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Potential of Tropical Feed Resources for Inclusion in Commercial Livestock Diet: A Mini Review

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ABSTRACT

The demand for locally accessible, reasonably priced, and environmentally resilient alternative feed resources has increased due to rapid population growth, climate variability, land degradation, and growing competition for land between human food and animal feed. To address this problem, the utilization of emerging feed resources in the tropics is important. Therefore, the objective of this review was to identify emerging topical feed resources, nutritional potential, limitations, and integration techniques for commercial livestock production. Trees and shrubs, improved legumes and grasses such as lablab and alfalfa, insect-based proteins, aquatic feeds, root and tuber crops, agro-industrial by-products, fruit and vegetable wastes, and fermented or biotechnologically enhanced feeds are just a few of the many emerging feeds that were found to be valuable options. Emerging feeds partly fill the gap in feed supply, reduce competition for food between humans and animals, lower feed costs, and contribute to self-sufficiency in nutrients from locally available feed sources. Despite the high potential of emerging feeds, their utilization remains limited due to several interrelated constraints, including the presence of anti-nutritional factors, high fiber content and low digestibility, variable and inconsistent nutrient composition, poor palatability, high moisture content, rapid spoilage, and seasonal availability. Additional barriers include inadequate processing and preservation technologies, lack of infrastructure and equipment, limited farmer knowledge and technical skills, weak extension services, and insufficient research-based feed standards. Consequently, these factors result in inconsistent feed quality and reduced economic returns for commercial livestock producers. The review highlighted that appropriate processing techniques such as drying, chopping, grinding, ensiling, fermentation, urea or ammonia treatment, heat treatment, enzyme supplementation, and mineral fortification are required to utilize emerging feeds. In conclusion, emerging feed resources represent a viable pathway toward sustainable, cost-effective, and climate-resilient livestock production in the tropics. Strengthening studies, improving processing and preservation technologies, enhancing extension services, and building farmer capacity are essential to unlock their full potential and ensure their successful adoption in commercial livestock feeding systems.

Keywords: Diet, Emerging feed, Integration strategy, Livestock, Nutritional factor

INTRODUCTION

The demand for livestock products is estimated to increase significantly due to population growth, urbanization, and changing dietary preferences (Thornton, 2010). As a result, optimizing livestock production through improved nutritional strategies has become a pressing concern for farmers, researchers, and the scientific community (FAO, 2012; Ayobami et al., 2024). Traditional feeding practices, which often rely on fixed formulations, can lead to inefficiencies in nutrient utilization, resulting in suboptimal growth performance and increased feed costs (Akintan et al., 2024). Furthermore, conventional feeding systems contribute significantly to environmental challenges, including nutrient waste, greenhouse gas emissions, and land degradation, necessitating a shift toward more sustainable practices (Beauchemin et al., 2008).

Feeding animals with low-quality or unbalanced diets negatively impacts their production levels, health, and overall well-being. Additionally, this type of feeding leads to the inefficient use of nutrients, resulting in the emission of harmful greenhouse gases (Giri et al., 2025). On a global scale, the production, processing, and transportation of feed contribute to 45% of the total greenhouse gas emissions from the livestock industry, with enteric methane accounting for 39% of these emissions (Gerber et al., 2013). Livestock production in tropical regions faces multiple constraints, such as a lack of availability and quality feed, especially during the dry season, animal diseases, and low genetic potential of indigenous animals (Duguma and Janssens, 2021). As feed accounts for 60-70% of total production costs in commercial livestock systems, the search for affordable and sustainable alternative feed resources has become a global priority (Makkar et al., 2014).

Consequently, identifying, characterizing, and utilizing novel and alternative feeding resources that are locally available, currently underutilized, and less competitive with human food will be essential to developing sustainable livestock production (Khanal, 2024). Utilization of emerging tropical feed resources is the best option to fill the gap

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(Chisoro et al., 2023). Many emerging tropical feed resources (ETFRs) are adapted to harsh climatic conditions such as drought, poor soils, and high temperatures and possess significant nutritional potential (Khanal, 2024), making them more resilient and reliable than conventional feed crops. These resources can support commercial livestock production if appropriately processed, evaluated, and incorporated into balanced rations (Chisoro et al., 2023).

