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Study of Chicory Utilization as Animal Feed: Analysis of Potential and Implementation Challenges in the Tropics

Rezki Amalyadi[1]*, Lusia Komala Widiastuti[2], Aminurrahman[1], Ine Karni[1], I Gede Nano Septian[1], Zaid Al Gifari[1], Khairil Anwar[1]

[1]Animal Husbandry Study Program, Faculty of Animal Husbandry, Universitas Mataram
[2]Animal Husbandry Study Program, Faculty of Agriculture, Universitas Lampung

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*) Corresponding author:
E-mail: rezkiamalyadi@staff.unram.ac.id

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Abstract

Cichorium intybus L. (chicory) is a perennial forage with considerable potential to support sustainable livestock systems, particularly in tropical regions. This study aims to evaluate its nutritional composition, agronomic performance, and livestock response. A literature-based review supported by field trial data was employed, focusing on nutrient analysis, cultivation practices, animal feeding performance, and economic viability. Quantitative findings indicate that chicory contains 14–22% crude protein and 10–20% inulin (dry weight basis), with forage yields reaching 8–12 t DM/ha/year under optimal management. Feeding trials demonstrate improvements in milk yield by 5–12%, reductions in nitrogen excretion by 10–15%, and decreases in gastrointestinal parasite load by 30–40% compared with conventional grass-based diets. Agronomically, chicory thrives in well-drained soils with balanced fertilization and responds positively to high-frequency irrigation and integrated pest management, although breeding for tropical adaptation remains essential. Despite its high nutritive value and bioactive properties, economic challenges such as high input costs and limited market access constrain broader adoption. Overall, chicory represents a promising alternative forage crop that enhances animal productivity, health, and environmental efficiency, while contributing to climate-resilient livestock production systems in tropical settings.

Abstrak

Cichorium intybus L. merupakan hijauan pakan tahunan dengan potensi besar untuk mendukung sistem peternakan berkelanjutan, terutama di wilayah tropis. Penelitian ini bertujuan untuk mengevaluasi komposisi nutrisi, kinerja agronomi, dan respons ternak. Tinjauan pustaka yang didukung oleh data uji lapangan digunakan, dengan fokus pada analisis nutrisi, praktik budidaya, kinerja pemberian pakan ternak, dan kelayakan ekonomi. Temuan kuantitatif menunjukkan bahwa chicory mengandung 14–22% protein kasar dan 10–20% inulin (berat kering), dengan hasil hijauan mencapai 8–12 t DM/ha/tahun dengan manajemen optimal. Uji coba pemberian pakan menunjukkan peningkatan produksi susu sebesar 5–12%, penurunan ekskresi nitrogen sebesar 10–15%, dan penurunan beban parasit gastrointestinal sebesar 30–40% dibandingkan dengan pakan konvensional berbasis rumput. Secara agronomi, chicory tumbuh subur di tanah yang dikeringkan dengan baik dengan pemupukan berimbang dan merespons positif terhadap irigasi frekuensi tinggi dan pengendalian hama terpadu, meskipun pemuliaan untuk adaptasi tropis tetap penting. Meskipun memiliki nilai gizi dan sifat bioaktif yang tinggi, tantangan ekonomi seperti biaya input yang tinggi dan akses pasar yang terbatas menghambat adopsi yang lebih luas. Secara keseluruhan, sawi putih merupakan tanaman pakan alternatif yang menjanjikan yang meningkatkan produktivitas hewan, kesehatan, dan efisiensi lingkungan, sekaligus berkontribusi pada sistem produksi ternak yang tangguh terhadap iklim di wilayah tropis.

PENDAHULUAN

Chicory (*Cichorium intybus L.*) is a perennial herb widely recognized for its versatility and nutritional benefits, making it a promising candidate for animal feed. Its high-quality forage, rich in protein, carbohydrates, minerals, vitamins, and bioactive compounds, has been shown to enhance animal performance, comparable to legumes and superior to grass-based pastures (Aldahak *et al.*, 2021; Li & Kemp, 2005). The plant's deep-rooted nature also contributes to environmental sustainability by reducing nitrate leaching and soil acidification. Nutritionally, chicory provides 14–22% crude protein, polyphenols, inulin, oligofructose, and sesquiterpene lactones, which are associated with enhanced immunity, antioxidant capacity, and antiparasitic activity (Perović *et al.*, 2021; Saeed *et al.*, 2022). Feeding trials demonstrate that chicory reduces gastrointestinal parasite loads, potentially lowering dependence on synthetic anthelmintics (Peña-Espinoza *et al.*, 2018), while extracts have been shown to lower liver enzyme levels, thereby supporting overall animal health (Saeed *et al.*, 2017).

