* 16S rRNA copy numbers associated with methanogen showed a mixed response with age 15 wk fenugreek, being reduced at 6 hr and 24 hr but showing inconsistent results at 12 hours depending on the comparison feed (Niu et al., 2021). This highlights that methanogen production dynamics are sensitive to specific time points and feed interactions.

The primary area of uncertainty lies in nitrogen metabolism, where ammonia-N levels can fluctuate depending on whether the system is closed (*in vitro*) or open (*in vivo*). While protozoal defaunation is a consistent and documented trend, the broad stability of the bacterial community suggests that fenugreek's antimicrobial action is specifically targeted rather than general. These mixed responses emphasize that while the core benefit of reduced methane is maintained, the temporal dynamics of methanogens and nitrogen utilization are sensitive modifiers that require careful monitoring.

Influence of form, dosage and species

Form and processing effect

The degree of seed processing can significantly impact outcomes:

Germination versus soaking

Heifers receiving the germinated seed form of fenugreek produced the greatest increase in nutrient digestibility and growth performance, followed by the soaked form (Abu El-Hamd et al., 2025), suggesting that these treatments enhance the bioavailability or activity of the beneficial compounds.

Roasting

Steers receiving 100 g/day of roasted fenugreek seeds had enhanced TVFA production but there was no additional improvement in methane reduction or the protozoal count compared to the raw seed consumption (Rejil et al., 2008).

Species and diet comparison

Species consistency

The core mechanism for methane reduction via a reduction in the acetate-to-propionate ratio and increased degradability were observed *in vitro* using rumen fluid for buffalos on a wheat straw / concentrate diet, using leaf extract (Dey et al., 2015; Rejil et al., 2008) and a general cattle inoculum (on an alfalfa-based diet, using whole plant forage) (Niu et al., 2021). This suggests the anti-methanogenic effects

of saponins are broadly effective across ruminant species; however, specific parameters outcomes, such as ammonia levels, are subject to *in vivo* species and diet variations.

The efficacy of fenugreek is dictated fundamentally by its structural form and dosage, with germinated seeds serving as the most bioavailable modifier for digestibility and growth. While the core anti-methanogenic mechanism was consistent across different bovine species, the effective dosage threshold appeared to be approximately 0.23 g/kg of body weight (El-Hamd et al., 2025), with considerably lower doses (approximately 0.0044 g/kg) often failing to produce a measurable response. This suggests that the physiological impact is highly dose-dependent and that safe, effective boundaries must be established based on the processing state of the supplement.

Mechanism underlying rumen effect

Fenugreek's steroidal saponins are key contributors to these ruminal benefits. They are believed to act by inhibiting the protozoa (defaunating action) and selectively influencing rumen bacteria and fungi (Abu El-Hamd et al., 2025; Dey et al., 2015). This action reduces the protozoal population, leading to the observed reduction in methane production and a shift in the hydrogen sink toward propionate production, contributing to the favorable VFA profile and improved energy utilization.

The overarching tendency of fenugreek supplementation is driven by the defaunating action of saponins, which realigns the rumen hydrogen sink to favor propionate over methane (Niu et al., 2021). This mechanism is consistent across bovine species, yet its efficiency is modified by the physical form of the additive, which determines the rate of saponin release. While the mechanism for methane reduction is well-understood, some uncertainty remains regarding the long-term adaptation of the bacterial microbiome to sustain saponin exposure.

Impact on growth performance and nutritional quality

Fenugreek supplementation can positively influence animal growth performance, with beneficial effects often observed when incorporated as soaked or germinated seeds (Fig. 2).