Despite their abundance, the utilization of ETFRs in commercial livestock production remains limited due to several constraints, including the presence of antinutritional factors, lack of standardized processing methods, limited research information, inadequate supply chains, and insufficient farmer awareness (Gadzama, 2025). Hence, for ETFRs to be effectively utilized, strategic approaches are necessary to incorporate them into organized commercial livestock rations (Makkar et al., 2014). Therefore, this study aimed to review the classification, nutritional potential, utilization constraints, and sustainable integration strategies of ETFRs in commercial livestock production systems.

OVERVIEW OF EMERGING TROPICAL FEED RESOURCES

Feeding strategies play a crucial role in determining the nutritional quality of animal products. The type and composition of an animal's diet directly influence the nutritional content of the products derived from them, such as meat, milk, and eggs. Various feeding strategies, including traditional and modern approaches, affect factors such as the balance of macronutrients, essential vitamins, and minerals, as well as overall product quality and safety. Alternative feed sources are being employed as agents to improve animal health and enhance the quality of animal products (Untea et al., 2023).

Emerging tropical feed resources are non-traditional, underused, or newly identified plant, animal, and microbial-based materials that are gaining recognition for their potential to supplement or replace conventional feed ingredients in animal diets. These feed materials are newly identified and are found in tropical regions such as Africa, Asia, and Latin America. Emerging feed resources can be used to feed livestock and have become increasingly important due to rising feed costs, climate change, competition for food between humans and animals, and the limited availability of traditional feed ingredients such as maize and soybean meal (Makkar et al., 2014).

The use of local novel feed substitutes or supplements, such as insect proteins, industrial by-products, and food waste, as alternatives to conventional feed materials has been researched and is still being explored extensively. This is a way for rural and small-scale farmers to feed their animals and increase production. The use of these local novel feed resources in Africa is expected to greatly support the growth of the livestock sector and help meet the current and projected demand for meat and livestock products in the region (Chisoro et al., 2023).

CLASSES OF EMERGING TROPICAL FEED RESOURCES

Multipurpose forage trees and shrubs

Woody fodder species such as *Moringa oleifera*, *Leucaena leucocephala*, *Sesbania sesban*, *Gliricidia sepium*, and *Calliandra calothyrsus* have been introduced and promoted to increase biomass for supplemental animal feed and soil fertility management (Geleto and Ayele, 2022; Amad and Zentek, 2023). The browse fodder is generally rich in protein and minerals and can be used in the dry season to supplement poor-quality natural pasture or fibrous crop residue to improve animal performance (Kemboi et al., 2017). Replacing 20% of soybean meal with *Moringa oleifera* increases milk production in dairy cows (Cohen-Zinder et al., 2016), and including 10% of *Moringa oleifera* in the diet enhances growth and immune response in broiler chickens, as reported by Jasim and Mohammed (2024). Improving the meat and bone quality of slow-growing male chickens that have access to outdoor areas (Faustin-Evaris et al., 2022). Additionally, its amino acid composition and protein digestibility are comparable to those of soybean, exceeding 92% in digestibility.

Leucaena contains high crude protein (24 - 30%), depending on the variety and time of year. The digestibility of the protein reaches 63%, and the digestibility of dry matter is between 60 and 70%, measured *in vivo* (Barros-Rodríguez et al., 2012). In this sense, the use of *Leucaena* as a protein supplement in livestock farming systems in tropical countries is widely accepted. In addition, it is a source of minerals such as sulfur, which can enhance rumen microbial populations (mainly cellulolytic fungi and bacteria; Barros-Rodríguez et al., 2014). Supplementing rice straw diets of growing native cattle with dried *Leucaena* leaves yielded positive outcomes. The sheep that were fed the diet containing 300 g/kg *Sesbania* foliage showed significantly higher average daily body weight gain (103 g/day) than the unsupplemented control group (75.6 g/day; Manaye et al., 2009).

Mulberry leaves are rich in nutrients, especially with a high crude protein content, and they provide balanced amino acids with high digestibility (Saddul et al., 2005; Yulistiani et al., 2015). When added to the diets of growing and fattening pigs at a 20% level, it successfully replaces conventional protein sources and reduces feeding costs (Peng et al., 2024).