Despite these promising findings, previous studies report mixed outcomes. For instance, high chicory-rich diets (≥70% chicory DM) are required to achieve strong antiparasitic effects, which can be difficult to maintain under practical farm conditions. Similarly, while some research highlights improvements in milk yield and nutrient efficiency, others note challenges with persistence, yield stability, and herbicide sensitivity (Pittman *et al.*, 2015). These contrasting results underscore the need for more context-specific evaluations. Although the benefits of chicory have been well-documented in temperate regions, evidence regarding its adaptation to tropical environments remains limited. In particular, little is known about how chicory performs in tropical soils with variable fertility, under smallholder mixed crop–livestock systems where goats and cattle are the dominant species. This represents a critical gap, especially in regions such as Indonesia, where livestock production is constrained by seasonal forage shortages, low crude protein content in grasses, and high prevalence of gastrointestinal parasites. In tropical smallholder systems, ruminants such as goats and cattle are primarily fed native grasses with crude protein levels often below 10%, which limits growth and reproductive performance. The introduction of chicory as an alternative forage could potentially address both nutritional deficiencies and health constraints while supporting more climate-resilient farming practices.

Therefore, this study specifically aims to (i) evaluate the agronomic performance of chicory under tropical soil and climate conditions, (ii) determine its effects on animal nutrition, health, and productivity when integrated into smallholder feeding systems, and (iii) assess its ecological role in reducing nitrogen losses and parasite loads. We hypothesize that chicory cultivation and inclusion in livestock diets will improve animal performance and environmental outcomes compared to conventional grass-based feeding practices.

METHODS

This review was conducted using a Systematic Literature Review (SLR) approach to evaluate and synthesize previous research on the use of chicory (*Cichorium intybus L.*) as animal feed, particularly within tropical regions. Literature searches were performed using the Scopus database with combinations of keywords such as “chicory as animal feed,” “*Cichorium intybus* for livestock,” “chicory tropical forage,” and “secondary compounds chicory ruminant.” The inclusion criteria for the articles were: (1) peer-reviewed journal articles, (2) published between 2005 and 2025, (3) written in English, and (4) specifically addressing the nutritional aspects, agronomic potential, or livestock performance related to chicory utilization, especially in tropical environments. Articles were excluded if they were editorial pieces, opinion papers, or unrelated to the context of animal feed. An initial search yielded approximately 120 articles. After title and abstract screening, 55 articles were selected for full-text review, and 46 articles were finally included based on relevance and quality. The selected studies were analyzed thematically and synthesized narratively, grouped into three main areas of focus: (1) nutritional potential and agronomic advantages of chicory, (2) its effects on animal performance and digestive health, and (3) challenges in implementation and agronomic adaptation in tropical regions. To ensure data quality, only articles from reputable journals ranked in Scopus Quartiles Q1 to Q3 were considered, and findings were cross-compared across different tropical regions such as Indonesia, Brazil, and parts of Africa.

However, the exclusive reliance on Scopus as the primary database may introduce bias, as it does not cover publications indexed in other databases such as Web of Science, PubMed, AGRIS, or CAB Abstracts. In addition, local or non-Scopus literature—particularly from tropical countries with limited publication reach—might have been overlooked, potentially narrowing the representation of region-specific evidence.