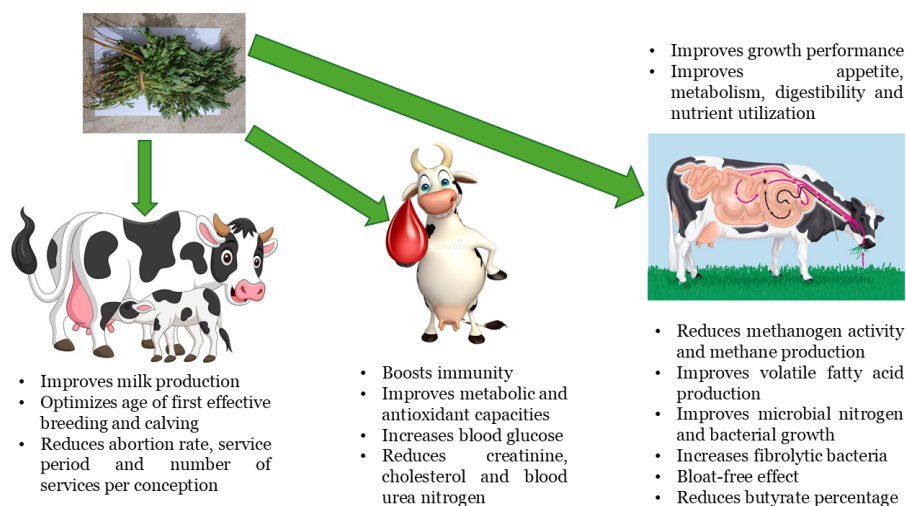


Fig. 2 Health-promoting effects of fenugreek in cattle.

Enhanced growth and efficiency

Friesian heifers fed diets supplemented with either soaked or germinated fenugreek seeds increased their final body weight (4.48–10.45%), total weight gain (10.28–22.18%), daily weight gain (10.19–22.16%) and economic efficiency (8.57–22.95%) compared to the control group (El-Hamd et al., 2025). Specifically, the soaked fenugreek seeds resulted in the highest final live body weight and average daily gain followed by the germinated seeds. This enhanced growth performance could be attributed to the steroidal saponins in fenugreek, which are believed to increase digestibility, promote beneficial rumen bacteria, enhance feed consumption, stimulate bile acid synthesis and facilitate lipid absorption (El-Hamd et al., 2025).

Thus, overall, fenugreek serves as a potent growth promoter when processed appropriately. The primary modifiers are the physical form of the seed and the resulting bioavailability of saponins, with soaked and germinated forms being considerably more effective than dry seeds. While the productivity gains were consistent in growing heifers, there is still uncertainty regarding whether these gains are primarily due to improved rumen environment or direct metabolic stimulation.

Increased intake and biological mechanisms

Consistent with the improved intake, Taiwo et al. (2022) reported that Holstein heifers fed a diet containing fenugreek seeds extract significantly increased their dry matter intake (DMI) and apparent total tract digestibility of DM, CP and neutral NDF. This effect of the fenugreek was suggested as being due to whetting of the hypothalamus, inciting appetite and consequently accelerating the total DM and daily concentrated feed intake (Degirmencioglu et al., 2016).

In terms of specific mechanisms, fenugreek is thought to stimulate the hypothalamus to increase voracity. Furthermore, the beneficial effects may be linked to specific active compounds such as lipophilic bioactive compounds found in sprouted fenugreek, as these compounds are known to have positive effects on overall health and disease prevention (Sura et al., 2023). In addition, fenugreek's mechanism involves estrogen-like compounds, such as diosgenin, which stimulates the milk production of water buffaloes (Degirmencioglu et al., 2016).

The above data reflects the consistent flow of increased intake and nutrient utilization across various bovine species. Key modifiers include the specific bioactive profile of the supplement and the animal's physiological need for increased energy during growth or lactation. There was a consistent effect of appetite stimulation, although the precise lipophilic compounds responsible for long-term health benefits remain an area for more detailed molecular investigation.

Variability, comparative interpretation and dose-response

However, the impact of fenugreek on growth parameters is not universally positive across all forms and dosages, indicating that efficacy may depend on the formulation, inclusion level and animal type.

Comparative analysis: Whole seeds versus extracts

Contrasting the positive result from El-Hamd et al. (2025) which used soaked or germinated seeds, a study by Suarez-Lorences et al. (2025) found no significant differences in initial body weight (BW), DMI, average daily gain (ADG) and feed-to-gain ratio (F:G) in steers fed fenugreek seed extract.

This disparity may have been due to differences in the form of supplementation and the resulting bioavailability.

Whole versus processed seeds

The physical processing (soaking versus germination) or the presence of a whole seed matrix may enhance the gradual release or absorption of active components such as saponins and fatty acids in the digestive tract (El-Hamd et al., 2025).

Fenugreek extract

Extracts may contain different profiles or concentrations of active compounds, potentially resulting in reduced efficacy, particularly when fed to finishing cattle that have different physiological requirements than growing heifers (Suarez-Lorences et al., 2025). Notably, another study using fenugreek seed extract in Holstein heifers reported a positive effect on DMI and digestibility, suggesting the variability may be complex and not solely due to the form of the extract (Suarez-Lorences et al., 2025).

