Pertanika J. Trop. Agric. Sci. 49 (3): 1491 - 1522 (2026)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Review Article

A Critical Review of *Leucaena leucocephala* Leaves as an Alternative Source of Dietary Supplement on the Production Performance of Growing Rabbits

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ABSTRACT

Rabbit meat is a potential option to conventional red meat due to its higher crude protein content (20-25%), lower fat level (6-10%), and rich nutrient profile. Despite these nutritional benefits, rabbit production remains underdeveloped in many regions due to limited market access, inadequate consumer awareness, and high cost of feed, which accounts for nearly 60-70% of total production expenses. Consequently, the development of cost-effective feeding strategies is essential to improve the profitability and sustainability of rabbit farming. One promising approach is the inclusion of alternative and locally available feed resources, such as *Leucaena leucocephala* (LL) leaves. Dietary supplementation with LL leaves at low to moderate levels (up to 10%) can improve growth performance, feed intake, nutrient utilisation, feed conversion efficiency, carcass quality, and economic returns in growing rabbits. These benefits are largely attributed to the rich protein content and favourable nutrient composition of LL leaves. However, inclusion levels above 10% may adversely affect rabbit health and productivity due to the presence of anti-nutritional factors (ANFs), primarily mimosine and tannins which can impair nutrient digestion, protein utilization, and metabolic functions. Therefore, careful management of dietary inclusion rates is required. Future research should focus on improving detoxification and processing methods, including sun- drying, soaking, fermentation, ensiling, microbial

ARTICLE INFO

Article history:
Received: 30 September 2025
Accepted: 03 June 2026
Published: 26 June 2026

DOI: https://doi.org/10.47836/pjtas.49.3.25

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e-ISSN: 2231-8542

degradation, chemical treatment and enzyme supplementation, to reduce ANFs and maximize safe utilization of LL leaves. This review synthesizes findings from studies published over the past 15 years on the effects of LL leaves supplementation on the production performance and productivity of growing rabbits.

Keywords: Anti-nutritional factors, economic efficiency, hycole rabbit, *Leucaena leucocephala*, production performance

INTRODUCTION

Globally, the meat production sector, primarily dominated by poultry, cattle, and swine, has continued to increase and is projected to grow further in the coming years (Hayat et al., 2023). Within this sector, rabbit farming has gained growing attention due to its significant contribution to food security, income generation and sustainable agriculture. Livestock production contributes nearly 40% of global agricultural income and supplies approximately one-third of the world's total protein consumption, thereby playing a significant role in combating malnutrition and improving global food security (Naqvi et al., 2025). Rabbits are as highly efficient meat-producing animals because of their fast growth rate, early sexual maturity, high reproductive capability, prolific breeding ability and superior feed conversion (Ghosh et al., 2008). In addition, rabbit meat is vastly nutritious and widely considered a healthy source of animal protein for humans due to its favourable nutritional composition (Kumar et al., 2024). Despite these benefits, rabbit meat consumption remains low in many regions, mostly because of inadequate market availability, insufficient culinary diversification, and relatively high retail prices (Idris et al., 2023).

Nevertheless, global production of rabbit meat continues to increase, with projections estimating output to reach nearly 1.8 million tonnes by 2025. China is projected to remain the leading producer, accounting for almost 62% of total global production (Mohd Aminuddin et al., 2023). In rabbit production, growth performance is vigorously influenced by feed quality, as dietary composition directly impacts feed intake, nutrient digestibility and overall productivity. Optimal growth is usually attained with diets containing 16-18% crude protein and 14-18% crude fibre (Atmaja et al., 2024).

Rising feed expenses and consumer demand for healthier meat products have strengthened the pursuit for sustainable and cheap alternative feedstuffs for livestock production (Almahallawi et al., 2024; Cho et al., 2024; Hasan et al., 2025; Usman et al., 2025). Among the potential alternatives, LL, a tropical leguminous shrub, has gained substantial attention because of its high nutritional content and adaptability. Its leaves contain 20%-30% crude protein and 12%-20% crude fibre on a dry matter basis, making it an important feed resource for rabbits and ruminants. In addition, the LL plant is characterised by constant year-round availability, fast growth, better drought tolerance and large biomass production, further improving its suitability as a forage crop.

Previous studies have presented that dietary inclusion of LL leaves can positively improve nutrient absorption, growth, and overall feed efficiency in rabbits (Lamidi & Akilapa, 2013; Makinde, 2016). Properly processed LL leaf meal has been described to improve dry matter consumption and weight gain while lessening the adverse effects of ANFs (Al-Amin et al., 2019; Debnath et al., 2016). These findings recognised that LL leaves have potential as an alternative nutrient source in rabbit nutrition.

However, higher consumption of LL leaf meal in rabbits is limited by the anti-nutritional compounds, which adversely affect growth, nutrient digestibility, feed intake, and overall health. Fayemi et al. (2011) stated that rabbit feed containing LL leaves with ANF concentration exceeding 1% led to low feed consumption and reduced growth. Similarly, consumption of unprocessed or untreated LL leaves has been linked to poor growth response and low feed conversion, basically due to the detrimental impacts of ANFs (Fayemi et al., 2011).

Anti-nutritional compounds restrict the broader application of LL leaves in both monogastric herbivore and ruminant feeding systems (Ahmed & Abdelati, 2009; Nursiwi et al., 2018). These chemicals depress protein and dry matter digestion, thereby diminishing nutrient absorption and the efficiency of feed utilisation. Furthermore, the proportion of dietary inclusion plays a significant role in determining animal productivity and performance. Excessive inclusion levels may compromise animal health status and productivity, suggesting the necessity for carefully optimised feeding plans (Ahmed & Abdelati, 2009; Fayemi et al., 2011).

Nevertheless, variations in reported findings concerning the optimal inclusion levels, digestibility and toxicity of LL leaves continue to restrict their application in rabbit production. Therefore, this review critically assesses the potential of LL leaves as an underutilised feed supplement for rabbits by evaluating their nutritional structure, recommended inclusion rates, limitations, benefits and implications for growth response, economic sustainability, nutrient utilisation efficiency and animal health.

Rabbit Digestive Tract and Function

The mechanism of fibre digestion in rabbits is illustrated in Figure 1. Rabbits are monogastric animals with a digestive system modified for the efficient utilisation of fibrous plant parts. A typical significant structure of the rabbit digestive tract is the enlarged hindgut, called the caecum, which functions as the main site of microbial fermentation (Varga, 2014). The caecum holds a dense population of microorganisms that ferment nutrients and fibrous fractions that escape digestion and absorption in the small intestine (Gidenne et al., 2002).

Digestion process in rabbits begins in the mouth, as in other mammals. Unlike ruminants, rabbits have a deficiency of enzymes needed to completely digest structural carbohydrates such as cellulose. As digesta pass via the gastrointestinal tract, fibrous

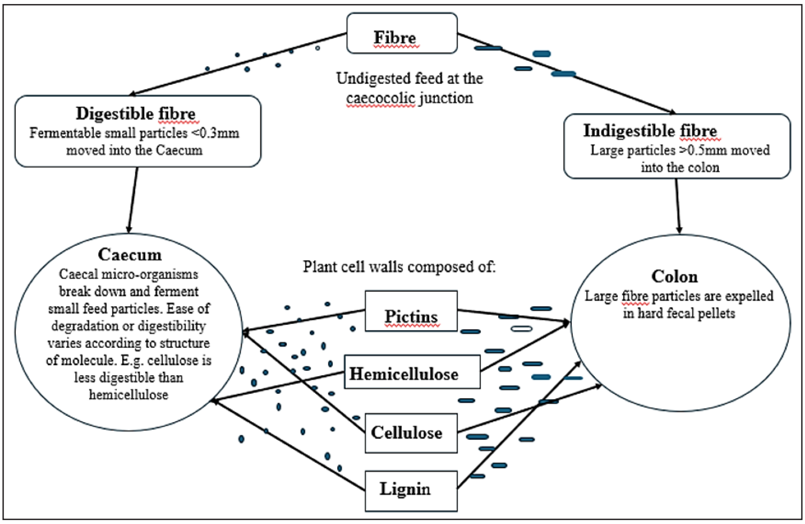

Figure 1. Mechanisms of fibre digestion in rabbits (Varga, 2014)

materials are selectively separated in the colon into digestible and indigestible portions. The digestible fibre, which holds fermentable nutrients, is redirected to the caecum, where bacterial fermentation breaks it down and releases valuable nutrients. In contrast, the indigestible fibre is compressed into hard faecal pellets and expelled as waste (Blas et al., 2020).