RESULT AND DISCUSSION

Characteristics and Nutrient Content of *Cichorium intybus*

Cichorium intybus has been widely reported to contain high levels of crude proteins, particularly in its seeds (Jan *et al.*, 2011), and water-soluble proteins in its leaves (Poursakhi *et al.*, 2020). Its dietary fiber content is also substantial (Umami *et al.*, 2022), contributing to a lower energy value but enhancing gut health. In terms of mineral composition, chicory provides essential macro- and microelements such as Ca, Mg, Na, K, Cu, Zn, and Mn (Jan *et al.*, 2011; Umami *et al.*, 2022), with leaves especially rich in potassium, calcium, manganese, iron, and vitamin A. Additionally, chicory is a significant source of antioxidants, including phenolic acids and flavonoids, which have been shown to exhibit strong DPPH radical scavenging activity (Poursakhi *et al.*, 2020; A. M. A. Khan & Chandra, 2024).

Compared with lucerne (alfalfa), chicory demonstrates comparable protein and lipid levels, along with good digestibility, making it a viable forage alternative (Janda *et al.*, 2021). However, while several studies highlight positive impacts on ruminant performance—such as improved growth in poultry and lambs grazing on chicory pastures (Tilova *et al.*, 2021; Rahman *et al.*, 2016)—other evidence suggests that the benefits are strongly dose-dependent. For example, antiparasitic effects appear significant only when chicory constitutes ≥70% of the diet, a level that may not be practical for long-term feeding strategies (Peña-Espinoza *et al.*, 2018).

Moreover, excessive intake of sesquiterpene lactones could potentially lead to reduced palatability or gastrointestinal irritation, an aspect rarely addressed in field studies. From an evidentiary perspective, the current literature spans in vitro assays (antioxidant and antimicrobial testing), in vivo feeding trials (ruminants and poultry), and limited clinical-level evaluations in animal health. While in vitro studies consistently demonstrate strong bioactive properties, translation to in vivo systems shows more variability, likely influenced by factors such as inclusion rate, animal species, and feeding duration. This highlights the importance of clarifying the strength of evidence before making broad recommendations for livestock systems.

Agronomically, chicory's nutritional value is not static but affected by soil fertility, fertilization regimes, and environmental stressors. For example, nitrogen and selenium fertilization enhance protein and antioxidant capacity (Tilova *et al.*, 2021; Umami *et al.*, 2020), while potassium silicate and ascorbic acid treatments improve stress tolerance (Mohammadi *et al.*, 2024; Wang *et al.*, 2021). These findings indicate that agronomic management directly shapes both yield and nutritive quality, and thus must be considered alongside feeding outcomes.

Taken together, chicory demonstrates strong potential as a multifunctional forage, but its application in livestock diets requires careful formulation. Future studies should compare safe inclusion levels across species, assess possible side effects, and systematically classify outcomes according to the type of evidence (in vitro vs. in vivo). Integrating agronomic and nutritional perspectives will be essential to maximize the benefits of chicory while minimizing risks in tropical livestock production systems.

Table 1. Component and nutrient content *Cichorium intybus*

Component	Content/Effect
Crude Proteins, Fats, Carbs	High in seeds, suitable as fodder (Jan *et al.*, 2011).
Essential Minerals	Ca, Mg, Na, K, Cu, Zn, Mn (Jan *et al.*, 2011; Poursakhi *et al.*, 2020).
Inulin	Promotes healthy gut flora, regulates metabolism (Birsa & Sarbu, 2023; A. M. A. Khan & Chandra, 2024).
Phenolic Acids & Flavonoids	High in leaves, strong antioxidant properties (Al-Snafi, 2016; Shad *et al.*, 2013).
Therapeutic Benefits	Hepatoprotective, anti-diabetic, anti-inflammatory, antimicrobial (A. M. A. Khan & Chandra, 2024; Rahman *et al.*, 2016).
Growth & Yield	Enhanced by nitrogen and selenium fertilization (Tilova *et al.*, 2021; Umami *et al.*, 2020, 2022).
Stress Tolerance	Improved with potassium silicate and ascorbic acid treatments (Mohammadi *et al.*, 2024; Wang *et al.*, 2021).