Dose response evaluation

The differences in findings may also be attributed to the dosage relative to the animal's BW, as the inclusion level in the studies varied greatly.

The effective dose in El-Hamd et al. (2025) was 50 g of soaked seeds for Friesen heifers with an average body weight of 216 kg, which approximates to 0.23 g of seeds / kg BW/d. In contrast Suarez-Lorences et al. (2025) provided 1.25 g of fenugreek extract/steer/d to finishing steers with an initial BW of approximately 286 kg, which was a much lower proportional dose of approximately 0.0044 g extract/kg BW/d. Given that the whole seed dose was magnitudes higher on a mass basis, the lack of growth response in the study by Suarez-Lorences et al. (2025) may reflect a suboptimal dosage of the fenugreek extract in finishing cattle diets or insufficient concentrations of the active component in the specific extract used.

Based on these results, fenugreek's effectiveness is highly dose-dependent and sensitive to the animal's life stage. The most important modifier appears to be the mass-based dosage relative to BW, with lower extract concentrations often failing to trigger growth responses. There is a clear lack of consistency between whole seeds and refined extract outcomes, creating uncertainty that underscores the need for standardized inclusion protocols in commercial rations.

Nutritional quality enhancement

Sprouting fenugreek greatly enhances its nutritional quality as animal feed through the reduction of antinutritional factors such as phytic acid and oxalates (El-Hamd et al., 2025).

Specifically, 2–4 d of sprouting can reduce phytic acid by 23–47.7% and increase inorganic phosphorus (El-Hamd et al., 2025). Furthermore, fenugreek sprouts been reported to contain lipophilic bioactive compounds that have beneficial effects on overall health and disease prevention (Sura et al., 2023). In addition, fenugreek reduced DM gain, total digestible nutrients gain, digestible crude protein gain and feed cost (El-Hamd et al., 2025).

Progress can be characterized by an improvement in both the chemical profile of the feed and the economic efficiency of the production cycle, where the primary modifier is the sprouting duration, which dictates the level of antinutritional factor reduction. While the benefits of sprouting are consistent and well-documented, the exact economic advantage remains subject to local market fluctuations in feed costs and the energy required for on-farm seed processing.

Effects on reproductive performance

Fenugreek fortification has a positive effect on the reproductive performance of bovines, primarily due to its modulatory effects on metabolic status and hormonal regulation, as detailed below.

Improved reproductive efficiency in heifers

El-Hamd et al. (2025) reported that a diet containing fenugreek seeds significantly enhanced major reproductive traits in heifers. Specifically, a study on Friesen heifers aged 1 yr demonstrated that supplementation with 50 g of fenugreek seeds/head/d improved reproductive efficiency. The germinated seeds yielded the best results, successfully reducing the age at first service, age at conception service, service period, number of services per conception and age at parturition.

Primarily, these improved reproductive traits were a result of fenugreek's ability to accelerate body weight gain, having subsequent positive effects on the onset of the ovulation period.

Overall, the pattern indicates that fenugreek supplementation, particularly in a germinated form, serves as an effective catalyst for reaching reproductive maturity earlier in heifers by optimizing growth trajectories and energy status. The primary modifier is the processing method, with germination offering superior bioavailability for young bovines during the pre-pubertal physiological stage. While the reduction in age at first service is consistently documented, there remains some uncertainty regarding the long-term impact on lifetime fertility and whether these gains are solely a result of weight gain or direct hormonal stimulation.

Hormonal and metabolic mechanisms

Fenugreek enhances reproductive function through both metabolic and endocrine-modulating pathways, as detailed below.

Metabolic regulation

Fenugreek seeds are rich in saponins which positively alter rumen fermentation and nutrient utilization. El-Hamd et al. (2025) reported that supplementation, particularly in the germinated form, resulted in a significant improvement in nutrient digestibility and decreased the cholesterol concentration in the blood which improved metabolic status and allowed fenugreek to trigger pituitary gland to release gonadotrophins, which restrict the progesterone secretion, a process impacted by dietary protein and its effects on progesterone and luteinizing hormone levels.

Endocrine modulation (phytoestrogenic effect)

The plant endocrine effects have been attributed to its phytoestrogenic properties. Fenugreek contains various bioactive compounds, including steroidal saponins (such as diosgenin) and flavonoids. These compounds are similar structurally to mammalian hormones, such as 17 β -estradiol, and can act as selective modulators of the estrogen receptors (ER α and ER β). This mechanism allows fenugreek to interfere with the synthesis, secretion, transport and metabolism of reproductive hormones which is key to its application as reproductive aid and galactagogue (Sura et al., 2023; Khan et al., 2018).