Inside the caecum, microbial fermentation releases crucial nutrients, including microbial proteins, volatile fatty acids (VFAs) and vitamins. These fermentation products are wrapped into soft, mucus-coated pellets commonly known as cecotropes. These cecotropes are ejected and immediately re-ingested by the rabbit via a process called coprophagy or cecotrophy. Re-ingestion permits nutrients synthesised in the caecum to move via the stomach and be efficiently absorbed in the small intestine. Volatile fatty acids produced during caecal fermentation contribute about 40% of the rabbit's daily energy supplies and play a key role in preserving caecal health. The production of VFAs helps keep the caecal pH slightly acidic, approximately 6.0-7.0, creating favourable environments for useful microorganisms while inhibiting the growth of detrimental bacteria (Gidenne & Fortun-Lamothe, 2002). This highly effective digestive approach enables rabbits to thrive well on high-fibre forage diets and effectively utilise plant parts that many other livestock species cannot.

Nutritional Composition and Requirements for Growing Rabbits

The nutritional needs of growing rabbits for optimal performance and health, presented in Tables 1 and 2, suggest that LL supplementation has the potential to meet these nutritional requirements. Their efficient inclusion in rabbit feed requires proper balancing,

Table 1
Nutritional requirements for optimum productivity in rabbits (Lebas, 2004)

Nutrients		**GROWTH**		**REPRODUCTION**		**Single Feed**
		18 to 42 days	**42 to 75 - 80 days**	**Intensive**	**Semi-intensive**	
Digestible Energy	(Kcal/kg)	2300	2500	2600	2500	2300
	(MJ/kg)	9.50	10.50	11.00	10.50	9.50
Crude Protein		151-161	161-171	182-191	172-176	161
Digestible Protein		111-121	122-132	131-141	121-131	111-126
Ratio Digest. Protein	(g/1000kcal)	46	49	52-54	51-53	49
Ratio Digestible Energy	(g/1 MJoule)	10.70	11.50	12.70-13.00	12.00-12.70	11.50-12.00
Lipids		21-26	26-41	41-51	31-41	21-31
Amino Acids						
Lysine		7.50	8.00	8.50	8.20	8.00
Sulfur amino acids (methio+cyst)		5.50	6.00	6.20	6.00	6.00
Threonine		5.60	5.80	7.00	7.00	6.00
Tryptophan		1.20	1.40	1.50	1.50	1.40
Arginine		8.00	9.00	8.00	8.00	8.00
Minerals						
Calcium		7.00	8.00	12.00	12.00	11.00
Phosphorus		4.00	4.50	6.00	6.00	5.00
Sodium		2.20	2.20	2.60	2.50	2.20
Potassium		<15	<21	<19	<19	<19
Chloride		2.80	2.80	3.50	3.50	3.00
Magnesium		3.00	3.00	4.00	3.00	3.00
Sulphur		2.50	2.50	2.50	2.50	2.50
Iron (ppm)		51	51	101	101	81
Copper (ppm)		6	6	11	11	10
Zinc (ppm)		26	26	51	51	41
Manganese (ppm)		8	8	13	13	11
Vitamins (Fat-soluble)						
Vit. A (UI/kg)		6001	6001	10001	10001	10001
Vit, D (UI/kg)		1001	1001	1001(<1500)	1001(<1500)	1001(<1500)
Vit. E (mg/kg)		≥30	≥30	≥50	≥50	≥50
Vit. K (mg/kg)		1	1	2	2	2

Note. DM, Dry Matter; Kcal/kg, kilocalories per kilogram; MJ/kg, *megajoules per kilogram*; g/1000 kcal,grams per 1000 kilocalories; g/1 MJoule, grams per megajoule

Table 2
Nutritional requirements for optimum health condition in rabbits (Lebas, 2004)

Nutrients	**GROWTH**		**REPRODUCTION**		**Single Diet**
	19 to 43 days	**43 to 76-81 days**	**Intensive**	**Semi-intensive**	
ADF	≥191	≥171	≥136	≥151	≥161
ADL	≥56	≥51	≥31	≥31	≥51
ADF Minus ADL (Cellulose)	≥131	≥111	≥91	≥91	≥111
Ratio ADL/Cellulose	≥0.41	≥0.41	≥0.350	≥0.400	≥0.400
NDF	≥32	≥310	≥300	≥315	≥310
NDF - ADF (Hemicellulose)	≥120	≥100	≥85	≥90	≥100
Ratio (Hemicellulose + Pectins)/ADF	≤1.30	≤1.3	≤1.3	≤1.3	≤1.3
Starch	≤141	≤201	≤201	≤201	≤161
Vitamins (Water Soluble, ppm)					
Vit. C	251	251	201	201	201
Vit. B_1	3	3	3	3	3
Vit. B_2	7	7	7	7	7
Nicotinamid	51	51	41	41	41
Pantothenic Acid	21	21	21	21	21
Vit. B_6	3	3	3	3	3
Folic Acid	6	6	6	6	5
Vit. B_{12}	.0.010	0.010	0.010	0.010	0.010
Choline	201	201	101	101	101

Note. Abbreviations: DM (Dry Matter), ADF (Acid Detergent Fibre), ADL (Acid Detergent Lignin), NDF (Neutral Detergent Fibre), ppm (parts per million)

detoxification and processing to lessen the adverse effects of ANFs. Growing rabbits need a well-balanced nourishment to support fast growth, effective nutrient utilisation, and stable physiological well-being. Digestible energy, ranging from 2300 to 2600 kcal/kg, is critical for maintaining metabolic activities and improving weight gain. Crude protein content of about 15-19% are required for muscle development, enzyme synthesis and tissue repair.

Dietary fibre, preferably between 13 and 18%, plays a crucial role in sustaining digestive health by influencing hindgut fermentation, stimulating gut motility, and lowering the risk of gastrointestinal disorders. Dietary fats serve as energy sources, boost feed palatability, and help the absorption of fat-soluble vitamins. Vitamins, namely A, D, E, and the B complex group, are essential for metabolic regulation, immune function and appropriate bone and tissue development. Minerals, including phosphorus and calcium, are indispensable for physiological balance, skeletal development and normal body functions. Sufficient water intake is equally significant, as it supports digestion, thermoregulation, nutrient transport and overall metabolic activities. Collectively, these nutrients essentially contribute to optimal growth response, increase feed efficiency, enhance health condition and better disease resistance.

Comparative Assessment of LL-Supplemented Diet and a Traditional Alfalfa-Based Diet in Rabbit Feed

Leucaena leucocephala leaves have attracted considerable interest as an alternative protein-rich forage for rabbit nutrition due to their high nutritional profile and adaptability to tropical environments. Several studies have compared the nutritional characteristics and feeding value of LL with the conventional alfalfa-based diet commonly used in rabbit production. Evidence indicates that LL can partially or completely replace alfalfa in rabbit diets without adversely affecting growth performance, nutrient utilisation, or health status when included at appropriate levels. A comparative summary of the nutritional and practical characteristics of LL-supplemented and traditional alfalfa-based rabbit diets is presented in Table 3.

