

Neglected Tropical Dairy Feeds: Alternative Cost-effective Feed Resources for Sustainable Dairy Development

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Abstract

The tropics are home to diverse and underutilized feed resources that hold significant potential to enhance dairy productivity and sustainability. However, many of these alternative feeds remain neglected in conventional dairy farming systems. This study explores the untapped potential of neglected tropical dairy feeds, emphasizing their nutritional value, availability, and implications for sustainable dairy development. By focusing on unconventional feedstuffs, such as agro-industrial by-products, wild forages, aquatic plants, and leguminous species, this paper aims to highlight the diverse options available to supplement or replace conventional feed resources like grasses, silages, and commercial concentrates. The study also delves into the nutritional composition, including protein, fiber, and mineral content, of these neglected feeds, assessing their suitability for dairy cattle under tropical conditions. Additionally, the research discusses the environmental and economic benefits of incorporating these alternative resources, such as reducing feed costs and minimizing dependence on imported feeds, while promoting a more sustainable agricultural system. The findings suggest that integrating neglected tropical dairy feeds into conventional feeding strategies can contribute to improving livestock health, performance, and overall productivity. This study provides valuable insights into sustainable dairy farming practices, offering a roadmap for harnessing the full potential of available feed resources in the tropics for improved dairy development.

Keywords: Agro-industrial by-products, alternative feeds, environmental sustainability, feed resources, nutrition, sustainable dairy development, tropical forages

INTRODUCTION

The tropical regions of the world, characterized by diverse climatic conditions and rich biodiversity, offer a variety of underutilized feed resources that have the potential to revolutionize dairy farming systems. Conventional dairy feed strategies, predominantly relying on imported concentrates and locally grown forages, are often inadequate and unsustainable in the face of rising production costs, environmental degradation, and climate change [1]. Consequently, there is a growing need to explore alternative feed sources that can reduce dependency on traditional feeds, ensuring the sustainability of dairy farming in these regions. Neglected tropical dairy feeds, including agro-industrial by-products, wild forages, and various legumes, are often overlooked despite their considerable nutritional value.

These alternative feed resources possess a wide range of beneficial properties, such as high protein content, fiber, and essential micronutrients, that can support dairy cattle health and productivity [2]. Tropical environments are particularly suited to

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growing such feeds, making them both cost-effective and accessible. However, many of these resources are not utilized to their full potential due to limited awareness, lack of research, and poor infrastructure for their processing and incorporation into feeding systems [3]. Understanding the nutritional composition, bioavailability, and digestibility of these feeds is essential for optimizing their use in sustainable dairy production systems, especially in developing regions with limited access to conventional feed inputs.

The novelty of this study lies in its comprehensive exploration of neglected tropical dairy feeds as viable alternatives to traditional feed resources. By systematically reviewing a range of underutilized feedstuffs, this research provides an in-depth analysis of their nutritional profiles, economic advantages, and environmental benefits. Unlike previous studies that focus on mainstream feed resources, this work uncovers the untapped potential of these alternative feeds, offering a novel perspective on their integration into sustainable dairy development. The findings aim to guide future research and policy development, paving the way for the widespread adoption of these resources, ultimately contributing to more resilient and cost-effective dairy farming in the tropics.

FORAGES AND BROWSE SPECIES

Acacia Leaves

Acacia species are highly adaptable and drought-tolerant, making them ideal for tropical environments. Acacia leaves are rich in protein and can be used as a supplementary feed for dairy cattle, especially during periods of feed scarcity [4]. These leaves also contain tannins, which can improve the animal's resistance to certain pathogens, though their high tannin content requires careful management to avoid any potential negative impacts on animal performance.

Albizia Leaves

Albizia species, including *Albizia lebbbeck*, are widely found in tropical regions and offer excellent nutritional benefits for dairy cattle. The leaves are rich in proteins, vitamins, and minerals, promoting improved milk production and overall animal health [5]. Their ability to regenerate quickly makes them a sustainable feed source, especially during dry seasons when other forage options may be scarce.

Bamboo Leaves

Bamboo leaves are an underutilized feed resource in many tropical areas. They are rich in fiber and contain essential minerals, like calcium and phosphorus, contributing to the health and growth of dairy cattle [6]. Bamboo leaves also have a high digestibility rate and can be an effective supplementary feed to other forage varieties, helping balance the cattle's nutrient intake and supporting milk yield during times of feed shortage.

Bauhinia Leaves

Bauhinia species, particularly *Bauhinia purpurea*, offer an excellent feed option for dairy cattle due to their high protein content and the presence of bioactive compounds. These leaves promote improved digestion and can help boost milk production. Bauhinia trees are hardy and can grow in a variety of soil types, making them an ideal feed source in tropical farming systems with varying climatic conditions.

Calliandra Leaves

Calliandra species, such as *Calliandra calothyrsus*, are high-protein, leguminous trees commonly used for animal feeding in tropical regions. The leaves have been found to improve the growth rate and milk yield of dairy cattle [7]. Additionally, Calliandra leaves contain tannins, which offer benefits in terms of reducing parasite loads and enhancing the animal's immune system. The species is fast-growing and well-suited for agroforestry systems.

Cassia tora

Cassia tora, also known as the wild senna, is a tropical leguminous plant often considered a weed but has significant potential as animal feed. The plant is rich in protein and fiber, which can help

improve dairy cattle productivity. It is highly drought-tolerant and can be utilized in areas where traditional fodder crops fail to thrive. Its leaves and seeds are both nutritious, though the seeds must be processed properly to avoid toxicity issues.