Feeding *Acacia angustissima* as supplements to rangeland pasture hay resulted in improved nutrient intake and higher nitrogen retention compared to rangeland pasture hay alone (Hove et al., 2001). Jatropha kernel meal is a good source of nutrients with a crude protein concentration of 620 to 770 g/kg dry matter and rich in essential amino acids such as leucine, Isoleucine, methionine, and phenylalanine (Saeed et al., 2017). Phesatcha et al. (2021) reported that Flemingia hay meal supplement in dairy steers affected the nutrient digestibility and improved ruminal fermentation, especially propionate.

Tropical legumes and pasture grasses

Improved legumes and grasses are known for their high biomass production, improved crude protein content (10-18%), better digestibility, and greater persistence when grazed. They are also more resistant to drought and diseases, which helps reduce the need for imported feed, enhances livestock performance and fertility, and improves soil fertility through nitrogen fixation, especially legume species (Lelamo, 2021). Forage legumes such as Hyacinth bean (*Lablab purpureus*), stylo (*Stylosanthes guianensis*), and silver leaf desmodium (*Desmodium uncinatum*) are well-suited to areas with high temperatures and low rainfall (Missanga et al., 2023). These legumes can be used in the cut-and-carry system or as an alternative during the wet season when yields are highest, and can be conserved for feeding during the dry season (Lelamo, 2021).

A mixture of lupin, pea, faba bean, and vetch could be used to replace soybean meal in the diet of intensively reared dairy ewes without compromising milk production, reducing environmental impacts and production costs of intensive dairy sheep farms, thus helping to increase the overall sustainability of the sector (Vouraki et al., 2023). *Brachiaria brizantha* has crude protein content ranging from 11.6 and high dry matter yield (Njarui et al., 2020). Feeding *Brachiaria* increases milk production from 4 to 4.6 litres/cow per day for low-yielding animals, representing a 15% increase, and 9 to 12.6 litres/cow per day for the relatively higher-yielding dairy cattle, representing a 40% increase in Kenya (Njarui et al., 2020).

Insect-based protein sources

Growing insects is becoming a more sustainable option to address the environmental challenges of current food and feed systems, such as deforestation, land degradation, and water pollution (Chia et al., 2019). Research on various insect meals indicates that they can replace at least 50% of soymeal protein in diets for pigs and other domestic animals, including poultry and fish (Makkar et al., 2014). Black soldier fly (*Hermetia illucens*) larvae meal (containing 40-65% crude protein and 30-35% lipid, Makkar et al., 2014), housefly maggots (*Musca domestica*), mealworm (*Tenebrio molitor*), and silkworm (*Bombyx mori*) pupae meal have been widely studied for use in animal feed (Aduna, 2019).

Inclusion of black soldier fly larvae meal in the diet of broiler chickens significantly increases average body weight, promoting early growth, improved productivity, and efficiency. In addition, modify the composition of cecal microbiota (increase in beneficial *Lactobacillus* species), which indicates potential health advantages related to gut integrity and function, and contributes to meat quality (Saidani et al., 2025). Use of maggot meal in the fish feed gave higher final weight and average daily gain than the fish diet and commercial diet (Gbai et al., 2018).

Termites are a valuable source of protein (46.3%), fats, and essential amino acids. Earthworms are a natural food source for poultry kept under free-range systems and, live or dried, are highly palatable to poultry. Super worm meal can replace up to 25% of fish meal protein in tilapia juveniles (*Oreochromis niloticus*) fish diet without any adverse effect on feed utilization and body composition (Tiroesele and Moreki, 2012).

Silkworms are high in protein, low in calcium, and have a low calcium-to-phosphorus ratio (Habeanu et al., 2023). They are particularly rich in essential amino acids. Silkworm meal can fully replace fishmeal in the diets of growing and finishing pigs without affecting carcass quality, meat quality, or blood parameters (Kumar, 2017).