Leucaena leucocephala

Leucaena leucocephala plant (Figure 2), commonly referred to as the "miracle tree," belongs to the Mimosoideae subfamily within the Fabaceae family, which encompasses roughly 50 species of shrubs and trees (Zayed et al., 2018). Owing to its rich nutritional composition and long lifespan, LL has obtained widespread acknowledgement. *Leucaena leucocephala* forage is globally distributed (Table 4) and widely cultivated across tropical and subtropical areas, with a projected global cultivation area of 2 to 5 million hectares of land (Zayed et al., 2018).

Native to Mexico and Guatemala, LL was introduced to the Philippines and subsequently spread across Southeast Asia in the early 16th century. By the late 19th century, its cultivation had extended further across the Asia-Pacific area and into Australia. Relatively, the LL species is easy to establish and is recognised for its high DM productivity, ranging from 3 to 30 tonnes per hectare yearly. However, variation in yield is strongly affected by environmental variables such as temperature, moisture availability and soil fertility level (Al-Amin et al., 2019). For example, the cultivar OFI 34/92 has been stated to produce about 6 tonnes of DM per hectare each year when planted at a spacing of 1.5 m × 0.25 m.

Management practices also affect productivity and overall performance. Cutting LL plants at a height of 100 cm tall can yield up to 24 tonnes of DM per hectare per annum, while a 10-week harvesting interval may surge production to around 25.7 tonnes per hectare. In addition, soil amendment with gypsum has been revealed to boost edible biomass output, increasing yield to 4.5 tonnes per hectare per annum in comparison to 2.3 tonnes without gypsum (Nakamanee et al., 2019).

Leucaena leucocephala survives well in tropical and subtropical climatic areas between 30°N and 30°S (Xuan et al., 2006), performing significantly at temperatures between 25 °C and 30 °C. Its growth response declines in cooler subtropical winter regions due to restricted cold tolerance. It does not thrive well under heavy shade, but is more shade-

Table 3

Comparative assessment of an LL-supplemented diet and a traditional alfalfa-based diet in rabbit feed (Adekojo S et al., 2014; Debnath et al., 2016)

Variables	Diets Supplemented with Leucaena Leaves	Traditional Alfalfa-Supplemented Diets	Main Functions / Implications
Crude Protein (CP)	Contains high protein levels (20-30%), similar to alfalfa diets	Rich in protein (17-22%)	Supplies protein required for growth and tissue development
Fibre Content (NDF/ADF)	Higher lignin concentration with slightly lower fibre digestibility	Better digestibility of fibre and promotes intestinal health	Provides fermentable fibre that supports caecal fermentation
Nutrient Digestibility (CP, DM)	Generally, slightly lower digestibility of nutrients	Higher digestibility of protein, dry matter, and energy	Enhances nutrient availability and energy supply
Growth Performance	Like alfalfa, when included at moderate rates (≤10%), but declines at higher levels	Consistently supports superior growth performance	Improves body weight gain, FCR and feed consumption
Feed Conversion Efficiency (FCR)	Better efficiency at low inclusion (around 10%), but poorer at higher levels	More stable and efficient feed conversion	Indicates feed utilisation efficiency and rate of growth response
Anti-Nutritional Factors (ANFs)	Contains mimosine and tannins; high levels may cause toxicity	Very low anti-nutritional compounds and safer for feeding	High ANFs reduce growth and nutrient use; low levels minimise toxicity
Palatability	Moderate acceptance, reduced at high inclusion rates	Highly palatable	Influences voluntary feed intake
Health Effects	Safe at low to moderate inclusion if properly processed; risks increase at high levels	Widely accepted and considered safe	Lower ANFs improve health and performance
Economic Efficiency	Considerably reduces feed cost	More expensive, especially in tropical areas	Can lower feeding cost to 53% at 10% inclusion rate
Recommended Inclusion Level	Around 10%; potentially higher with effective processing	Commonly used at 30-40% of the diet as a forage source	Help optimise productivity and performance
Environmental Adaptability	Well-suited to tropical and subtropical climates	Performs best in temperate environments	Affects sustainability, availability, and production cost

ADF: Acid Detergent Fibre; NDF: Neutral Detergent Fibre; DM: Dry Matter

Figure 2. Leucaena leucocephala plants (Nakamanee et al., 2019)

Table 4
Global Leucaena distribution (Zayed et al., 2018)

Region	Countries
Central America	Costa Rica, Mexico, Nicaragua, Guatemala, Panama, El Salvador, Honduras
Asia	Philippines, Thailand, Taiwan, India, Cambodia, Bhutan, Indonesia, Laos, Vietnam, Malaysia, Pakistan, Sri Lanka, Iran, Japan, Iraq
Australasia	Papua New Guinea (New Guinea, New Britain, Bismarck Archipelago), Australia
Caribbean	Dominican Republic, Jamaica, Haiti, Cuba, Bermuda, Puerto Rico, Grenada, Cayman Islands, Bahamas
Indian Ocean	Seychelles (Aldabra, Rodrigues, Islands), Madagascar, Mauritius, Christmas Island, Chagos Archipelago
Africa	Malawi, Kenya, Nigeria, Somalia, Ghana, Zimbabwe, Uganda, Sierra Leone, Sudan, Togo, Senegal, Angola, Liberia, Guinea, Chad, Guinea-Bissau, Niger, Mali, São Tomé and Príncipe, South Africa,
Middle East	Yemen, Saudi Arabia,
Europe	Spain
North America	United States (Arizona, Hawaii, Virgin Islands, Texas, Florida), Georgia
Pacific Ocean	Polynesia (Tahiti, Moorea), Fiji (Caroline Islands),
South America	Peru, Venezuela, Chile, Brazil, Argentina, Bolivia, Colombia, Guyana

tolerant compared to many other tree legumes (Verma, 2016). It grows well in humid to subhumid environmental conditions with yearly rainfall ranging from 650 mm to 3000 mm and can endure dry seasons lasting 4 to 6 months. It exhibits a mean tolerance to salinity, frost and temporary waterlogging (up to about three weeks). Its growth declines under adverse conditions like acidic soils (pH < 5.5), severe frost, and soils deficient in nutrients like phosphorus, potassium and calcium. Furthermore, it is susceptible to elevated salinity and high aluminium concentrations, both of which can markedly deteriorate its growth performance.

Effects of Dietary Inclusion of LL on Microbial Dynamics, Fermentation, and Mimosine Toxicity

Incorporation of LL leaf in rabbit feed creates a dose-dependent trade-off between nutritional enhancement and constraints by anti-nutritional compounds, with significant implications for toxin metabolism, hindgut fermentation and microbial ecology. At mean inclusion rates, LL can support cecal fermentation by providing fermentable protein and fibre portions that enhance microbial substrate availability and VFAs production. Yet, increasing supplementation rates decreases fermentation efficiency mainly because of ANFs, particularly tannins and mimosine, which can bind dietary proteins and carbohydrates, inhibit microbial enzyme activities, and lower overall nutrient availability and digestibility.

Dietary inclusion of LL can also alter the cecal microbial ecosystem significantly. Initial exposure to the LL diet may suppress sensitive bacterial populations, causing momentary drops in microbial activity and growth response. Partial microbial adaptation may occur over time, reflected in the regaining of the fermentation role. This adaptation is limited in rabbits compared to ruminants. Rabbits lack specialised and efficient microbial groups capable of degrading the toxic metabolites of mimosine, including 2,3-dihydroxypyridine (2,3-DHP) and 3,4-DHP, leading to limited detoxification capability and accumulation of toxic substances.

When inclusion rate exceeds safe thresholds (commonly reported beyond 20% dietary inclusion or higher mimosine/tannin consumption), adverse consequences such as hepatic dysfunction, alopecia and increased mortality have been documented (Fayemi et al., 2011). Prominently, subclinical conditions may still arise at lower levels of inclusion, with histopathological changes in key organs detected even without obvious clinical signs (Carlos Machado et al., 2012). Processing approaches like heat treatment and ensiling can partly mitigate toxicity by lowering mimosine and tannin concentration, thereby enhancing digestibility and fermentation performance. Overall, the addition of LL in rabbit feed is restricted by its anti-nutritional profile and the low microbial detoxification capability of the hindgut ecosystem. Efficiency of nutrient utilisation therefore, relies on careful dose optimisation and proper feed processing methods to balance improved supply of nutrients against risks of microbial inhibition and systemic toxicity.