Crotalaria Species

Crotalaria species, particularly *Crotalaria juncea*, are valuable for their high protein content and potential to improve soil fertility in tropical farming systems. These plants can be used as forage for dairy cattle, providing essential nutrients like nitrogen, phosphorus, and potassium. While they offer significant nutritional benefits, they also contain pyrrolizidine alkaloids, which can be toxic if not carefully managed, requiring proper processing and feeding guidelines.

Desmanthus virgatus

Desmanthus virgatus, a leguminous plant native to the tropical regions of America, is highly valued for its high protein content and its ability to withstand dry conditions. It is an excellent feed resource for dairy cattle, offering both high-quality protein and fiber, which are essential for optimal digestion [8] and milk production. Its resilience in arid environments makes it a sustainable feed choice during dry seasons or droughts.

Ficus Leaves

Ficus species, including *Ficus carica* and *Ficus sycomorus*, are widely distributed in the tropics and provide a reliable source of feed for dairy cattle [9]. The leaves are rich in minerals, especially calcium and magnesium, which are essential for bone health and overall metabolic function in dairy cattle. *Ficus* leaves also promote better rumen health and can improve milk yield when incorporated into a balanced feeding system.

Flemingia macrophylla

Flemingia macrophylla is a high-protein legume used for fodder in tropical dairy farming systems. This shrub is highly valued for its nitrogen-fixing abilities, which enhance soil fertility [10]. The leaves are rich in proteins and fiber, which support dairy cattle's growth and milk production. Its resistance to drought and pests makes it a reliable feed resource, particularly in areas with unpredictable weather patterns.

Gliricidia sepium

Gliricidia sepium, commonly known as the "mother of cocoa," is widely used in tropical agroforestry systems. The leaves are high in protein and can be fed to dairy cattle to improve milk production and health [11]. *Gliricidia* also provides excellent ground cover, preventing soil erosion, and acts as a nitrogen-fixing plant, enriching the soil in areas where traditional crops are less viable. Its rapid growth and resilience to pests make it a valuable feed option.

***Gmelina arborea* Leaves**

Gmelina arborea, a fast-growing tree species native to tropical Asia, provides an excellent source of forage for dairy cattle. The leaves contain adequate amounts of protein and fiber, which contribute to increased milk yield. *Gmelina* trees can be grown in a variety of soil types, making them versatile for use in tropical farming systems. Additionally, they provide shade and windbreaks, benefiting overall livestock welfare.

Grewia Species

Grewia species, including *Grewia africana*, are shrubs and small trees that grow well in tropical and subtropical climates. Their leaves are rich in fiber and protein, offering a cost-effective, sustainable feed option for dairy cattle. *Grewia* also helps with soil conservation, making it ideal for agroforestry systems. While their growth is slow, these plants are resilient to harsh conditions, providing a reliable source of nutrition during dry spells.

Hibiscus rosa-sinensis

Hibiscus rosa-sinensis, commonly known as the Chinese hibiscus, offers high-quality forage for dairy cattle, with its leaves being rich in nutrients such as calcium, magnesium, and vitamins [12]. This plant grows quickly and can be harvested multiple times during the year, making it an excellent supplementary feed resource. Its high fiber content helps in promoting digestive health and improving the overall well-being of dairy cattle.

Indigofera tinctoria

Indigofera tinctoria, also known as true indigo, is a leguminous shrub with high protein content, making it an excellent feed for dairy cattle. It is highly drought-tolerant and thrives in tropical regions with low rainfall [13]. Indigofera not only provides valuable nutrients but also improves soil quality by fixing nitrogen, reducing the need for chemical fertilizers. This makes it an environmentally sustainable option for improving dairy productivity.

Leucaena leucocephala

Leucaena leucocephala is one of the most widely used leguminous forage plants in the tropics. It is high in protein and essential amino acids, contributing significantly to improved dairy cattle growth and milk production [14]. Leucaena also fixes nitrogen in the soil, enhancing soil fertility. However, care must be taken to manage its intake due to its presence of mimosine, a compound that can be toxic in large amounts if not processed correctly.

Moringa oleifera

Moringa oleifera, known as the “drumstick tree,” is highly nutritious and offers a wealth of vitamins, minerals, and proteins, making it an excellent feed for dairy cattle. The leaves, in particular, are rich in calcium, iron, and vitamins A and C, contributing to improved milk quality and cattle health [15]. Moringa is fast-growing and drought-resistant, making it an ideal forage resource for areas with limited rainfall.

Mulberry Leaves

Mulberry leaves are highly nutritious, rich in proteins, minerals, and antioxidants, and provide an excellent feed resource for dairy cattle. They are particularly beneficial for improving milk quality and promoting animal growth [16]. Mulberry trees are fast-growing, and the leaves can be harvested multiple times throughout the year. The leaves’ high digestibility ensures that dairy cattle receive maximum nutritional benefits when incorporated into their diet.

Sesbania grandiflora

Sesbania grandiflora, commonly known as the “vegetable hummingbird,” is a leguminous tree that is a high-protein forage resource for dairy cattle. The leaves are rich in essential nutrients and have been found to improve milk production. This plant thrives in tropical environments and has the added benefit of nitrogen fixation, improving soil fertility. Its rapid growth and ability to regenerate make it a sustainable feed option for tropical dairy systems.