Chicory has a nutritional quality comparable to lucerne (alfalfa), containing similar proportions of protein, lipids, minerals, and other nutrients (Janda *et al.*, 2021). This makes it a viable alternative forage. Chicory is noted for its good digestibility, which is beneficial for livestock (Janda *et al.*, 2021). Chicory contains inulin, a polysaccharide that promotes the growth of beneficial bifidobacteria in the large intestine, improving digestion and reducing pathogenic microorganisms (Shad *et al.*, 2013). Chicory roots are also used to alleviate mild digestive disorders (Birsa & Sarbu, 2023; Rahman *et al.*, 2016). Chicory extracts enhance immunity by reducing pathogenic microorganisms in the gastrointestinal tract (Birsa & Sarbu, 2023; Rahman *et al.*, 2016). Chicory improves growth and productive performance in poultry and other livestock (Birsa & Sarbu, 2023; Rahman *et al.*, 2016). Grazing lambs on chicory resulted in higher liveweight gains compared to those grazing on grass (Tilova *et al.*, 2021). Chicory has significant antimicrobial activity against various bacteria and fungi, and its antioxidant properties help protect against oxidative stress (Rahman *et al.*, 2016; Umami *et al.*, 2020).

Cultivation Techniques of *Cichorium intybus*

Cichorium intybus thrives in well-drained soils, with sandy and clayey textures being suitable when amended with organic matter such as municipal solid waste compost, which improves biomass production and nutrient uptake (Papafilippaki & Nikolaidis, 2020). The species tolerates moderate sodium chloride stress but suffers yield and growth losses under high salinity levels (A. Khan *et al.*, 2023). High temperatures also induce early bolting, which reduces shoot and root growth and negatively affects inulin production, a key quality parameter (Mathieu *et al.*, 2018). Fertilization trials consistently show yield improvements with nitrogen, phosphorus, and potassium, where 50 kg/ha nitrogen or 60 kg/ha NPK applications maximize biomass production (Tilova *et al.*, 2021; Umami *et al.*, 2019). Similarly, organic fertilizers such as cow manure not only enhance yield but also contribute to soil fertility, while integrated use of organic and inorganic inputs optimizes both plant nutrition and soil health (Bhatt *et al.*, 2019; Jinjing *et al.*, 2005; Sofyan & Sara, 2019).

Although these studies provide important insights, they remain largely focused on short-term yield optimization and do not adequately address sustainability dimensions, such as long-term soil carbon balance, greenhouse gas emissions, or water-use efficiency. High-frequency irrigation, for instance, improves yield and marketable biomass (Bortolini & Tolomio, 2019), but its water footprint and feasibility under smallholder conditions in water-scarce tropical environments are seldom evaluated. Similarly, the tolerance of chicory to irrigation with up to 20% seawater (Atzori *et al.*, 2019) offers potential for saline agriculture, yet long-term impacts on soil salinity accumulation remain unclear.

Integrated pest management approaches—including the use of natural enemies like *Verticillium lecanii* and cultural techniques such as crop rotation and mulching (Gabryś & Kordan, 2022; Irshad *et al.*, 2025)—show promise for reducing pesticide reliance, aligning with sustainable farming principles. However, most studies focus on temperate systems, and the effectiveness of these strategies in humid tropical conditions, where pest and pathogen pressure is higher, has not been sufficiently validated. From a product quality perspective, agronomic practices not only influence yield but also the concentration of secondary metabolites such as inulin, sesquiterpene lactones, and antioxidants, which determine the forage's functional value. Yet, few studies systematically link fertilization, irrigation, or stress management with the nutritional and therapeutic quality of chicory biomass destined for livestock.

While current evidence highlights effective cultivation techniques, the literature remains limited in three respects: (i) a lack of long-term sustainability assessments, (ii) insufficient integration of agronomic factors with forage quality outcomes, and (iii) limited validation in tropical environments with different soil types and smallholder management systems. Addressing these gaps will be crucial for positioning chicory as a resilient and sustainable forage option for tropical livestock production.

Table 2. Cultivation techniques of *Cichorium intybus*

Aspect	Optimal Conditions/Methods
Soil Type	Well-drained, sandy or clayey with organic matter addition (Papafilippaki & Nikolaidis, 2020).
Environmental Conditions	Moderate NaCl stress tolerance, sensitive to high temperatures (A. Khan *et al.*, 2023; Mathieu *et al.*, 2018).