Nutritional Content of *Leucaena leucocephala* Foliage

The nutritional content of different LL species mentioned in Table 5 demonstrated that LL foliage is a fibrous, highly nutritious forage widely recognised as a valuable feed ingredient for ruminants and monogastric herbivores (Montoya-Flores et al., 2020). Across various species and cultivars, its crude protein constituent typically ranges from 18% to 28%, demonstrating its potential as a plant-based source of protein (Nakamanee et al., 2019). In addition to its rich protein concentration, LL leaf meal comprises essential amino acids,

Table 5
Nutritional content of different LL species (Nakamanee et al., 2019)

Species	**% (Dry Matter)**				
	CP	**ADF**	**NDF**	**Lignin**	**Hemicellulose**
Leucaena (cv. Tarramba K636)	33.50	19.70	33.50	10.90	13.80
Leucaena (ssp. glabrata cv.) Cunningham	34.70	23.70	34.70	8.20	11.10
Leucaena (ssp. zacapana OFI 56/88)	35.00	23.20	35.00	6.40	11.90
Leucaena (OFI 52/88)	36.20	25.50	36.20	8.50	10.70
Leucaena (OFI 83/92)	34.10	23.00	34.10	10.30	11.10
Leucaena (ssp. stenocarpa1 OFI53/88)	38.00	27.00	38.00	11.40	11.00
Leucaena (ssp. esculenta OFI 47/87)	34.70	23.30	34.70	8.60	11.40
Leucaena (ssp. paniculata 2 OFI 52/87)	38.00	24.90	38.00	10.00	13.10
Leucaena lanceolata (OFI 43/85)	37.90	25.00	37.90	7.70	12.90
Leucaena lempirana (OFI 6/91)	38.90	25.90	38.90	10.50	12.00
Leucaena (ssp. glabrata OFI 34/92)	35.90	23.90	35.90	8.60	12.10
Leucaena (ssp. nelsonii3 OFI 47/85)	43.30	31.00	43.30	11.80	12.30
Leucaena (OFI 81/87)	44.00	35.40	44.00	3.50	3.60
Leucaena (OFI 83/87)	35.90	25.40	35.90	12.00	10.40
Leucaena (OFI 17/86)	42.20	29.30	42.20	10.00	12.80
Leucaena (ssp. magnifica4 OFI 19/84)	41.50	29.80	41.50	11.00	11.70
Leucaena (OFI 61/88)	39.30	25.70	39.30	9.50	13.70
Leucaena (OFI 137/94 (CQ 3439)	36.40	26.00	36.40	10.40	10.40

vitamins and minerals, with an amino acid profile similar to soybean meal, making it a potential alternative source of feed ingredient for rabbits and other livestock, particularly in developing and tropical regions (Debnath et al., 2016).

The nutritional composition of LL is determined by plant maturity and plant part, with the CP value declining as harvest intervals increase. For example, protein content may reduce from 21% at 6 weeks of regrowth to nearby 16% at 12 weeks of cutting interval (Nakamanee et al., 2019; Zayed et al., 2018). Furthermore, this reduction emphasises the significance of optimal harvesting time to maximise nutritional output. Beyond its protein contribution, LL facilitate growth, enhances physiological performance, and improves metabolic functions due to its balanced nutrients (Wiratmini et al., 2021). Finally, its rich amino acid structure and wide availability in tropical countries place LL as a cheap, accessible protein feed supplement capable of partially or fully substituting conventional feed ingredients in the rabbit diet (Adedeji et al., 2013; Vijayakumar & Srinivasan, 2018).

Inclusion of Varying Rates of LL in Rabbit Feed

The implications of varying levels of LL leaves inclusion in the rabbit ration (Table 6) vary primarily due to the concentration of ANFs. Previous studies suggested that incorporating

Table 6

The impact of varying levels of LL leaf meal inclusion in rabbit feed

LL Inclusion (%)	Impacts on Growth Response and Health Status	Observed Outcomes	Reference(s)
0% (Control)	Represents the baseline diet with no LL inclusion. Animals maintained standard diets with normal growth, feed intake, and physiological health parameters.	Normal growth performance and health status under conventional feeding conditions.	(Adedokun Olubukola et al., 2021)
10%	Considered a safe inclusion level for optimal production performance and health status.	Improved growth response and reduced expenses on feed production.	(Debnath et al., 2016) (Makinde et al., 2015) (Lamidi & Akilapa, 2013) (Adedeji et al., 2013) (Makinde, 2016) (Al-Amin et al., 2019)
15%	Moderate inclusion level is associated with acceptable feed consumption and FCR with minimal adverse health effects.	Average nutrient utilisation, moderate growth response, and acceptable carcass yield.	(Castillo-Luna et al., 2022)
20%	Considered a potentially unsafe inclusion level if detoxification or processing is not done due to anti-nutritional factors.	Low growth response, decreased nutrient absorption efficiency, and potential health impairment.	(Fayemi et al., 2011)
25-30%	High inclusion levels are associated with significant toxicity issues, particularly in female and young rabbits, mainly due to ANFs.	Increased mortality, poor growth response, and deteriorated health status.	(Abd El-Galil et al., 2007)

LL leaves up to 10% supports optimal growth, improved feed utilisation efficiency, enhanced health condition, and economic output (Al-Amin et al., 2019; Debnath et al., 2016). At a 15% inclusion rate, rabbits exhibit moderate feed consumption and feed conversion ratio, with minor adverse health effects, signifying that this level may still support productivity without considerably compromising physiological function and well-being (Castillo-Luna et al., 2022).

Increasing LL inclusion to 20% demonstrated more noticeable risks due to higher ANF content, resulting in low feed intake, decreased weight gain, and clinical signs of toxicity and loss of hair (Fayemi et al., 2011). When the inclusion rate surpasses 20%, these negative impacts become severe, predominantly in females and young rabbits, with a sharp increase in mortality. This demonstrates a critical toxicity level where the detrimental effects of ANFs offset the nutritional benefits of LL leaves (Abd El-Galil et al., 2007). Overall, current research findings support limiting LL inclusion level to not more than 10% in rabbit feed to optimise growth, maintain good health status and economic efficiency while minimising the hazards linked to ANFs.

Impact of LL Inclusion on Body Weight

Leaf of LL has gained increasing consideration as a sustainable dietary option for rabbits due to its superior nutritional profile and ability to influence nutrient utilisation and growth performance. Many research investigations have demonstrated that its inclusion in rabbit rations can improve weight gain while simultaneously reducing expenditure on feed. For instance, Pérez-Bautista et al. (2023) stated an average daily weight gain of 23.18 g/rabbit/day in rabbits offered LL foliage compared to those fed conventional commercial feed. Likewise, Castillo-Luna et al. (2022) found that partial substitution of wheat with LL leaves did not adversely affect growth performance or carcass yield, suggesting its suitability as a feed for rabbits. Al-Amin et al. (2019) also reported improved weight gain at 10% level of supplementation of leaf meal, while Fayemi et al. (2011) noted a significant growth response when ensiled LL leaves were incorporated into the diets.

Furthermore, Wiratmini et al. (2021) discovered that 30% inclusion rate of water-soaked LL leaf meal enhanced feed efficiency and weight gain, highlighting that appropriate processing can improve its nutritional status. However, its inclusion is constrained by the existence of ANFs, predominantly mimosine, which can depress growth if not sufficiently reduced. Certainly, studies have documented reduced final body weight when air-dried leaves were incorporated, highlighting the undesirable impact of an insufficient processing method (Adekojo et al., 2014; Hafsa et al., 2016). These conflicting findings underscore the relevance of effective detoxification techniques such as ensiling, soaking and fermentation to curtail ANF levels and optimise the quality of feed. Further research is required to establish optimal inclusion levels across various growth stages and to compare LL leaves with other protein-rich forages to better describe their role in rabbit nutrition.