Trema orientalis

Trema orientalis, also known as the poison tree, is another valuable feed resource in tropical dairy systems. Its leaves are high in protein and fiber, supporting dairy cattle health and productivity. While the tree is fast-growing and drought-resistant, care must be taken to manage its use, as it can be toxic in large quantities. However, when properly processed, it provides a valuable supplementary feed option during times of scarcity.

CROP RESIDUES AND AGRO-WASTE**Avocado Seed Meal**

Avocado seed meal, a by-product of avocado processing, is rich in carbohydrates and fiber, making it a valuable feed resource for dairy cattle. Although it contains some levels of antioxidants and

beneficial phytochemicals, it also has a high fat content, requiring careful management. When processed and used in moderation, avocado seed meal can contribute to increased milk yield and promote healthy digestion in dairy cattle. Its use also helps reduce waste from avocado processing industries.

Banana Peels

Banana peels are commonly discarded in tropical regions but are an excellent source of fiber, potassium, and other micronutrients for dairy cattle. They can help promote rumen health by providing digestible fiber, which is essential for optimal digestion and milk production [17]. When dried and processed, banana peels can be used as an effective supplementary feed, particularly during periods of forage scarcity. They also offer a sustainable method of reducing agricultural waste.

Cocoa Pod Husks

Cocoa pod husks are a significant by-product of cocoa processing. Although they are often discarded, cocoa pod husks can be a valuable feed resource for dairy cattle, providing fiber and carbohydrates. The high tannin content in cocoa husks can be beneficial for controlling parasitic infections, but care must be taken to ensure proper processing to avoid toxicity. They are often used in combination with other feed ingredients to balance their nutritional value.

Coconut Husk Fiber

Coconut husk fiber, or coir, is derived from the outer shell of coconuts and is often considered a waste product. While its primary use is in industries, like horticulture, coconut husk fiber can also be used as roughage for dairy cattle. It is high in fiber, which aids in promoting rumen function and digestion. When processed and supplemented with other feed sources, it can enhance the fiber intake of dairy cattle, particularly in low-fiber regions.

Coffee Pulp

Coffee pulp, a by-product of coffee bean processing, is rich in carbohydrates and fiber. While its primary use has been in composting or as organic waste, it can also be utilized as a feed resource for dairy cattle [18]. The pulp provides valuable nutrients and can be included in feed mixtures to improve digestibility and milk yield. Proper drying and fermentation of coffee pulp are important for eliminating any potential anti-nutritional factors before feeding.

Cottonseed Hulls

Cottonseed hulls, a by-product of cotton production, are widely available and used as a low-cost feed ingredient. These hulls are high in fiber and provide a good source of roughage to dairy cattle [19]. While they are not highly nutritious in terms of protein content, they help in stimulating rumen function and can serve as a filler in dairy rations. When used in combination with higher-protein feed sources, cottonseed hulls can improve the efficiency of feed utilization.

Groundnut Haulms

Groundnut haulms, the stems and leaves of groundnut plants, are rich in fiber, protein, and essential minerals, making them an ideal feed resource for dairy cattle. These haulms are a valuable supplement during the dry season when other fresh forages may be scarce. Groundnut haulms are typically fed fresh or dried, and they provide sufficient roughage to maintain healthy rumen function. Their high protein content also supports milk production.

Jackfruit Peels

Jackfruit peels, which are commonly discarded during the processing of jackfruit, are a rich source of fiber and carbohydrates. When processed and dried, these peels can be used to supplement the feed of dairy cattle [20]. The high fiber content in jackfruit peels promotes rumen health and supports digestion. These peels also contain small amounts of essential vitamins and minerals that help in enhancing overall animal health and milk yield.

Maize Cobs

Maize cobs are often treated as waste after harvesting maize grains but can provide valuable nutrition for dairy cattle. The cobs are high in fiber, which aids in maintaining rumen function and promoting digestive health. When ground or processed, maize cobs can be included in dairy rations to help meet the fiber requirements of cattle [21]. They are particularly useful as a supplementary feed when forages are not readily available or when cost-effective alternatives are required.

Mango Kernel Meal

Mango kernel meal, produced from the seeds of mangoes after fruit processing, is rich in carbohydrates and provides an excellent energy source for dairy cattle [22]. Although it is low in protein, it can be used as a supplement to improve the energy density of dairy rations. Mango kernel meal also contains beneficial fats, which support the overall health and growth of dairy cattle. This agro-waste product can be processed to reduce antinutritional factors and incorporated into feeding systems for better utilization.

Millet Husks

Millet husks, a by-product of millet grain processing, are high in fiber but relatively low in protein. They serve as an excellent roughage source in dairy cattle feed. The high fiber content of millet husks supports healthy digestion and rumen function. While millet husks do not provide significant amounts of protein, their role in providing essential fiber is crucial, particularly in regions where forage availability may be limited. They are often used in combination with higher-protein feeds.

Oil Palm Fronds

Oil palm fronds, a by-product of oil palm cultivation, are abundant in tropical regions where oil palm plantations are common. These fronds are high in fiber and can be used as roughage in dairy cattle diets. They provide essential nutrients, particularly when other forage options are scarce. The use of oil palm fronds also helps reduce waste from oil palm production, making them an environmentally sustainable choice. Their inclusion in animal feed requires proper processing to improve digestibility.