Aquatic feed resources

Duckweed is a good feed supplement in diets for monogastric and ruminant animals such as chickens, pigs, cattle, sheep, and goats, as well as fish in aquaculture. Its advantage over other protein sources is that it is characterized by better availability and absorption of amino acids, including lysine and methionine, as well as of vitamins (Sońta et al., 2019). Fingerlings fed on 50% commercial feed + 50% dried duckweed presented a higher weight gain than the ones fed on dried duckweed alone (Tavares et al., 2008).

Azolla (*Azolla pinnata*) is another emerging aquatic feed source that offers numerous benefits for livestock health and productivity, making it a valuable feed supplement in the livestock industry. Azolla is a nutrient-rich feed supplement for livestock that can increase feed efficiency, promote animal growth, and increase milk and meat production (Agarwal et al., 2024). About 1.5-2 Kg Azolla, when fed to milch animals after mixing with concentrate in a

1:1 ratio along with adlib sorghum fodder, has increased milk production by 20.96% in cows. The increase in milk (litres) and fat content (%) was 1-1.5 and 4.3-4.7;1-1.4 in cows, respectively (Yanshi and Anshu Rahal, 2019).

Spirulina and Chlorella microalgae contain 60-70% protein along with essential fatty acids and pigments that are beneficial for monogastric animals, and aquaculture generally compares favorably with soya bean meal and rapeseed meal (Becker, 2013). Chicken dietary supplementation of Spirulina enhanced cost efficiency, health, product quality, decreased cholesterol content, and altered the egg yolk colour, keeping in view the consumer preferences (Suryanarayana, 2024). Additionally, certain types of seaweed have the potential to lower enteric methane emissions, as reported by Li et al. (2018). Seaweeds, especially red and green macroalgae such as Ulva, Gracilaria, and Palmaria, are rich in protein (10-35%), polysaccharides, iodine, and trace minerals. These qualities make them appealing as not only supplements but also as possible substitutes for soy, fishmeal, and synthetic additives in livestock and aqua feeds, as noted by Pereira et al. (2019).

Root, tuber, and starch-based emerging feed resources

Root and tuber crops such as cassava, sweet potato, and taro offer high-energy feed options (Sanginga and Mbabu, 2015). Cassava peels contain 2-5% crude protein but are energy-dense, making them a suitable replacement for maize, according to Onyimonyi and Okeke (2021). Cassava leaves have a higher protein content, ranging from 22-30%, but they require detoxification to reduce cyanide levels. They are also high in energy, and cassava chips can replace up to 50% of maize in poultry diets, as found by Eruvbetine et al. (2003).

Supplementation of sweet potato vines silage increases dry matter intake, milk yield, and the milk components such as milk fat and solids-non-fat in dairy cows (Galla et al., 2020). It contains a moderate to high protein content (160-230 g/kg) and a reasonable fibre level (260 g/kg), according to Gakige et al. (2020). Sweet potato vines have been incorporated into goat and pig diets, in fresh or silage form, respectively, with both studies showing increased feed intake and better growth performance, indicating the potential of sweet potato vines as a viable feed supplement for livestock (Megersa et al., 2013).

Agro-industrial and fruit processing by-products

Agro-industrial by-products come from processing tropical crops and include items such as coffee husk, cocoa pod husks, banana and pineapple waste, sugarcane bagasse, molasses, cottonseed cake, sesame cake, coconut meal, and palm kernel cake (Shah et al., 2025). These are secondary products generated from agricultural processing industries and are often abundant, inexpensive, and frequently discarded, despite their nutritional value. They are affordable and available throughout the year, help in reducing waste and environmental pollution, and provide valuable sources of energy and protein, as pointed out by Shah et al (2025).

Whole cottonseed has a relatively high level of crude protein (15-25%), fat (10-33%), and cellulose (25-30%), with an average energy content of 14.52 ME MJ/kg (Charray et al., 1992). It has been safely used in ruminant diets at up to 25% of dry matter (Arieli, 1992). Whole cottonseed has an apparent digestibility of 72.4% and produces minimal methane gas due to low rumen methane production, about 4.3% (Arieli, 1998). Salting whole cottonseed can improve intake, but mixing it with other by-products gives the best results in terms of intake and growth performance (Charray et al., 1992). Whole cottonseed has been found to contain free dietary gossypol in the range of 4-17 g/kg DM (McDonald et al., 2011), which causes respiratory distress, impaired body weight gain, heart failure, anorexia, weakness, apathy, and death after several days (Gadelha et al., 2014).