Feed Intake

Feed intake in rabbits offered LL foliage is influenced by palatability, nutrient density, and ANF concentration. When appropriately managed, LL supplementation can enhance growth and feed conversion efficiency. However, its dietary inclusion must be carefully managed to obtain maximum benefits from LL-based diets. A study by Pérez-Bautista et al. (2024) involved 20 New Zealand rabbits that were assessed during the fattening stage to compare a commercial diet to diets supplemented with LL leaves. Results showed that rabbits offered LL-inclusive diets exhibited higher feed consumption (47.7-48.0 g/day) than those offered a standard commercial ration, indicating better palatability and voluntary feed consumption. Equally, Pérez-Bautista et al. (2023) found that inclusion of up to 33%

LL leaves enhanced both growth and feed intake, stressing its potential nutritional benefits when used at moderate rates.

On the contrary, findings are not fully consistent across different studies. Debnath et al. (2016), in a 56-day trial involving New Zealand White rabbits, compared a commercial basal diet to diets containing 10% and 15% LL leaf meal. The results showed that rabbits fed control feed recorded the highest daily feed intake (109 g/day), whereas those offered 10% (75.55 g/day) and 15% (83.57 g/day) inclusion rates consumed less feed. The reduction in intake suggests that higher inclusion rates of LL leaf meal negatively affected palatability and intake, likely due to the effects of ANF's content. Effective processing can mitigate these effects and promote growth and feed utilisation efficiency without compromising dry matter consumption (Wiratmini et al., 2021). The evidence from current literature indicates a delicate balance between the nutritional benefits of LL foliage and the risks connected to its ANFs. While lower inclusion can improve performance, responses differ depending on concentration level, processing technique and diet formulation.

Current investigations are basically limited to short and medium-term results, leaving gaps in understanding long-term physiological adaptation, chronic exposure to mimosine, and its broader metabolic impacts. Future work should focus on establishing safe inclusion thresholds across different growth stages and explaining mechanisms of mimosine metabolism, gut microbial variation, and nutrient utilisation efficiency.

Digestibility of Crude Protein

The efficiency of crude protein digestibility in growing rabbits fed LL leaves is primarily influenced by the plant’s high protein content, alongside its substantial anti-nutritional compounds. Research findings on protein digestibility in rabbits remain inconsistent, mainly due to factors such as processing method, animal physiological status, inclusion level, and diet composition. Several studies reported a positive response of LL inclusion at lower levels. For example, Debnath et al. (2016) found improved CP digestibility at 10% inclusion level, while Carlos Machado et al. (2012) highlighted that this enhancement may be described by increased caecotrophy. Correspondingly, Parra-Almao et al. (2021) also reported higher CP digestibility of up to 85.9% in diets supplemented with LL.

In disparity, other studies have found neutral or negative effects, such as Adekojo et al. (2014), who reported lower digestibility in rabbits offered air-dried LL leaves, highlighting the influence of processing. Ikyume et al. (2019) stated no significant variations in CP digestibility when LL leaves were mixed with concentrate feed, suggesting that balanced supplementation may alleviate adverse effects. However, Aboul-Ela, et al. (2007) reported declined protein digestibility in rabbits fed LL as the main dietary protein source. Comparative research further indicates that LL usually exhibits lower nutrient digestibility than other forages like *Moringa oleifera*, although processing techniques can partially reduce ANFs and improve nutrient utilisation in rabbits (Safwat et al., 2014).

The differences in digestibility values are largely attributed to ANFs, which can harm enzyme activity, interfere with protein metabolism and lower nutrient absorption. Unlike conventional protein sources like soybean meal, *Moringa oleifera* contains lower rates of these compounds, contributing to its consistently higher protein digestibility. Despite mounting research interest, a vital limitation in the present literature is the lack of long-term research assessing chronic exposure to LL-associated ANFs and their overall effects on nutrient metabolism and the health of rabbits. Future research should therefore centre on optimising processing techniques and determining safe inclusion thresholds that lessen toxicity while maximising protein digestibility, especially at higher dietary incorporation rates.

Fiber Digestibility

The current literature on the inclusion of LL leaves in rabbit diets presents contradictory findings regarding fibre digestibility and nutrient utilisation. Leaves of LL are valued for their relatively high protein and fibre composition, making them a potential option; however, their nutritional advantages are highly dependent on inclusion rate, processing strategies, plant maturity, composition of diet and the proportion of ANFs.

Evidence indicated that rabbits, being hindgut fermenters, are physiologically adapted to fibre diets and can tolerate crude fibre rates of up to 30% in their feed (Makinde et al., 2015). Within this condition, moderate inclusion of LL leaf in rabbit feed has often been associated with normal or improved digestibility. For example, Safwat et al. (2014) found a rise in nutrient digestibility when inclusion rates rose from 30% to 40%, suggesting a threshold level where moderate substitution improves fermentative efficiency. Correspondingly, Adekojo et al. (2014) and Debnath et al. (2016) documented improved digestibility metrics at lower levels of inclusion, which may signal improved microbial adjustment and effective use of moderately incorporated LL. This positive result is not the same across different studies. Other research investigations reported neutral or reduced digestibility values with increasing LL leaf addition. Hafsa et al. (2016) and Nieves et al. (2004) found diminished nutrient and fibre (NDF and ADF) digestibility compared to the conventional forage feed, such as alfalfa-based diets, indicating depressed fibre utilisation at higher inclusion rates. This divergence is supported by Safwat et al. (2015), who discovered that while moderate addition may improve fermentation, excessive replacement of traditional forages can impair the digestion of fibre.

The discrepancy in findings may be attributed to different interacting factors. Research evidence showed that inclusion level seems to be dose-dependent, with low to medium rates supporting microbial functions while higher levels likely exceeding the digestive capability due to ANFs. Plant maturity also significantly influences fibre quality as older LL leaves contain higher lignified, indigestible fibre portions, thereby lowering digestibility. Processing techniques critically alter nutritional yield. Diet formulation and the balance between LL and traditional forages vigorously influence the dynamics of fermentation in the hindgut. The evidence shows that fibre digestibility in LL-based rabbit feed is not inherently fixed but is highly dependent on several factors. The main limitation recognised across studies is the absence of standardised inclusion and processing guidelines, especially concerning the detoxification of ANFs. Addressing this gap involves systematic assessment of treated LL leaves under controlled, long-term in vivo trials to determine safe supplement thresholds that optimise nutrient utilisation and animal health. Standardisation is indispensable for converting LL leaf meal into a reliable and sustainable feed resource for rabbits.

Carcass Weight and Dressing Percentage

Inclusion of LL leaves in diets of growing rabbits has produced inconsistent results on dressing percentage, carcass yield, and organ development, mostly depending on inclusion level and form of processing the leaf meal diet. Makinde et al. (2015) found increased relative weights of metabolically active organs, principally the liver, kidney, and heart in rabbits offered diets comprising of 20% LL leaf meal. This response was considered an adaptive physiological constraint, reflecting increased detoxification process in response to anti-nutritional chemicals. Makinde (2016) further strengthened these findings, suggesting that hypertrophy of the organ may represent a compensatory mechanism to ease toxin load. Consistent with these findings, Fayemi et al. (2011) reported that clinical signs and symptoms of toxicity, including alopecia, hepatic damage, and necrotic lesions in rabbits exposed to comparable dietary inclusion rates.