Orange Peels

Orange peels, often discarded as waste during fruit processing, are a valuable source of fiber and antioxidants. These peels contain essential nutrients, such as vitamin C, calcium, and potassium, which are beneficial for dairy cattle health [23]. When properly dried and processed, orange peels can be incorporated into dairy rations to improve fiber intake and support overall animal well-being. They also help in the reduction of waste from citrus fruit processing industries.

Pineapple Peels

Pineapple peels, a by-product of pineapple fruit processing, are high in fiber and rich in beneficial enzymes like bromelain. These peels can be utilized as an alternative feed source for dairy cattle, promoting better digestion and rumen health. Pineapple peels also contain various vitamins and minerals, contributing to the overall nutrition of dairy cattle [24]. Proper drying and fermentation can improve the digestibility of pineapple peels and reduce any potential anti-nutritional factors.

Plantain Peels

Plantain peels, which are often discarded after the fruit is processed, are a rich source of fiber and carbohydrates. They can be used as a supplementary feed resource for dairy cattle, particularly in areas where plantain is a common crop. The peels offer several beneficial nutrients, including potassium and magnesium, which are important for maintaining dairy cattle health. When processed, they can be included in feed rations to boost fiber intake and enhance rumen function.

Rice Husks

Rice husks, a by-product of rice milling, are widely available and can be used as a roughage feed for dairy cattle. These husks are high in fiber, which is essential for maintaining healthy digestion and

promoting rumen function. While rice husks are low in protein, they are a cost-effective source of fiber, especially in regions where rice is a major crop. Their use also helps reduce agricultural waste from rice production.

Rubber Seed Meal

Rubber seed meal is a by-product of rubber production, obtained after extracting oil from rubber seeds. This meal is rich in protein, making it a valuable supplement for dairy cattle, especially in tropical regions [25]. However, it contains some anti-nutritional factors, such as tannins, which must be processed to improve its digestibility and nutritional value. When properly treated, rubber seed meal can be included in dairy rations to support growth and milk production.

Sorghum Stover

Sorghum stover, the stalks and leaves left after harvesting sorghum grain, is commonly used as roughage in livestock feeding systems. It is high in fiber and provides essential bulk for proper rumen function. Although sorghum stover is not particularly rich in protein, it can be used effectively as a filler in feed rations when combined with higher-protein feed sources. It is also drought-tolerant and widely available in tropical regions.

Sugarcane Bagasse

Sugarcane bagasse is a fibrous by-product of sugarcane processing. It is rich in cellulose and hemicellulose, making it an excellent source of roughage for dairy cattle [26]. Sugarcane bagasse can be used as a cost-effective feed resource to improve fiber intake and rumen health. Proper processing, such as fermentation or grinding, is necessary to enhance its digestibility. It also serves as an environmentally sustainable option, reducing waste from the sugarcane industry.

Yam Peels

Yam peels, a by-product of yam processing, are rich in fiber and carbohydrates, making them an excellent feed resource for dairy cattle. These peels can help improve rumen function and provide essential nutrients to support dairy cattle health and milk production. While low in protein, yam peels are a useful supplement in regions where yam is a staple crop. They are typically dried and processed to reduce antinutritional factors and increase digestibility.

LEGUME AND OILSEED BY-PRODUCTS

Balanites Seed Meal

Balanites seed meal, derived from the seeds of the *Balanites aegyptiaca* tree, is a high-protein by-product. It contains essential amino acids, making it an excellent supplement for dairy cattle diets. Although it has a high protein content, the presence of certain anti-nutritional factors, such as saponins and tannins, requires proper detoxification before it can be used as animal feed. After processing, Balanites seed meal can help in enhancing milk production and supporting overall health in dairy cattle.

Baobab Seed Cake

Baobab seed cake, a by-product from baobab fruit processing, is rich in protein, fiber, and minerals such as calcium, iron, and potassium. The seeds contain beneficial bioactive compounds, which may enhance immune function and health in dairy cattle [27]. Baobab seed cake can be used as a protein supplement, particularly in tropical regions where the baobab tree is abundant. However, it is important to process the cake adequately to eliminate anti-nutritional factors and improve digestibility.

Castor Bean Meal

Castor bean meal, a by-product of oil extraction from castor seeds, is high in protein and can be a valuable feed ingredient for dairy cattle. However, raw castor bean meal contains ricin, a toxic protein that poses a risk to livestock. Through detoxification processes, such as heat treatment, castor bean meal can be rendered safe for animal consumption. After proper detoxification, castor bean meal is a rich source of protein and essential amino acids that can support growth and milk production.

Cottonseed Meal

Cottonseed meal, a by-product of cottonseed oil extraction, is one of the most commonly used protein supplements in animal feed [28]. It is rich in protein and contains essential amino acids necessary for optimal dairy cattle growth and milk production. Cottonseed meal also contains fiber, which supports rumen health and digestion. However, the presence of gossypol, a toxic compound in cottonseed meal, can be harmful to dairy cattle if fed in excess. Detoxifying cottonseed meal or limiting its inclusion rate is essential for safe feeding.

Jatropha Meal

Jatropha meal, derived from the seeds of the *Jatropha curcas* plant, is a high-protein by-product. Jatropha seeds contain toxic compounds, such as phorbol esters and lectins, which can be harmful to livestock if consumed raw. However, through proper detoxification methods, such as fermentation or heat treatment, Jatropha meal can be made safe for use as a protein supplement in dairy cattle diets [29]. Detoxified Jatropha meal provides essential nutrients that can support milk yield and improve the overall health of dairy cattle.