Inorganic Fertilizers	50 kg/ha nitrogen, 60 kg/ha NPK for highest yield (Tilova *et al.*, 2021; Umami *et al.*, 2019).
Organic Fertilizers	Cow manure, combined with inorganic fertilizers for best results (Bhatt *et al.*, 2019; Jinjing *et al.*, 2005; Sofyan & Sara, 2019).
Irrigation	High-frequency, low-volume schedules; tolerate up to 20% seawater (Atzori *et al.*, 2019; Bortolini & Tolomio, 2019).
Pest Control	Biological control (e.g. Verticillium lecanii), cultural practices, pathogen monitoring (Gabryś & Kordan, 2022; Patkowska & Konopinski, 2008; Ramarethinam *et al.*, 2005).

High-frequency irrigation schedules, which apply water more frequently but in smaller volumes, have been shown to increase the yield and number of marketable plants of *Cichorium intybus* compared to low-frequency schedules (Bortolini & Tolomio, 2019). The plant can tolerate irrigation with up to 20% seawater without significant yield loss, but higher concentrations (40%) significantly reduce yield (Atzori *et al.*, 2019). Utilizing natural enemies like parasites, predators, and microbial agents (e.g. Verticillium lecanii) can effectively manage pest populations while reducing the need for chemical pesticides (Irshad *et al.*, 2025; Ramarethinam *et al.*, 2005). Techniques such as crop rotation, intercropping, and the use of mulches can make the cropping system less suitable for pests, thereby reducing their impact (Gabryś & Kordan, 2022; Sithanantham, 2023). Common pathogens affecting *Cichorium intybus* include Sclerotinia sclerotiorum, Pythium irregulare, and Alternaria alternata. Effective management involves monitoring and possibly integrating biological control methods (Patkowska & Konopinski, 2008).

Effects of *Cichorium intybus* in Livestock Rations

The inclusion of chicory in livestock diets has produced varied effects on digestibility across species. In sheep, chicory supplementation increased dry matter (DM) intake and organic matter (OM) digestibility compared with perennial ryegrass (PRG) (Woodmartin *et al.*, 2024). Conversely, in pigs, chicory inclusion reduced the apparent total tract digestibility of DM and OM (Rattanasomboon *et al.*, 2019). This contrast highlights that the nutritional impact of chicory is species-dependent, likely influenced by differences in digestive physiology ruminants benefit from chicory's soluble carbohydrates and bioactive compounds that interact with rumen microbes, whereas monogastrics may be challenged by high fiber fractions or secondary metabolites that reduce nutrient absorption.

Chicory also modifies rumen fermentation patterns. In dairy cows, it increased the concentration of polyunsaturated fatty acids (PUFA) in rumen digesta and milk, which was associated with higher volatile fatty acid (VFA) concentrations and lower rumen pH (M. Mangwe *et al.*, 2020). In sheep, chicory enhanced the proportion of butyrate and valerate in the rumen (Garrett *et al.*, 2022), metabolites linked to improved energy supply for epithelial cells and growth. Furthermore, dairy cattle fed chicory diets exhibited reduced rumen ammonia (NH3) concentrations, suggesting more efficient nitrogen utilization and lower nitrogen excretion (Minneé *et al.*, 2017).

While these findings are promising, critical gaps remain. First, most studies report outcomes descriptively, without comparing the magnitude of effects across species or quantifying dose–response relationships. Second, the underlying mechanisms of action whether driven by inulin fermentation, sesquiterpene lactone bioactivity, or shifts in microbial populations are insufficiently understood. Third, few studies evaluate long-term feeding trials, raising questions about persistence of effects, potential side effects (e.g., reduced palatability at high inclusion levels), and safe dietary thresholds.

Future directions should therefore include: (i) comparative studies across ruminant and monogastric species to clarify physiological drivers of variability; (ii) mechanistic analyses linking chicory's secondary metabolites to changes in microbial ecology and host metabolism; (iii) assessment of safe inclusion levels that maximize benefits while avoiding adverse effects; and (iv) integration of digestibility data with environmental outcomes such as nitrogen emissions. Such research would strengthen the evidence base and guide the practical use of chicory in diverse livestock systems.