Divergent studies reported minimal or no adverse physiological implications at moderate rates of inclusion. Candelaria-Martinez et al. (2021) observed insignificant alteration in visceral organ weights when LL leaf meal was added as a dietary supplement, whereas Castillo-Luna et al. (2022) demonstrated that partial substitution of wheat up to 15% LL leaves did not negatively impact carcass yield. These findings indicated that low to moderate inclusion levels may be physiologically acceptable under a controlled feeding system. However, negative effects became more visible at higher inclusion. Studies by Mtenga & Laswai (1994) and Tangendjaja et al. (1990) discovered reduced growth response and impaired carcass quality when LL incorporation upsurges from 40-60%, ascribing these effects primarily to ANFs. The literature outlined a clear dose-dependent response; nonetheless lacks consensus on a universally safe inclusion threshold. The literature highlights a critical gap in defining the optimal inclusion rate for LL leaf in rabbit nutrition. Most existing findings are short-term and do not sufficiently include cumulative toxicological impacts or long-term physiological adjustment. Additionally, there remains insufficient agreement on the most effective detoxification approaches or on dietary plans capable of decreasing anti-nutritional impacts. Future studies should be directed at long-term feeding experiments, systematic evaluation of supplementation levels, and integrated mitigation approaches such as fermentation, chemical and biological detoxification, and genetic selection for low-mimosine varieties. These approaches are vital to improving the safety and nutritional reliability of LL as a sustainable feed resource in rabbit production.

Economic Efficiency of LL Leaves Inclusion

Leucaena leucocephala leaf incorporation into rabbit rations has been associated with improved growth rate and lower feeding costs, largely due to its relatively high CP content and potential to partly substitute for more costly commercial feed ingredients. Research by Wiratmini et al. (2021) reported higher weight gain and better feed efficiency without adverse effects on DM intake, indicating efficient nutrient absorption. Similarly, Candelaria-Martinez et al. (2021) discovered that combining LL leaves with *Guazuma ulmifolia* foliage depressed carcass fat deposition while preserving meat yield, suggesting its utilisation for the production of lean meat. Moreover, Debnath et al. (2016) found substantial economic returns, involving a 53% reduction in the cost of producing 1 kg of live weight when LL was incorporated at 10% of the diet, highlighting its strong short-term economic benefits.

Notwithstanding, the commercial application of LL leaves is hindered by the presence of ANFs, which can cause toxic effects if inadequately handled. Nevertheless, findings suggest that simple processing strategies, such as soaking, can significantly diminish mimosine content and associated toxicity dangers (De Angelis et al., 2021). Corresponding findings by Sarkar et al. (2021) indicated that processing appropriately and controlled dietary supplementation can mitigate ANF's effects while preserving nutritional value in both rabbits and other species of livestock. Yet, these benefits must be measured against additional operational expenses associated with detoxification, processing infrastructure and labour, which may limit scalability in commercial production systems.

A key limitation in the present literature is the insufficient data on long-term comprehensive economic assessment that integrates productivity output with processing and management expenditure. Inconsistency in LL nutritional composition driven by geographic, seasonal and post-harvest processing variances further complicates the constant economic assessment process (De Angelis et al., 2021). Thus, its true value as a justifiable feed ingredient remains dependent on context. Further research should therefore explore multi-location and multi-season experiments, alongside standardised assessment of detoxification systems and inclusion levels tailored to special rabbit breeds and production systems. Additionally, robust cost-benefit models integrating labour, availability of local feed and processing inputs are indispensable to determine the actual commercial feasibility of LL-based feeding strategies. Overall, though LL leaves show strong potential as a cost-effective and nutritionally viable feed supply for rabbit farming, its widespread implementation depends on resolving critical constraints related to cost variability, toxicity management and system-specific performance results. An integrated evidence-based merging of nutritional and economic data is essential to establish standardised protocols for its safe and profitable inclusion in rabbit feed.

The Anti-nutritional Compounds in LL

The rate of ANFs and the dry matter digestibility percentage of different LL cultivars is presented in Table 7. The ANFs commonly found in LL leaves that adversely affect rabbit production performance include tannins and mimosine. Tannins are polyphenolic compounds known to interfere with nutrient absorption and metabolic processes, whereas mimosine is a non-protein amino acid which can disrupt protein synthesis and DNA replication. These compounds contribute to impaired growth, reduced feed intake and toxicity. A study by Pal et al. (2010) revealed that mimosine impedes protein biosynthesis in rabbits, resulting in toxic indicators such as stunted growth. The toxic implications of LL supplementation have been documented in multiple species, including cattle, sheep, and rabbits, while in goats, clinical signs like alopecia have been detected (Vijayakumar & Srinivasan, 2018). In rabbits specifically, extreme inclusion of LL leaves has been associated with limited growth response (Adedeji et al., 2013). Feed containing higher levels of LL leaves disrupts metabolic processes, causing alopecia and feed-related toxicity in rabbits (Al-Amin et al., 2019). Inclusion rate of up to 20% LL has been reported to induce severe alopecia in rabbits (Makinde et al., 2015), substantiating earlier findings by D’mello (1992). The post-mortem investigations of affected animals further discovered pathological lesions such as necrosis, hepatic congestion and oedema, supportive of earlier evidence of tannin-induced and mimosine organ impairment (Awosanya & Akinyode, 1995).

Tannins form stable tannin protein complexes, diminish protein digestibility and impair growth response (Schofield et al., 2001). Tannins existing in both stems and leaves decrease DM digestibility, although they may simultaneously upsurge the proportion of caecal undegradable protein (Schofield et al., 2001). The astringent taste of tannin can also reduce voluntary feed consumption, inhibit the activity of digestive enzymes and further compromise nutrient absorption (Makkar, 2005). Leaves of LL contained relatively high content of mimosine (1.64%) and tannins (1.20%) after sun drying (Fayemi et al., 2011). At elevated inclusion levels above 20% of rabbit diets, these leaves have been linked to severe health outcomes, including hepatic dysfunction, alopecia, reduced growth performance and higher mortality.

Bioactivity and Phytochemical Contents of LL Leaves

Leucaena is a leguminous plant extensively cultivated in tropical and subtropical areas and documented for its multifaceted applications in traditional medicine, agriculture and

Table 7
The rate of ANFs and DMD of different LL cultivars (Nakamanee et al., 2019)

Species	The Anti-nutritional Compounds % (DM)				%DMD (24h)
	Mimosine	%	Tannin	%	
Leucaena (ssp. glabrata cv. Cunningham)	Mimosine	3.2	Tannin	0.9	75
Leucaena (ssp. OFI 56/88)	Mimosine	2.4	Tannin	0.5	75
Leucaena (OFI 52/88)	Mimosine	3.2	Tannin	1.8	73
Leucaena (OFI 83/92)	Mimosine	2.9	Tannin	2.1	72
Leucaena (ssp. stenocarpa1 OFI 53/88)	Mimosine	2.1	Tannin	2.3	52
Leucaena (ssp. esculenta OFI 47/87)	Mimosine	1.1	Tannin	3.2	65
Leucaena (ssp. paniculata2 OFI 52/87)	Mimosine	1.6	Tannin	0.9	67
Leucaena (OFI 43/85)	Mimosine	3.1	Tannin	1.0	74
Leucaena (OFI 6/91)	Mimosine	2.3	Tannin	0.4	71
Leucaena (ssp. glabrata OFI 34/92)	Mimosine	3.3	Tannin	1.1	80
Leucaena (ssp. nelsonii3 OFI 47/85)	Mimosine	2.9	Tannin	0.9	53
Leucaena (OFI 81/87)	Mimosine	2.4	Tannin	0.5	58
Leucaena pulverulenta (OFI 83/87)	Mimosine	2.2	Tannin	3.4	44
Leucaena (OFI 17/86)	Mimosine	2.0	Tannin	0.3	69
Leucaena (ssp. magnifica4 OFI 19/84)	Mimosine	1.9	Tannin	0.3	68
Leucaena (OFI 61/88)	Mimosine	3.3	Tannin	0.3	65
Leucaena (OFI 137/94 (CQ 3439)	Mimosine	1.6	Tannin	2.7	59

Note. DM means Dry Matter; OFI means Oxford Forestry Institute; DMD means Dry Matter Digestibility

environmental management. Its leaves are particularly high in bioactive phytochemicals, including alkaloids, tannins, flavonoids and triterpenoids like lupeol, which collectively contribute to its antibacterial, anti-methanogenic and antioxidant activities (Elzaiat et al., 2024; Shakak et al., 2025). Among LL alkaloids, mimosine is a major compound associated with antimicrobial function, where it is noted to hinder bacterial cell wall biosynthesis, principally peptidoglycan formation, ultimately causing bacterial growth inhibition and cell mortality (Rosida et al., 2017). Kaempferol-3-O-rutinoside, quercetin-3-O-rhamnoside and luteolin-7-glucoside are flavonoids broadly distributed in pods, leaves and flowers. However, these compounds apply antibacterial effects via multiple mechanisms involving disrupting membrane integrity, binding to bacterial proteins and inhibiting essential metabolic activities, while demonstrating strong antioxidant activity through the free radical scavenging process (Mohammed et al., 2015).