This framework describes a synergetic relationship where improved digestive efficiency creates a metabolic surplus that coupled with phytoestrogenic signaling, drives reproductive success. The primary modifiers are the specific saponin and flavonoid profiles found in the seed, which directly determine the intensity of estrogen receptor modulation and pituitary response. Consistency has been reported in the ability of fenugreek to improve nutrient status, yet uncertainty persists regarding the precise molecular interactions between plant-derived steroids and bovine-specific hormone receptors across different breeds.

Reduced abortion rate and calving interval

A study by Moreno et al. (2023) demonstrated that fenugreek straws reduced the abortion rate and calving interval when fed to pregnant cattle at 100 kg/animal. This was attributed to the positive effects of fenugreek on overall pregnancy success and inter-calving efficiency. Studies have indicated that the form

and dosage of fenugreek can act as a natural feed additive to improve reproductive performance in bovines due to its effect on metabolic status and hormonal regulation (Abu El-Hamd et al., 2025; Moreno et al., 2023).

The current evidence suggests a positive correlation between reduced abortion rates and enhanced calving efficiency when fenugreek by-products are utilized by mature cattle. The physiological stage of pregnancy and the dose (specifically the high-volume use of straws) are the critical modifiers for these outcomes. However, there is considerable uncertainty regarding the safety threshold for high-volume intake, as excessive consumption of fenugreek straws has also been linked to detrimental neurological disorders and muscular hemorrhages.

Effects on carcass characteristics

Studies on the effect of fenugreek fortification in bovines have demonstrated that it did not significantly influence the carcass traits. For example, a study by Suarez-Lorences et al. (2025) found no significant differences in key carcass traits between the effects of feeding fenugreek extract at 1.25 g/steer/d, or a combination of fenugreek and encapsulated lecithin at 6 g/steer/d, for 186–190 d. These traits included adjusted final BW, hot carcass weight, longissimus muscle (ribeye) area, fat depth and marbling score. Based on these results, while fenugreek may influence other physiological and metabolic parameters, its direct impact on meat quality and quantity in cattle (at least under these experimental conditions) appeared to be negligible.

Effects on hematological parameters

The influence of fenugreek on hematological and biochemical blood parameters in cattle has resulted in varied and sometimes contradictory results, depending on the form of fenugreek and the specific parameters analyzed, as detailed below.

Positive or beneficial effects

Reduced creatinine and cholesterol

Diet containing dry or soaked or germinated fenugreek seeds fed to heifers significantly reduced the creatinine and cholesterol levels, measured in milligrams per deciliters, compared to the control group (El-Hamd et al., 2025). This reduced cholesterol level was attributed to the fenugreek's hypocholesterolemic properties.

Reduced blood urea nitrogen

Holstein heifers fed on a diet containing fenugreek seed extract had significantly reduced blood urea nitrogen (BUN) level (Taiwo et al., 2022). This reduced BUN level was attributed to efficient nitrogen utilization by reduced amino acid deamination or increased bacterial ammonia uptake for microbial protein synthesis in the rumen (Taiwo et al., 2022).

Overall, fenugreek supplementation contributes to superior metabolic efficiency and improved lipid profiles in young cattle. The primary modifiers for these benefits are the processing form (such as germination or extraction) and the animal's physiological stage, with heifers showing consistent responses in nitrogen efficiency. While the reduction of cholesterol was a consistent finding, uncertainty remains regarding the exact minimum dosage required to sustain these metabolic improvements across different breeds.

Mixed or potentially negative effects

Increased globulin and urea levels

El-Hamd et al. (2025) demonstrated that a diet supplemented with 50 g of germinated Fenugreek seeds fed to heifers significantly increased the levels of globulin (measured in grams per deciliter) and urea (measured in milligrams per deciliter) compared to the heifers receiving dry or soaked fenugreek seeds. The increased globulin level signified an immune response; however, the increased urea level indicated altered protein metabolism or kidney function.

Increased liver enzymes and creatinine kinase

Cattle fed on fenugreek (100 kg/animal) showed no significant effects on their overall hematology; however, biochemical analysis indicated significant increases in the levels of alkaline phosphate, aspartate aminotransferase, lactate dehydrogenase and creatinine kinase (Moreno et al., 2023). Increased levels of these enzymes signify muscle or liver tissue damage.