Mustard Oil Cake

Mustard oil cake is a by-product of mustard seed oil extraction. It is an excellent source of protein and essential fatty acids, which are beneficial for dairy cattle. The cake contains high levels of glucosinolates, compounds that can impact digestion and milk flavor. However, when included in moderate amounts and processed properly, mustard oil cake can be a valuable feed ingredient, especially in regions where mustard is commonly grown. Its inclusion in dairy rations enhances the nutritional quality and helps in promoting milk production [30].

Neem Seed Cake

Neem seed cake is a by-product of neem seed oil extraction, known for its high protein and fiber content. It also contains bioactive compounds, such as azadirachtin, which can have anthelmintic and antimicrobial effects. Although neem seed cake has beneficial properties, the presence of certain anti-nutritional factors requires proper processing before use in dairy cattle feed [31]. When adequately processed, neem seed cake can help improve digestion, enhance milk yield, and support animal health, making it a valuable supplement in tropical dairy farming systems.

Palm Kernel Cake

Palm kernel cake is a by-product of palm oil extraction, derived from the kernels of palm fruit. It is rich in protein and essential fats, which are valuable for supporting dairy cattle growth and milk production [32]. Palm kernel cake is particularly useful as a protein supplement in regions where oil palm is cultivated. However, it contains high levels of fiber, which may reduce its digestibility. Palm kernel cake can be incorporated into dairy rations in combination with other feed ingredients to ensure a balanced nutritional profile.

Sesame Seed Cake

Sesame seed cake, a by-product of sesame oil extraction, is rich in protein, essential fatty acids, and minerals such as calcium and phosphorus. It serves as an excellent supplement for dairy cattle, especially in regions where sesame is grown. Sesame seed cake can help improve milk yield and overall cattle health. However, the presence of anti-nutritional factors, such as sesamin, requires careful processing to optimize its nutritional value. After proper treatment, sesame seed cake can be safely included in dairy rations for enhanced performance.

Sunflower Seed Cake

Sunflower seed cake, produced after oil extraction from sunflower seeds, is a high-protein by-product that can be used as a supplement in dairy cattle feeding systems. It contains essential amino acids and fatty acids that contribute to overall cattle health and milk production [33]. Sunflower seed cake is

particularly beneficial in improving the energy density of rations, especially when combined with other feed ingredients. Proper processing ensures that sunflower seed cake can be safely included in dairy diets, providing a sustainable and cost-effective protein source.

AQUATIC AND ALGAL RESOURCES

Azolla

Azolla is a small, floating aquatic fern known for its high protein content and rapid growth rate. It thrives in flooded conditions and has the potential to be cultivated in paddy fields or other aquatic environments. Azolla is rich in essential amino acids, vitamins, and minerals, making it a valuable supplement for dairy cattle [34]. It also contains nitrogen-fixing bacteria, which enrich the surrounding water and soil. Azolla is highly digestible and can be incorporated into dairy cattle rations, especially in tropical regions where its growth is most efficient.

Duckweed

Duckweed is a fast-growing aquatic plant that floats on the surface of ponds, lakes, and other bodies of water. It is a rich source of protein, essential fatty acids, and minerals such as calcium and iron. Due to its high digestibility and rapid growth, duckweed is an excellent candidate for inclusion in dairy cattle feed [35]. Furthermore, duckweed can be sustainably harvested, making it an environmentally friendly resource. Its nutritional profile supports improved milk production and overall cattle health when used as part of a balanced diet.

Enteromorpha

Enteromorpha, a type of green algae, is found in coastal areas and freshwater bodies. This algae species is rich in proteins, lipids, vitamins, and minerals, making it a potential nutrient source for livestock. Enteromorpha has a high digestibility rate, which makes it a valuable addition to dairy cattle rations. Algal components, such as antioxidants and essential fatty acids, can promote better health and immune function in dairy cows. Incorporating Enteromorpha into dairy diets can support both growth and milk yield, especially in regions where other high-quality forage resources are limited.

Hydrilla verticillata

Hydrilla verticillata is a submerged aquatic plant that grows in freshwater environments. It is known for its high biomass production and nutrient density, containing a significant amount of protein, fiber, and minerals. *Hydrilla verticillata* is also rich in chlorophyll, which makes it a good source of micronutrients such as vitamin A. When processed appropriately, it can be included in dairy cattle diets to supplement protein and provide beneficial micronutrients. Its ability to grow rapidly in nutrient-rich waters makes it a sustainable resource for livestock feeding in tropical and subtropical regions.

Ipomoea aquatica

Ipomoea aquatica, commonly known as water spinach or kangkong, is a leafy aquatic plant widely cultivated in tropical regions. It is rich in protein, fiber, vitamins, and minerals, offering a nutritious supplement to dairy cattle diets [36]. Water spinach grows in flooded conditions, making it an efficient crop that can be harvested multiple times throughout the year. Its high moisture content and digestibility make it an excellent resource for improving milk production, especially when combined with other protein-rich feed ingredients in dairy rations.