The tannin proportion was reported at around 6.57% in LL leaves (Mahanani et al. (2020), contribute to bactericidal properties by complexing with proteins of microbial cell wall, increasing membrane permeability disruption and depressing enzymatic activities. In ruminants, these tannins are also linked to low methanogenic archaea populations, thus contributing to decreased methane emissions and enhanced environmental sustainability and management (Alduwish et al., 2025; Aydin, 2024; Khatoon et al., 2025). Lupeol, a triterpenoid compound, further boost the plant's bioactivity profile, demonstrating antimicrobial, anti-inflammatory and cytotoxic properties. Spectroscopic evaluation has confirmed lupeol occurrence in leaf extracts, with a UV absorption point typically observed between 210-214 nm (Zarina et al., 2017). MS-GC profiling of dichloromethane extracts has further identified compounds like lupeol (14.7%), β-sitosterol (9.1%), squalene (41%), phytol (34%), and other fatty acid methyl ester compounds (Bassey et al., 2023). Overall, these findings underscore LL leaves as a noteworthy reservoir of pharmacologically active phytochemicals with possible applications in antimicrobial healing, livestock feed optimisation, and methane mitigation tactics. Finally, further in vivo studies are necessary to fully elucidate and harness these bioactive compounds for agricultural and biomedical innovation.

Mimosine

Mimosine is a non-proteinogenic amino acid occurring naturally in leguminous plants, including LL and *Mimosa pudica*. It is chemically identified as β-[N-(3-hydroxy-4-oxopyridyl)]-α-aminopropionic acid and displays structural resemblance to tyrosine because of its 3-hydroxy-4-pyridone ring (Figure 3). Thus, this structural mimicry allows its interference with the synthesis of protein and key metabolic activities. The cytotoxic impacts of mimosine are primarily connected to cell cycle arrest at the G1 phase, inhibition of DNA multiplication, and interruption of metal homeostasis via strong chelation of transition metals, including iron and zinc, by this means promoting oxidative stress and triggering cell death. These mechanisms buttress its toxicological indicators, including reproductive impairment, growth retardation, cataract formation, alopecia and hepatic injury.

Mimosine, despite its toxicity, has proven notable pharmacological potential. In research involving cancer, it has been reported to impede p21-activated kinase 1 (PAK1), an oncogenic signalling kinase involved in tumour cell proliferation and survival (Nguyen & Tawata, 2016). In addition, extracts of *Mimosa pudica* comprising mimosine have

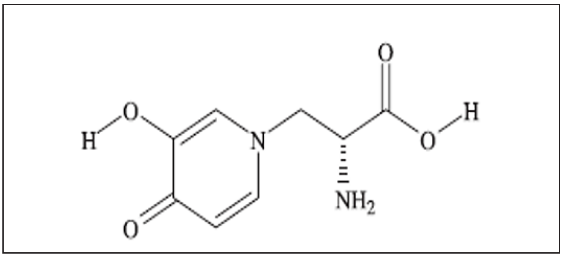

Figure 3. Chemical Structure of Mimosine (Xuan et al., 2006)

demonstrated hepatoprotective effects, likely mediated via decreased lipid peroxidation and enhanced activity of antioxidant enzymes in alcohol-induced liver injury in persons (Adurosakin et al., 2023).

The inclusion of forages comprising mimosine, such as LL, in animal feed signals imperative safety alarms, particularly for monogastric herbivores like rabbits. Gut microbial consortia in ruminants, including *Clostridium butyricum, Synergistes jonesii* and *Streptococcus lutetiensis,* can effectively degrade mimosine and its toxic metabolites, comprising 3,4- and 2,3-dihydroxypyridine (DHP), to less harmful compounds. This detoxification system is absent in rabbits, due to a lack of a specialised microbiota population (Derakhshani et al., 2016). Consequently, ingestion of plants high in mimosine in rabbits may result in impaired reproduction, oxidative hepatic impairment, disruption of tyrosine metabolism and reduced growth. Even though ruminant-based research continues to search for microbial adaptation and detoxification tactics for DHP and mimosine (Shelton & Brewbaker, 1994), there is a lack of recent direct investigations in rabbits. Modern-day research in the nutrition of rabbits instead centres on safe phytogenic additives like *Padina pavonica* and extruded linseed, which improve meat quality without causing adverse physiological impacts on rabbits (Fehri et al., 2025).

Current evidence does not establish the safe inclusion rate of mimosine in plants in rabbit feed. Contrary to ruminants, rabbits lack the microbial capability to detoxify mimosine and its metabolites, rendering their application physiologically and nutritionally harmful. Future research may search microbial engineering or targeted inoculation approaches to aid detoxification within the rabbit cecal environment; such approaches remain investigational. Pursuing this direction would involve integrative methodologies merging metagenomics, in vitro cecal fermentation models, and synthetic biology to identify and reconstruct appropriate detoxification pathways. Such a strategy would also necessitate a stable microbial colonisation and functional persistence inside the rabbit gut ecosystem. Mimosine-containing forages like LL will remain unsuitable for rabbit nutrition until such interventions are validated.

Tannin

Tannin is a polyphenolic phytochemical extensively present in LL leaves and seed pods. It occurs predominantly in the form of condensed tannin (proanthocyanidins), which are polymers of flavan-3-ols, even though smaller fractions of hydrolyzable tannins from gallic and ellagic acid esters may also exist. Tannin compounds exhibit a double biological profile, combining pharmacological benefits with significant anti-nutritional implications, particularly in monogastric herbivores like rabbits (Figure 4). Tannins from a functional perspective demonstrate antioxidant behaviour through scavenging reactive oxygen species and chelating transition metal ions, in so doing limiting oxidative impairment. However,

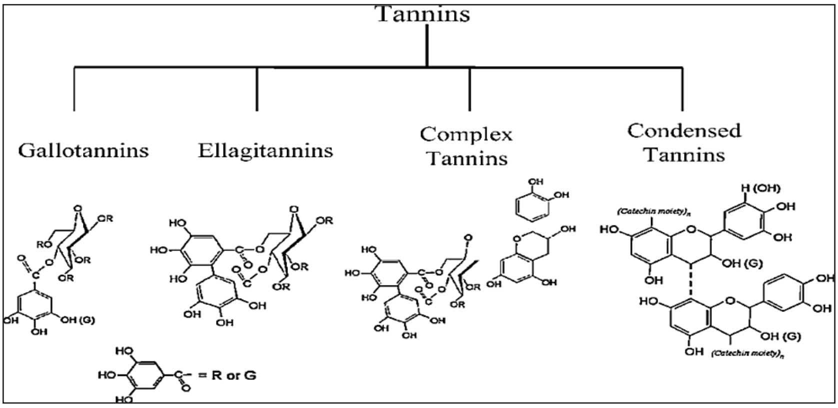

Figure 4. Tannin chemical structure (Aguilar et al., 2007)

they also display antimicrobial characteristics by disrupting microbial cell membranes and impeding significant enzymatic functions, whereas their anti-inflammatory impacts are related to suppression of lipoxygenase action and downregulation of the pro-inflammatory cytokines process (Zarina et al., 2017). In spite of these useful properties, tannins can impair nutrient use by forming stable complexes with digestive enzymes and dietary proteins, leading to low protein digestibility and diminished growth response when dietary concentrations surpass 1% (Fayemi et al., 2011).