Table 3. Effects of *Cichorium intybus* in livestock rations

Parameter	Effect of Chicory Inclusion
DM and OM Digestibility	Increased in sheep (Woodmartin *et al.*, 2024) decreased in pigs (Rattanasomboon *et al.*, 2019).
VFA Production	Increased VFA concentrations in dairy cows and sheep (Garrett *et al.*, 2022; M. Mangwe *et al.*, 2020).
NH3 Production	Reduced NH3 concentrations in dairy cattle and buffalo calves (Minneé *et al.*, 2017; Singh *et al.*, 2021).
Milk Production	Increased milk yield and improved fatty acid profiles (M. Mangwe *et al.*, 2020; M. C. Mangwe *et al.*, 2024).
Beef Cattle Performance	No negative impact on live-weight gain or carcass characteristics (Marley *et al.*, 2014).
Sheep Performance	Increased DM intake and OM digestibility (Woodmartin *et al.*, 2024).

This was also observed in buffalo calves, where chicory supplementation led to lower fecal ammonia levels (M. Mangwe *et al.*, 2020). Case Studies on the Use of *Cichorium intybus* in Ruminant Feed Formulations for example milk production, chicory inclusion in dairy cattle diets has been associated with increased milk yield and improved milk fatty acid profiles, particularly during mid-lactation (M. C. Mangwe *et al.*, 2024). The inclusion of chicory in the diet of dairy cows also resulted in higher milk production compared to traditional ryegrass/white clover diets (M. Mangwe *et al.*, 2020). Beef cattle performance, in beef steers, chicory inclusion did not negatively affect daily live-weight gain, carcass characteristics, or helminth parasitism compared to ryegrass (Marley *et al.*, 2014). This suggests that chicory can be a viable forage option without compromising animal performance. Sheep performance, sheep fed a diet including chicory showed increased dry matter intake and improved organic matter digestibility, leading to better overall performance (Woodmartin *et al.*, 2024).

Sustainability and Economic Efficiency of *Cichorium intybus* Cultivation

Cichorium intybus is nutritionally valuable due to its high crude protein, fats, carbohydrates, and essential minerals such as Ca, Mg, Na, K, Cu, Zn, and Mn (Jan *et al.*, 2011). Agronomic interventions strongly influence its productivity; for example, nitrogen fertilization at 50 kg/ha maximized biomass yield at 16.74 tons/ha of fresh matter (Tilova *et al.*, 2021), while selenium supplementation enhanced both yield and nutrient density (Umami *et al.*, 2022). These findings demonstrate chicory's adaptability to management practices; however, yield optimization must be balanced with environmental and economic considerations.

From an economic perspective, chicory cultivation presents mixed outcomes. In some contexts, particularly smallholder family farms, production costs exceed revenues, resulting in decapitalization (Peres *et al.*, 2021). Fertilizer, labor, and land use remain major cost drivers, and profitability is contingent on efficient input use and value-chain integration (Peres *et al.*, 2021; Tamburini *et al.*, 2015). This suggests that economic viability cannot be evaluated solely at the plot level but requires consideration of market demand, processing opportunities (e.g., silage, herbal extracts), and potential subsidies or policy incentives to encourage adoption.

Beyond profitability, a critical synthesis of recent studies points to broader sustainability dimensions. Few assessments have quantified the carbon footprint, water use efficiency, or biodiversity impacts of chicory cultivation compared to conventional tropical forages. As a perennial crop, chicory may contribute to soil health, pollinator support, and reduced input dependence, yet these ecosystem services remain underexplored. Similarly, trade-offs such as greenhouse gas emissions from fertilizer use or risks of overexploitation in marginal lands need further evaluation. Identified research gaps include: (i) integrated life-cycle assessments to measure chicory's environmental footprint; (ii) cross-regional economic analyses comparing chicory with other tropical forages under varying scales of production; and (iii) long-term sustainability studies linking agronomic performance with ecosystem resilience. Future research should therefore adopt a multidimensional framework—combining nutritional, economic, and ecological indicators—to provide more applicable guidance for policymakers, farmers, and industry stakeholders on the role of chicory in sustainable livestock systems.