Lemna Minor

Lemna minor, commonly known as small duckweed, is a tiny aquatic plant that grows on the surface of slow-moving waters. It is high in protein, amino acids, and micronutrients, making it a suitable supplement for dairy cattle feed [37]. Lemna minor has a fast growth cycle, allowing for rapid biomass production that can be harvested multiple times per year. Its small size and high digestibility make it an efficient feed resource. The inclusion of Lemna minor in dairy cattle diets can contribute to enhanced milk production, improved feed conversion, and overall health.

Nannochloropsis

Nannochloropsis is a type of microalgae that is rich in essential fatty acids, particularly omega-3 fatty acids, as well as proteins, vitamins, and minerals. This microalga is cultivated in both freshwater and marine environments and has significant potential as a supplement in dairy cattle nutrition [38]. Nannochloropsis has been shown to improve overall health, immune function, and milk quality in dairy cows. It is particularly useful in dairy systems where marine algae are available, and its incorporation into rations can provide a sustainable and high-quality nutrient source for livestock.

Sargassum spp.

Sargassum is a type of brown seaweed found in coastal areas, known for its high nutritional value. It contains proteins, minerals, and bioactive compounds, such as polysaccharides, which have been shown to promote gut health and improve digestion in livestock. The inclusion of Sargassum spp. in dairy cattle diets can help enhance feed efficiency, milk yield, and overall cattle health. The sustainable harvesting of Sargassum also offers environmental benefits, as it can reduce the accumulation of seaweed in coastal areas while providing a valuable feed resource for dairy production.

Spirulina

Spirulina is a blue-green microalga known for its exceptional nutritional profile, including high-quality proteins, vitamins, minerals, and essential fatty acids. It has been widely studied for its positive effects on animal health, growth, and immune function. Spirulina is easily digestible and can be used as a supplement in dairy cattle diets to improve milk production, support digestion, and enhance overall well-being [39]. It is also a sustainable and environmentally friendly resource that can be cultivated in controlled environments, making it an ideal choice for integrating into dairy farming systems.

Water Hyacinth

Water hyacinth is a floating aquatic plant that grows rapidly in freshwater bodies and is often considered an invasive species. However, it has significant potential as a feed resource for livestock. Water hyacinth is rich in fiber, protein, and minerals such as calcium and phosphorus. It can be processed to remove toxic compounds and used as a supplement in dairy cattle rations. The inclusion of water hyacinth in dairy diets can contribute to improved digestion, milk yield, and cattle health, especially in regions where it is abundant and readily available [40].

UNCONVENTIONAL PROTEIN SOURCES**Black Soldier Fly Larvae Meal**

Black soldier fly larvae meal is derived from the larvae of the black soldier fly (*Hermetia illucens*). It is a high-protein feed ingredient, containing essential amino acids, lipids, and micronutrients, which makes it an ideal supplement for dairy cattle. This larvae meal is a sustainable resource, as the larvae feed on organic waste materials, thus providing a dual benefit of waste recycling and high-quality protein production. Incorporating black soldier fly larvae meal into dairy cattle diets can improve milk yield, growth, and overall health while reducing environmental impact.

Earthworm Meal

Earthworm meal is a high-protein by-product derived from the processing of earthworms, known for their rich content of essential amino acids, fats, and minerals. Earthworm meal has high digestibility, making it an excellent supplement in animal feed, including dairy cattle diets [41]. It contains bioactive compounds that may promote digestive health and immune function in dairy cattle. The use of earthworm meal as a protein source is sustainable, as it can be produced by cultivating earthworms on organic waste. Its incorporation into dairy rations helps improve cattle health, milk yield, and feed conversion efficiency.

Locust Meal

Locust meal, produced from locusts, is a highly nutritious protein source rich in amino acids, fats, and essential minerals. Locusts are an excellent source of high-quality protein, making them a valuable

ingredient in dairy cattle feed. This unconventional protein source can be particularly useful in regions where locusts are abundant or where traditional protein sources are limited. Locust meal is also an environmentally sustainable option, as locusts can be cultivated using minimal resources. Its inclusion in dairy rations contributes to improved growth, milk production, and overall cattle health.

Maggot Meal

Maggot meal is derived from the larvae of various fly species such as the housefly. It is a rich source of protein, essential amino acids, and lipids. Maggot meal has a high digestibility rate, making it an effective supplement for dairy cattle diets [42]. The larvae are produced by feeding organic waste, making maggot meal a sustainable and eco-friendly protein source. Incorporating maggot meal into dairy rations has the potential to improve milk yield, enhance growth, and support overall cattle health. Its high nutritional content makes it an alternative to conventional protein sources.

Silkworm Pupae Meal

Silkworm pupae meal is a by-product of the sericulture industry, produced from the larvae of the silkworm (*Bombyx mori*). It is a protein-rich ingredient, containing essential amino acids, lipids, and micronutrients beneficial to livestock. Silkworm pupae meal has a high digestibility rate and is highly palatable to dairy cattle [43]. Its inclusion in dairy diets can support improved milk production and overall cattle health. Additionally, silkworm pupae meal is a sustainable feed option, utilizing the waste material from silk production. The nutritional profile of silkworm pupae meal makes it a valuable protein supplement for dairy farming systems.

Snail Meal

Snail meal, made from dried and ground snails, is a rich source of protein, amino acids, and minerals such as calcium and phosphorus. Snails are low in fat and have high-quality protein, which makes snail meal an excellent supplement for dairy cattle, especially in regions where snails are abundant. Snail meal can improve the growth rate, milk production, and health of dairy cattle. Moreover, it is a sustainable protein source, as snails can be easily cultivated and raised on organic materials. Incorporating snail meal into dairy rations provides a natural and cost-effective way to enhance the nutritional value of dairy products.