Tropical fruit industries generate large amounts of nutrient-rich waste. Mango kernel meal contains 10-12% fat and 8-10% protein with high energy levels. Broiler chickens fed up to 10% mango kernel meal performed similarly to those fed maize (Ravindran and Blair, 2019). Papaya peels have higher crude protein levels, exceeding 110-130 g/kg DM, which is enough to meet the protein needs of small ruminants for maintenance and moderate growth. When included at moderate levels (10-30%) in laying hen, papaya peels improve digestion of protein and energy due to their nutrient content, supporting balanced rumen fermentation (Azevedo et al., 2011).

Pineapple waste contains a lot of soluble sugars (40-75% DM; about 70% sucrose, 20% glucose, and 10% fructose) and pectin, which is comparable to cereal grains for livestock. The high amount of fiber makes pineapple waste widely used for ruminant animal feed compared to pigs and poultry (Idayanti et al., 2021). Citrus pulp is an excellent energy source for ruminants, improving milk fat (FAO, 2018). It also improves rumen fermentation and increases butterfat yield in cows (Bampidis and Robinson, 2006). The by-products of oranges and lemons, mainly peels and rinds, are produced in large quantities from the citrus juice industry. Banana peels have high moisture content, low protein levels, and a significant amount of soluble sugars. When preserved as silage along with dry fodder, they become a suitable feed option for cattle when used with other feeds (Makwana et al., 2025).

Coffee pulp contains associated bioactive compounds, such as polyphenols with good antioxidant properties, which endow additional health benefits and anthocyanins that have potential applications as natural food colorants. The polyphenols can prevent or decrease the peroxidation of fatty acids, reduce oxidative stress in animals at critical physiological stages, and increase the shelf life of animal meat when it is included in their diets. Ensiling coffee pulp has higher crude protein content and lower values of nitrogen-free extracts and tannin (Ameca et al. 2018).

Novel and underutilized vegetation

Novel feed resources in livestock feed can be cost-effective, that is, feed costs, production costs, and increased revenue. The resources are often abundant and can be harvested easily, reducing the need for expensive commercial feed concentrates and conventional feed ingredients (Chisoro et al., 2023).

Enset by-products are rich in fiber and energy and are suitable for cattle (Tsegaye and Struik, 2002), and bamboo, often referred to as the 'world's giant grass,' has emerged as a potential solution to conventional livestock feed, known for its rapid growth, drought tolerance, high biomass production, and adaptability to diverse soil types and climates. Bamboo leaves are rich in protein, fibre, and essential minerals, and can improve livestock health and productivity, reduce methane emissions from ruminants, contributing to more sustainable and climate-resilient livestock farming practices (Zali, 2024; Sasu et al., 2025).

NUTRITIONAL POTENTIAL OF EMERGING TROPICAL FEED RESOURCES

Potential emerging feed resources include leaves and seeds of Moringa, Taro, Mango, Cassava, Pigeon pea, agro-industrial by-products such as rice bran and filter sugar cake (Ben Salem et al., 2004; Muleta, 2024). Poor-quality cellulosic roughages from farm residues such as stubbles, haulms, vines, and from other agro-industrial by-products such as slaughter-house by-products and those from the processing of sugar, cereal grains, citrus fruits, and vegetables from the processing of food for human consumption also come under the category of emerging feeds (Onte et al., 2019).

Emerging tropical feed resources often include newly commercialized feeds such as insects, algae, and hybrid tropical forages, which have shown both nutritional and economic benefits (Makkar, 2018). Non-conventional feeds such as *atella* and mill waste, which have moderate protein content and lower fibre levels, can be used as possible protein sources to improve the nutritional value of poor tropical feed materials in animal feeding systems (Gebremariam and Belay, 2021). As illustrated in Table 1, the nutritional profiles of emerging feedstuffs vary significantly depending on their constituent ingredients.