Increased alanine aminotransferase

Heifers fed on a diet containing soaked or germinated fenugreek had significantly increased the alanine aminotransferase (ALT) levels compared to those fed dry fenugreek seeds (El-Hamd et al., 2025). Increased ALT is a common indicator of liver stress or damage.

Increased blood glucose

In Holstein heifers, diet supplementation with fenugreek seeds extract led to a significant increase in blood glucose (Taiwo et al., 2022). This could be attributed to

enhanced dry matter intake (DMI) and nutrient digestibility or to the propionate-increasing effect of condensed tannins in the extract (Taiwo et al., 2022).

The emerging pattern suggests that while fenugreek stimulates immunity and energy production, high doses or specific processed forms may cause hepatic and muscular strain. The most critical modifiers are the dosage volume particularly for raw straws and the physical form of the seed, which dictates the bioavailability of potentially stressful bioactive compounds. There is consistency in the observations of increased glucose and globulin levels; however, there is considerable uncertainty regarding the long-term safety of the observed liver enzyme elevations and whether they represent permanent damage or transient metabolic adaptation.

Adverse health effects

Beyond metabolic and production parameters, some studies detailed below have reported adverse health outcomes associated with fenugreek consumption in cattle, particularly at higher doses or in specific forms (Fig. 3). It is critical to clarify that the severe neurological and pathological effects reported hereafter are associated with high intake levels of fenugreek straw or atypical exposure scenarios; these outcomes are not extrapolated to the standard dietary inclusion of fenugreek seeds used as supplements.

Muscular hemorrhages and nerve lesions

Moreno et al. (2023) documented that cattle consuming 100 kg/animal of fenugreek straws exhibited muscular hemorrhages and edema in the hindlimbs and around peripheral nerves. In severely affected cattle, this resulted in muscle atrophy. Furthermore, microscopic examination revealed major nerve lesions, primarily in the sciatic nerve. These lesions were characterized by both inter and interfascicular edema, as well as perineural hemorrhages. In addition, edema comprised of cellular debris, separated the nerve layer, while individual nerve fibers exhibited axonal degeneration. Irregular axons and disrupted myelin patterns were also confirmed via immunohistochemistry.

Granulomatous myositis and liver inflammation

Pathological studies revealed that cattle that had consumed fenugreek straws exhibited granulomatous myositis consistent with chronic besonotiosis (Moreno et al., 2023). Furthermore, these cattle displayed non-inflammatory *Sarcocystis* spp. cysts and liver inflammation.

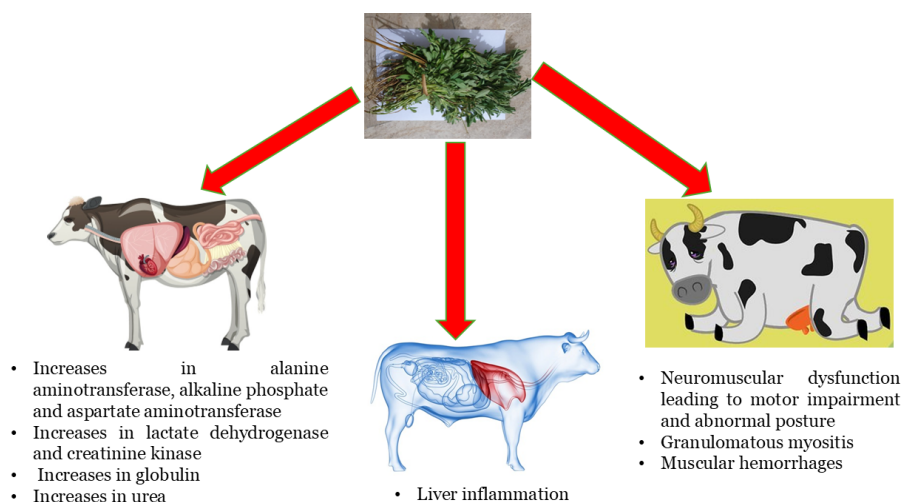


Fig. 3 Adverse health effects associated with fenugreek consumption in cattle.