Termite Meal

Termite meal is a high-protein feed ingredient derived from termites, which are rich in essential amino acids, fats, and minerals. Termites are also an excellent source of enzymes that can support digestion in livestock. When processed into a meal, termites can be used to supplement protein in dairy cattle diets. Termite meal is a sustainable option, as termites are highly efficient at converting organic matter into protein. Incorporating termite meal into dairy rations can contribute to improved milk production, overall cattle health, and feed efficiency, making it an innovative and sustainable protein source for dairy farming.

Toad Meal

Toad meal is an unconventional protein source made from processed toads. Toads are rich in protein and contain a variety of essential amino acids and minerals. While toad meal is not commonly used in livestock feeding, its nutritional composition makes it a viable protein supplement for dairy cattle in regions where toads are abundant. The meal is highly digestible, and its inclusion in dairy rations can enhance growth and milk yield. Although there may be concerns regarding the collection and processing of toads, it remains a potential alternative protein source when handled appropriately.

Yeast Biomass

Yeast biomass, particularly from yeast species, like *Saccharomyces cerevisiae*, is a protein-rich by-product from fermentation processes. It contains high levels of protein, B vitamins, and essential minerals, making it a valuable feed ingredient for dairy cattle. Yeast biomass is highly digestible and supports rumen health, improving feed conversion efficiency and milk production [44]. Additionally,

yeast biomass is a sustainable feed resource, as it can be produced as a by-product of the brewing and biofuel industries. Its incorporation into dairy diets can enhance performance and provide essential nutrients to support overall health.

Zooplankton Biomass

Zooplankton biomass, derived from microscopic aquatic animals, such as crustaceans and rotifers, is a nutrient-dense protein source. It contains high levels of protein, essential fatty acids, and amino acids, making it a valuable supplement for dairy cattle. Zooplankton is typically harvested from freshwater or marine environments, offering a sustainable source of protein. Its inclusion in dairy rations can improve growth, milk yield, and overall health by enhancing the nutritional profile of the feed. Additionally, zooplankton biomass can contribute to a more sustainable feeding system, reducing reliance on traditional protein sources.

FERMENTED AND PROCESSED FEEDS

Brewer's Spent Grains

Brewer's spent grains (BSG) are the residual by-product from the brewing industry. Rich in fiber, protein, and essential micronutrients, BSG has significant potential as a feed ingredient for dairy cattle. Fermenting or processing BSG increases its digestibility, making it a valuable resource for cattle nutrition. Incorporating brewer's spent grains into dairy rations can improve milk production, provide a source of fiber for rumen health, and contribute to the reduction of organic waste. As an affordable and sustainable resource, BSG offers a unique opportunity to optimize dairy farm feed strategies.

Cassava Peel Silage

Cassava peel silage is produced by fermenting the peels of cassava tubers. Cassava peels are rich in fiber, carbohydrates, and residual nutrients, but their high levels of cyanogenic compounds can pose a challenge for direct feeding. The fermentation process reduces these compounds and improves the nutritional value of cassava peel silage, making it a safe and valuable feed resource for dairy cattle [45]. When included in dairy diets, cassava peel silage can contribute to better rumen function, increased feed intake, and enhanced milk yield while reducing waste associated with cassava processing.

Cocoa Pod Husk Silage

Cocoa pod husk silage is produced by fermenting cocoa pod husks, a by-product of cocoa bean processing. These husks are typically discarded, but their high fiber and polyphenol content make them a valuable feed ingredient when properly fermented. Fermentation enhances the digestibility and palatability of cocoa pod husk silage, making it a sustainable and economical feed option for dairy cattle. Including cocoa pod husk silage in dairy rations can improve rumen health, milk production, and reduce the environmental impact of cocoa processing waste.

Fermented Palm Kernel Cake

Fermented palm kernel cake is produced by fermenting palm kernel cake, a by-product of palm oil extraction. The fermentation process enhances the protein quality of palm kernel cake by improving amino acid availability and reducing anti-nutritional factors. As a high-protein ingredient, fermented palm kernel cake can significantly improve the nutritional content of dairy cattle diets [46]. Its inclusion in dairy rations supports better milk production, growth, and feed efficiency. Moreover, using fermented palm kernel cake promotes sustainability by converting a waste product into a valuable livestock feed resource.

Fish Silage

Fish silage is produced by fermenting fish by-products such as fish carcasses, heads, and offal. Rich in protein, fats, and essential amino acids, fish silage provides a high-quality feed ingredient for dairy cattle. The fermentation process not only improves the digestibility and nutritional quality of fish silage but also helps reduce the odor and spoilage associated with raw fish waste. Incorporating fish silage into dairy diets can enhance milk yield, promote growth, and contribute to sustainable waste management in the aquaculture industry.

Mango Seed Kernel Silage

Mango seed kernel silage is produced by fermenting mango seed kernels, which are rich in carbohydrates, fats, and some proteins. Mango seed kernels are typically discarded as waste but can be effectively utilized for livestock feeding. The fermentation process improves the nutritional profile and digestibility of mango seed kernel silage, making it a suitable and sustainable feed resource for dairy cattle. Including mango seed kernel silage in dairy rations can help reduce waste, support improved growth, and enhance milk production, offering a cost-effective and environmentally friendly feeding option.