Table 1. Main source of tropical emerging livestock feeds and their chemical composition

	Chemical composition								
Source of emerging feed	DM	Ash	CP	CF	NDF	ADF	EE	ME (MJ/kg DM)	References
Atella	13.23	6.00	15.90	Na	40.60	19.30	Na	11.81	Gebremariam and Belay (2021)
Coffee pulps	91.13	10.82	13.24	Na	55.19	52.14	1.72	1.33	Wogderess (2016); Ameca et al. (2018)
Rice brans	89.2	Na	6.06	14.09	Na	Na	2.6	4.45	Laswai et al. (2013); Alewi et al. (2022)
Mango peel	20.8	2.6	3.21	Na	11.8	9.51	1.39	18.0 GE (MJ/kg)	Marcos et al. (2020)
Avocado peel	23.6	1.9	9.88	Na	11.5	10.4	58.9	30.5 GE (MJ/kg)	Marcos et al. (2020)
Avocado seed kernel	89.73	3.33	16				11.74	17.52	Getahun et al. (2025)
Cassava leaves	89.4	13.47	21.5	Na	62.1	49.3	6.72	3.9	Oni et al. (2011)
Cassava root chips	92.3	2.9	2.3	0.3			0.8	16.12	Muleta (2024)
Taro leaves	93	12.89	21.27	6.44			4.00	0.23	Muleta (2024)
Soya bean husk	89.55	5.20	12.32	32.54	66.10	49.72	2.70	10.07	Chellapandian (2019); Shuaib et al. (2023)
Green cabbage waste	11.00	8.75	11.85	11.85	25.55	23.14	1.89	12.17	Mahgoub et al. (2018)
Dry tomato vines	94.99	13.87	15.75	32.22	59.77	36.42	1.85	Na	Galal et al. (2020)
Dried tomato pomace	91.01	3.28	21.11	29.33	65.24	40.93	9.21	20.15 GE (MJ/kg)	Omer and Abdel-Magid (2015)
Enset corm	89.53	4.8	3.35				0.57	15.11	Getahun et al. (2025)

Fish by-product meal	87.95	41.88	43.01	Na	53.81	40.17	1.45		Samadi et al. (2023)
Poultry waste	90.38	28.82	21.34	16.09	Na	Na	2.61	5.93	Laswai et al. (2013); Usman et al. (2019)
Banana leaves	91.84	9.78	10.63	29.35	49.8	36.8	8.43	4.5	Laswai et al. (2013); Selim et al. (2022)
Bamboo leaves	61.8	11.43	8.49	35.56	54.7	38.9	4.67	8.41	Laswai et al. (2013); Selim et al. (2022)
Seaweed	18.78	14.19	10.13	6.9	16.5	9.7	3.56	Na	Selim et al. (2022)
Sugarcane bagasse	89.9	4.87	3.81	37.89	75.6	58.8	0.5	Na	Selim et al. (2022)
Pineapple peel	15.08	4.93	8.01	Na	26.48	11.97	0.35	7.34	Kiatti et al. (2023)
Pineapple pomace	20.98	2.78	8.81	Na	21.53	9.75	0.3	7.36	Kiatti et al. (2023)
Sweet potato vine	90.68	12.01	12.43	20.71	44.84	39.46	1.68	8.34	Chen et al. (2024)
Mealworm	97.02	6.99	53.83	7.53	Na	Na	28.03	Na	Sajid et al. (2023)
Earthworm	94.23	10.07	38.99	0	18.26	5.93	7.5	Na	Samadi et al. (2023)
Moringa leaves	77.4	14.1	26.3	8.8	Na	Na	5.7	10.0	Laswai et al. (2013)
Banana pseudostem hay	93	12.4	3.5	Na	64.6	36.2	1.3	5.63	Laswai et al. (2013); Oliveira et al. (2014)
Banana kocho	93.59	20.34	10.04	Na	Na	Na	0.88	7.20	Getahun et al. (2025)
Mango seeds	89.04	2.85	8.93	21.93	Na	Na	3.5	Na	El-Sanafawy et al. (2023)
Mango seed kernel	58.13	2.61	5.95	2.32	Na	Na	11.54	13.97 (ME MJ/kg)	Elgindy (2017); Beriso and Tesfaye (2024)

ADF: Acid detergent fibre, CF: Crude fibre, CP: Crude protein, EE: Ether extract, GE: Gross energy, ME: Metabolizable energy, Na: Not available, NDF: Neutral detergent fibre.