Neurological disorders

Another major concern is the development of progressive neurological disorders in cattle consuming fenugreek straws, as reported on Sicilian farms. This disorder, affecting 8–65% of cattle, is characterized by hindlimbs paresis due to peripheral nerve degeneration (Rizzo et al., 2025). In the later stages, the affected cattle exhibited fetlock knuckling, ultimately leading to terminal recumbency (Rizzo et al., 2025). Furthermore, the cattle fed 100 kg/animal fenugreek straws developed proprioceptive positioning deficits and abnormal postures due to the hindlimbs paresis. In severe cases, forelimbs paresis, recumbency and knuckling over at the fetlocks were also observed. Affected cattle exhibited trembling locomotion and raised tails when forced to move. Tragically, approximately 60% of cattle died due to recumbency and inability to feed. While, potential diagnosis of these neural disorders includes hypocalcemia, hypokalemia, hypomagnesemia, organophosphates, cycadales and vitamin E deficiency, the neurological disorder could be linked to alkaloids exhibiting serotonergic receptor activity (Moreno et al., 2023; Rizzo et al., 2025). A Canadian study by Cowan et al. (2025) also reported fenugreek forage toxicosis in dairy cattle, causing weakness, ataxia, knuckling, walking on hocks and recumbency leading to mortality or euthanasia. This toxicosis was linked to emaciation and sciatic nerve and spinal cord axon degeneration, despite the absence of nutritional deficiencies, mycotoxin contamination, or liver mineral/vitamin abnormalities.

Lack of liver abscesses

Notably and in contrast to some other adverse effects, a study by Suarez-Lorences et al. (2025) found no significant

difference in the occurrence of liver abscess in cattle fed fenugreek extract at 1.25 g/steer/d or a combination of fenugreek and encapsulated lecithin at 6 g/steer/d over an extended period.

Collectively, these findings highlight critical areas of concern, particularly regarding the use of fenugreek straw at high intake levels or specific forms of supplementation. Such adverse neurological, muscular and organ pathologies underscore the importance of careful consideration of the dosage, the form of fenugreek and potential toxicological effects, which could negate any observed benefits in production.

Conclusion

Fenugreek presents a complex and dual profile as a feed additive for cattle, offering a range of nutritional and phytochemical benefits alongside promising physiological and production gains. Its rich composition, including steroidal saponins, phenolics and essential fatty acids, contributes to enhanced metabolic and antioxidant capacities, as well as improved rumen fermentation. This results in enhanced digestibility, increased microbial nitrogen, a beneficial shift in the VFA profile (reduced acetate-to-propionate ratio) and significantly reduced methane production.

Synthesis of field applicability

Recommended applications

The benefits of fenugreek could be maximized while ensuring animal welfare and product quality, by applying the

following application guidelines synthesized from the current evidence: 1) supplementation with 50 g/d of germinated or soaked seeds to improve BW gain, nutrient digestibility and reproductive efficiency (reducing the age of first service and parturition); 2) low-dose seed extract supplementation (approximately 0.23 g/kg BW) for up-regulating energy production pathways and antiviral defense mechanisms while reducing oxidative stress; and 3) the inclusion of raw or roasted ground seeds at approximately 2% of the diet (100 g/d) for consistent reduction of methane production and protozoal populations.

Applications requiring caution

While fenugreek does not significantly alter carcass traits, its distinctive aroma and flavor can compromise the organoleptic quality of meat and milk. Producers should exercise caution regarding the timing and dosage of fenugreek to avoid negative consumer perceptions.

Furthermore, some forms of supplementation (germinated versus soaked) may increase liver enzymes (ALT) or urea levels, necessitating routine monitoring of liver and kidney function during extended use.

Practices inappropriate for field use

Feeding fenugreek straws at high intake levels (100 kg/animal) must be avoided. This practice has been linked to severe neurological disorders, including peripheral neuropathy, hindlimb paresis and recumbency, as well as muscular hemorrhages and organ inflammation, often leading to mortality.

Future research directions

Future research should focus on addressing existing deficiencies to optimize fenugreek use in bovine diets, including: 1) deep investigation into the specific alkaloids and mechanisms responsible for the neurotoxicity associated with high-dose straw intake; 2) the definition of standardized inclusion levels for extracts versus whole seeds to ensure consistent production benefits without triggering adverse health or flavor-related effects; 3) utilizing transcriptomics to elucidate the chronic effects of fenugreek on gene expression, health markers and ruminal microbial population dynamics *in vivo*.

Addressing these gaps systematically should facilitate the beef and dairy industries to leverage fenugreek as a natural, efficacious feed additive, while ensuring animal health and safety.

Conflict of Interest

The authors affirm that there are no conflicts of interests

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