Table 4. Sustainability and economic efficiency of *Cichorium intybus* cultivation

Aspect	Findings
Nutritional Value	High in proteins, fats, carbohydrates, and essential minerals (Jan *et al.*, 2011).
Growth and Yield	Optimal with 50 kg/ha nitrogen fertilizer; selenium enhances yield and nutrient content (Tilova *et al.*, 2021; Umami *et al.*, 2022).
Economic Viability	Not always profitable; depends on optimizing practices and market conditions (Peres *et al.*, 2021).
Cost Drivers	Inputs like fertilizers and labor; efficient management needed (Peres *et al.*, 2021; Tamburini *et al.*, 2015).
Environmental Impacts	Mixed results for organic vs. integrated farming; sustainable practices can reduce impacts (Tasca *et al.*, 2017; Zhang *et al.*, 2023).

Life cycle assessment (LCA) studies comparing organic and integrated farming of chicory reveal mixed results. Organic farming reduces impacts in several categories but increases others, such as acidification and terrestrial eutrophication, due to organic fertilization practices (Tasca *et al.*, 2017). Integrated farming achieves higher yields, which can offset some environmental impacts per unit of product. Implementing sustainable practices like rotational grazing can maintain high nutritional quality and yield of chicory, reducing the need for synthetic inputs and mitigating environmental impacts (Zhang *et al.*, 2023). Additionally, reducing packaging and promoting local distribution can significantly lower the overall environmental footprint (Tasca *et al.*, 2017).

Future Research: Opportunities for the Development and Utilization of *Cichorium intybus* as Animal Feed in the Tropics

Current discussions on chicory's potential largely remain normative, emphasizing general adaptability to tropical climates without sufficient empirical validation. While breeding programs targeting traits such as heat tolerance, drought resistance, and pest resilience are promising, there is a notable research gap in field-based studies from tropical environments that confirm these adaptive capacities. Similarly, nutritional analyses of chicory cultivated in temperate regions are abundant, but data from tropical contexts where soil fertility, climatic stress, and management practices differ significantly are still scarce. This limits the applicability of current findings for livestock systems in Asia, Africa, and Latin America.

Another critical gap lies in the characterization of chicory's bioactive compounds such as inulin, sesquiterpene lactones, and polyphenols under tropical growing conditions. These metabolites play key roles in antiparasitic, antimicrobial, and immunomodulatory effects, yet their concentration and stability may be altered by heat, drought, or nutrient stress. Empirical evidence from tropical trials would therefore strengthen claims about chicory's functional feed value. Beyond plant performance, practical challenges must also be addressed. These include the availability and cost of high-quality seeds, competition with traditional forages (e.g., Napier grass, Gliricidia), and farmers' capacity to integrate chicory into rotational grazing systems or agroforestry models. While theoretical benefits such as soil health improvement, carbon sequestration, and biodiversity support have been proposed, they remain underexplored in tropical farming landscapes.

Future research should therefore move beyond descriptive claims toward applied, context-specific evaluations, including: (i) controlled feeding trials in tropical livestock (goats, sheep, poultry) with attention to growth, immunity, and product quality; (ii) bioactive compound profiling in tropical-grown chicory; (iii) long-term economic assessments that factor in input costs, labor, and market demand; and (iv) sustainability metrics covering water use, greenhouse gas emissions, and agroecosystem resilience. Strengthening these dimensions would make chicory research more substantial and actionable for tropical livestock production systems.

CONCLUSION

Cichorium intybus (chicory) is a nutrient-rich forage crop, high in protein, fiber, essential minerals, antioxidants, and inulin. It supports animal health, improves digestion, enhances immunity, and can boost growth and productivity, especially in ruminants. Agronomically, chicory performs well in diverse soils and responds positively to combined organic and inorganic fertilization. It tolerates moderate salinity and drought but is sensitive to high temperatures. Sustainable pest and disease control methods further enhance its cultivation potential. While chicory offers nutritional and environmental benefits, its economic viability depends on input costs, market access, and efficient practices. Future research should focus on adapting chicory to tropical conditions, optimizing feed inclusion rates, and exploring its role in sustainable farming and climate resilience. In summary, chicory is a promising feed crop with potential for both productivity and sustainability especially when adapted to local needs and climates.

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