CONSTRAINTS OF EMERGING TROPICAL FEED RESOURCES

Anti-nutritional factors

Some new feed materials are known to contain high levels of lignin, silica, toxins, and various anti-nutritional compounds, while offering low energy and protein content (Beriso, 2022). A major problem in using legume plants as feed for ruminant animals is the presence of tannins and other anti-nutritional substances such as saponins, cyanogens, mimosine, and coumarins, which reduce the absorption and use of nutrients (Andhale, 2024).

Processing and technological limitations

Non-conventional feed resources often require specific processing and preservation techniques to enhance their nutritional value and decrease any potential anti-nutritional factors. However, there is a lack of proper processing and preservation techniques for these resources, which limits their utilization (Muleta, 2024).

Mechanical treatments such as grinding fibrous crop residues, pelletizing, extrusion, and dehydration need costly and energy-consuming machines, which are rare or expensive in tropical regions (Sundstøl and Owen, 1985). Techniques such as grinding, pelletizing, steaming, or heating need fuel or electricity, but many rural areas lack reliable electricity to run feed mills in Ethiopia (Mengistu et al., 2017).

Seasonality, availability, and perishability

The availability of non-conventional feed resources can be limited, especially during dry seasons or in areas with low agricultural productivity. Additionally, the composition and quality of these resources may also vary seasonally, making it difficult to formulate consistent and balanced diets (Muleta, 2024). Tropical crop residues and fruit waste are typically available only during harvest seasons (Devendra and Leng, 2011). Research has shown that drying and ensiling non-traditional feeds such as fruit and vegetable waste are effective preservation techniques that help overcome seasonal supply problems (Wadhwa and Bakshi, 2013).

The high moisture content of wet brewery grain (80 to 85%) makes the by-product particularly susceptible to microbial growth and subsequent spoilage within 7 to 10 days (Chanie and Fievez, 2017). This issue limits their strategic use unless suitable preservation methods are available. Treatments such as drying, grinding, and storage can improve the use of these resources, but adequate research and development are needed to optimize processing methods (Andhale, 2024).

Lack of knowledge, limited research, and extension services

Producers often lack knowledge of the optimal timing for crop harvest, processing techniques (such as silage, drying, and ensiling), detoxification approaches, and feed formulation standards (Tolera et al., 2012). Many small-scale farmers may lack the knowledge, skills, and resources necessary to effectively incorporate these feed sources into their feeding practices (Sime and Duguma, 2025). Inadequate data on the nutritional value and digestibility of novel feedstuffs remains a primary barrier to their widespread use in animal production (Muleta, 2024). According to FAO (2012), many tropical feed resources remain poorly studied, thereby restricting their adoption and limiting the availability of accurate nutrient composition data. As noted by Devendra and Leng (2011), insufficient extension support for safe inclusion levels, processing procedures, and ration formulation is an additional barrier to the use of emerging feed sources.

PROCESSING AND INTEGRATION STRATEGIES OF EMERGING TROPICAL LIVESTOCK FEED INTO COMMERCIAL DIET

Many ETFRs require significant processing before they can be used. Various processing techniques, such as fermentation, boiling, sun-drying, ensiling, autoclaving, milling, soaking, sprouting, germination, gamma radiation, and genomic technology, effectively reduce certain anti-nutritional factors, such as cyanogenic glycosides, oxalate, and trypsin inhibitors (Olarinre et al., 2022; Lahutiya and Yadav, 2023). Insects need drying, grinding, and safe handling of the substrate (Chia et al., 2021). Cassava requires sun-drying, fermentation, or boiling to eliminate cyanide (Egboduku et al., 2024). Duckweed and Azolla should be dried or partially sun-cured to prevent spoilage (Chaji and Pormhammad, 2025).