Excessive tannin consumption in rabbits offered LL-based diets has been associated with clinical and physiological toxicity, including retarded weight gain, poor feed conversion, hepatic congestion, alopecia, and high mortality at higher inclusion rates. Tannin content in LL is highly variable and mainly influenced by plant part, plant maturity and post-harvest processing procedures. For instance, sun-dried LL leaves might contain about 1.2% tannins, while hydroponically aged seeds showed a marked drop from roughly 9% to 1.1% after 20 days of treatment (López Valoy et al., 2012). Likewise, ensiling and hot-water treatment can further lower tannin levels to safer ranges of around 0.77-1.1%, thus improving digestibility and animal performance (Fayemi et al., 2011). Overall, tannins in LL contribute important bioactive properties and also present significant anti-nutritional dangers when present in excess. Appropriate processing strategies, namely ensiling, fermentation and thermal treatments, can substantially reduce tannin concentration, thereby improving the safety and nutritional efficacy of LL as a high-protein feed resource with agricultural and pharmacological relevance.

Methods Used to Lower Anti-Nutritional Factors Content in LL

Different processing strategies have been examined to reduce ANFs, particularly mimosine and tannins, in LL leaves intended for rabbit feeding, each varying in efficacy, nutrient conservation, and practical viability (Table 8). Thermal processing, like boiling, can partly

Table 8
Methods for minivmising anti-nutritional compoundsv

Method	Impacts on ANFs	References
A combination of LL with other forages	Mixing *Leucaena* with other forage materials can reduce the effective concentration of anti-nutritional compounds through dilution, thereby lessening their harmful impacts on rabbits. But this approach does not fully eliminate the toxins.	(De Angelis et al., 2021) (Bernardino et al., 2021) (Pérez-Bautista et al., 2023)
Sun drying	Sun drying can cause a minor decrease in ANFs through exposure to sunlight and heat, although its effect on mimosine is limited. It may also improve palatability while maintaining much of the nutrient content.	(Adekojo et al., 2014) (Silva et al., 2024) (Agbo et al., 2017) (Debnath et al., 2016)
Soaking in normal H_2O	Soaking in fresh water helps lower mimosine and other water-soluble anti-nutritional compounds. This treatment may also modestly improve nutrient utilisation.	(Adekojo et al., 2014) (Wiratmini et al., 2021)
Hot H_2O soaking	Hot water soaking provides a greater reduction in ANFs than cold water soaking, particularly for mimosine, due to faster leaching aided by heat. Significant reductions may occur within 24 hours.	(Adekojo et al., 2014) (Fayemi et al., 2011)
Boiling	Boiling is highly effective in reducing ANFs through thermal degradation and leaching of toxic compounds. However, excessive boiling may also lead to nutrient losses.	(Agbo et al., 2017)
Ensiling	Ensiling lowers ANFs through microbial fermentation during storage. This process can substantially reduce ANFs, thereby improving growth performance, feed efficiency and rabbit health.	(Fayemi et al., 2011) (Chen et al., 2014)
Fermentation	Fermentation is considered one of the most effective detoxification methods. Beneficial microbes degrade mimosine and tannins efficiently, resulting in marked improvements in rabbit growth and overall health.	(Nursiwi et al., 2018) (Utami & Akbar, 2025)

degrade mimosine and improve digestibility, with benefits reported on improved rabbit growth (Agbo et al., 2017), though its usefulness is affected by the risk of substantial nutrient loss when exposure time is excessive, making the control process essential to avoid declining feed quality. Drying approaches are generally effective for dropping mimosine content while maintaining a better nutrient composition, alongside enhancements in the palatability of the diet. Soaking practices, involving prolonged water-soaking (36 hours) and hot-water treatment at nearly 60 °C for 24 hours, provide reasonable falls in mimosine content and can enhance intake moderately, with hot water soaking offering a more promising balance between nutrient retention and detoxification than prolonged boiling (Adekojo et al., 2014). Fermentation efficiently reduced both tannins and mimosine, enhancing animal performance such as health condition and carcass quality, mainly in systems where regulated microbial processing is feasible.

Ensiling stands out among the more effective biological and preservation methods, for its consistent decrease of both mimosine and tannin while simultaneously improving feed efficiency and growth outcomes, particularly when done over extended periods (around 6 weeks) (Fayemi et al., 2011). The effectiveness of ensiling depends on appropriate anaerobic conditions and standardisation of the process, which may restrict adoption in low-resource locations. Blending LL leaves with alternative forage leaves can dilute ANF strengths and improve protein balance, offering low-cost but comparatively moderate detoxification impact. Long-term genetic improvement of LL cultivars can also reduce the ANF level. Overall, these methods can be classified from lower to higher effectiveness in ANFs mitigation and productivity gains from forage blending to fermentation. Selection of a suitable method should therefore be determined by operational scale, infrastructure, and the needed balance involving detoxification efficiency and nutrient preservation.

Contributions to the Rabbit Industry

Leucaena leucocephala leaves are a potential low-cost alternative feed resource for rabbit farming, specifically in tropical and resource-scarce regions where traditional protein sources are expensive or limited. The high crude protein concentration and digestibility value support the use of LL leaves as a partial replacement for commercial feed ingredients to enhance production efficiency.

Research evidence indicates that LL supplementation can increase rabbit performance and health status. Pérez-Bautista et al. (2023) found higher feed consumption and growth response in rabbits fed fresh LL leaves compared to those on commercial diets alone, suggesting positive impacts on voluntary feed intake and weight gain. Economically, LL inclusion may reduce reliance on soybean meal and alfalfa in commercial concentrates, thereby lowering feed costs and supporting cheap rabbit meat production, particularly for smallholder farmers.

However, the practical utilisation of LL remains limited by anti-nutritional compounds, which impair animal productivity and health at high inclusion levels. The variability in findings among different studies also indicated inconsistent animal responses and highlights the necessity for safe inclusion thresholds, standardised feeding strategies and effective detoxification methods.

Overall, LL leaves inclusion showed strong potential as a sustainable and economical feed resource for rabbit production based on the literature; however, their successful application depends on various factors, which include balanced dietary inclusion and further long-term study on productivity and safety.

CONCLUSION

This critical review of LL leaves incorporation into rabbit feed recommends that an inclusion level of 10% appears optimal for enhancing production performance. At this level of inclusion, significant improvements are observed in feed efficiency, body weight gain and nutrient utilisation, alongside a potential decrease in feed cost and improved health benefits. However, exceeding 10% inclusion threshold without effective and appropriate processing or detoxification may compromise nutrient utilisation and result in adverse physiological implications, including organ dysfunction in the liver, heart and kidneys. Clinical symptoms such as necrotic lesions and alopecia have also been reported under higher inclusion. These negative outcomes were primarily attributed to anti-nutritional compounds in LL foliage, specifically mimosine and condensed tannins, which interfere with metabolic activities and nutrient absorption. Therefore, careful management of the inclusion level is necessary to balance nutritional benefits with safety concerns. Further research should focus on the development and validation of efficient detoxification or processing methods, as well as strategies to boost digestibility and decrease anti-nutrient activity. Additionally, long-term feeding trials and assessments of LL in combination with other forage feedstuffs across varying inclusion gradients are required to establish robust and context-specific feeding standards. Overall, optimised use of LL foliage could offer a cost-effective feed resource, contributing to decreased production expenses, improved farmer profitability and boosting the availability of rabbit meat, particularly in tropical and low-resource agricultural regions.

ACKNOWLEDGEMENT

Special appreciation and acknowledgement are extended to the Ministry of Higher Education Malaysia for awarding the Malaysia International Scholarship for postgraduate studies, and to the University of the Gambia for granting study leave.

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