Methods such as ferrous sulphate, chopping, de-huling, autoclaving, grinding, lactic acid fermentation (reduces tannins by 60% (Zhang et al., 2026), alkaline treatment up to 90% in agro-industrial by-products and tree leaves (Olarinre et al., 2022). At 60°C for 6 hours, it effectively reduced anti-nutrient content in tiger nut tannins by 61%, polyphenols by 48%, phytate by 44%, oxalate by 58%, and alkaloids by 13%, as well as improving the nutritional value (Kemboi et al., 2023).

Main methods to reduce hydrogen cyanide levels and improve cassava peels' consumption by ruminants involve soaking, boiling, sun-drying, ensiling, and sulphur addition (Padmaja and Steinkraus, 1995). Heat treatment and fermentation are effective in reducing protease inhibitor activity in plant-based feed (Olukomaiya et al., 2020).

Goitrogens, commonly found in avocado peels, can interfere with iodine metabolism, potentially leading to thyroid enlargement and reduced metabolic efficiency (Tripathi and Mishra, 2007). Iodine supplementation in poultry diets is recommended to counteract the effects of goitrogens (Surai et al., 2019). Lectins, also found in high levels in avocado peels, can bind to the intestinal lining, impairing nutrient absorption and causing digestive issues (Vasconcelos and Oliveira, 2004). Thermal processing and enzymatic treatments are effective ways to reduce lectin activity (Zhang et al., 2026).

When phytase supplements are added to broiler diets, they improve their overall growth and development, and enhance calcium and phosphorus uptake by bones (Rizwanuddin et al., 2023). The crude protein (CP) content of the treated rice straw increased as urea-molasses treatment increased from 0 to 4% (Akinfemi et al., 2020). For aflatoxin-contaminated oilseeds used in animal feed, ammonization is considered the preferred processing method (Kemboi et al., 2023).

CONCLUSION

Emerging tropical feed resources offer a promising approach to address the ongoing challenges of feed scarcity, high feed prices, and the growing competition between human and animal nutrition in tropical areas. These resources are valuable because they are nutritionally rich, widely available, and can thrive in difficult environmental conditions. They can be used as substitutes for or as supplementary materials to traditional feed ingredients such as maize, soybean meal, and alfalfa. ETFRs include various types such as multi-purpose forage trees and legumes, insect-based protein sources, aquatic plants, improved grasses, fruit and vegetable by-products, and feeds that have been fermented or enhanced through biotechnology. These feeds have shown great potential to boost commercial livestock production while reducing environmental impacts and feed costs.

Despite these benefits, several factors hinder the use of ETFRs in livestock systems. These include issues such as high water content, short shelf life, and the presence of antinutritional substances, including tannins, cyanogenic glycosides, oxalates, and mimosine. There is also an inconsistency in nutrient levels, a lack of standardized processing methods, poor storage facilities, limited knowledge among farmers, and insufficient support from extension services. The availability of these feeds can vary with the seasons, and the reliability of agro-industrial supply chains is uncertain, which complicates their year-round use. Advanced processing techniques such as ensiling, fermentation, extrusion, pelleting, and heat treatment are not widely used due to high costs, limited equipment, a lack of technical skills, and weak infrastructure. To make ETFRs valuable, there should be collaboration among researchers, government officials, extension workers, and feed producers. Improving farmer education, developing affordable processing methods, supporting research on detoxification and enhancing nutritional content, and establishing effective supply chains can greatly increase the use of these feeds. To properly use these new feed resources, it is advisable to conduct further research to evaluate their nutritional value and economic viability for livestock.

DECLARATIONS

Authors' contributions

Mule Demlie, Nestanet Beyero, and Awoke Kefyalew designed the review. Nestanet Beyero constructed the title and offered a constructive idea for revising the manuscript. Mulu Demlie conducted the conceptualization, literature search, writing, and original draft. Awoke Kefyalew contributed to the literature search, visualization (tables), drafting the review, and editing. All authors read and approved the final version of the manuscript to be published.

Availability of data and materials

The data that support the findings of this study are available in the present study.

Competing interests

The authors declared no conflicts of interest.

Ethical considerations

The authors declare that this manuscript is original and is not being considered elsewhere for publication. Ethical issues, including consent to publish, misconduct, fabrication of data, and redundancy, have been checked by all authors. The authors did not use any AI applications for writing and preparing this article.

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