Pineapple Peel Silage

Pineapple peel silage is created by fermenting pineapple peels, which are high in fiber, antioxidants, and some micronutrients. The fermentation process enhances the palatability and nutritional value of pineapple peel silage, making it a suitable feed ingredient for dairy cattle. Incorporating pineapple peel silage into dairy diets can promote better rumen function, improve feed utilization, and reduce the environmental impact of pineapple processing waste. Its inclusion in dairy rations helps optimize farm resource management while providing a sustainable and affordable feed option.

Poultry Litter

Poultry litter, consisting of bedding material, feces, and feathers, can be used as a feed ingredient for dairy cattle after proper treatment and processing [47]. It is rich in nitrogen, phosphorus, and organic matter, but it often contains high levels of pathogenic microorganisms that can pose health risks to livestock. Through fermentation or composting, poultry litter can be treated to improve its safety and nutritional value. When processed properly, poultry litter can be a cost-effective and sustainable feed resource, contributing to improved milk production and the reduction of waste on poultry farms.

Rice Bran Fermented with *Aspergillus* spp.

Rice bran fermented with *Aspergillus* spp. involves the inoculation of rice bran, a by-product of rice milling, with beneficial fungal strains of *Aspergillus* to improve its nutritional content. The fermentation process enhances protein digestibility, reduces anti-nutritional factors, and increases the availability of essential amino acids. Rice bran fermented with *Aspergillus* spp. can be a valuable protein source for dairy cattle, supporting better milk production, feed conversion, and overall health [48]. By utilizing rice bran as a fermented feed ingredient, dairy farming systems can reduce waste and promote sustainability.

Sugarcane Tops Silage

Sugarcane tops silage is produced by fermenting the leaves and tops of sugarcane plants, which are often left as waste after harvesting. These tops are rich in fiber, and when fermented, they become more palatable and digestible for dairy cattle. Sugarcane tops silage is an affordable and sustainable feed option, especially in sugarcane-growing regions. Incorporating this silage into dairy rations can improve rumen health, enhance feed utilization, and contribute to higher milk production. Moreover, utilizing sugarcane tops as a feed resource helps reduce environmental waste and supports more efficient resource use in dairy farming systems.

MISCELLANEOUS BY-PRODUCTS AND WILD FRUITS

Breadfruit Waste

Breadfruit waste is a by-product generated during the harvesting and processing of breadfruit. It consists of the peel, seeds, and other parts not consumed by humans. Rich in fiber and carbohydrates, breadfruit waste can be utilized as an energy source for livestock. When properly processed or fermented, breadfruit waste can provide dairy cattle with a cost-effective, nutrient-rich feed ingredient. Incorporating breadfruit waste into dairy rations can help reduce farm waste, lower feed costs, and contribute to the sustainability of farming systems, especially in regions where breadfruit is abundant.

Cashew Apple Residue

Cashew apple residue is the leftover part of the cashew nut processing, consisting of the fruit pulp and husk. This residue is rich in sugars, fiber, and various micronutrients. Although cashew apple residue is often discarded, it can be processed and used as an alternative feed resource for dairy cattle [49]. The high sugar content of cashew apple residue can provide a quick energy source for livestock, while its fiber content can promote healthy rumen function. Incorporating this by-product into dairy feed formulations can help reduce waste and optimize farm resource management.

CUSTARD APPLE SEED MEAL

Custard apple seed meal is produced by grinding the seeds of the custard apple fruit. These seeds are high in protein and essential fatty acids but often discarded as waste. After proper processing to remove anti-nutritional compounds, custard apple seed meal can be used as a protein supplement in dairy cattle diets. The nutritional profile of this meal can improve overall milk production and animal health. Utilizing custard apple seed meal as an alternative feed resource contributes to reducing waste and enhances the sustainability of dairy farming systems.

Date Seed Meal

Date seed meal is obtained from the seeds of dates, a by-product of date processing. The seeds are rich in fiber, protein, and micronutrients, but they are often discarded as waste. After proper grinding and processing, date seed meal can be included in dairy cattle diets as a high-fiber and protein-rich ingredient. This by-product provides a sustainable alternative to conventional feed sources, helping to reduce feed costs and improve feed utilization [50]. Incorporating date seed meal into dairy rations supports better rumen health and enhances milk production efficiency.

Fig Waste

Fig waste includes the parts of the fig fruit that are not consumed such as overripe fruits, damaged figs, or those left over after processing. Rich in sugars, fiber, and essential vitamins, fig waste can be used as a supplemental feed ingredient for dairy cattle. When properly processed, fig waste can improve the nutritional quality of livestock diets, provide a sustainable energy source while reducing farm waste. Fig waste contributes to more efficient feed resource management, especially in regions where figs are cultivated in abundance.

Guava Seed Meal

Guava seed meal is made from grinding the seeds of guava fruits, which are typically discarded after consumption. Guava seeds are rich in protein, fiber, and beneficial compounds, making them a valuable feed resource for dairy cattle [51]. After proper processing to remove anti-nutritional factors, guava seed meal can be incorporated into dairy rations to enhance protein intake and support healthy growth. Using guava seed meal in dairy feeds contributes to waste reduction, lowers feed costs, and provides a sustainable, nutrient-rich feed option.

Papaya Seed Meal

Papaya seed meal is derived from grinding the seeds of papaya fruits, which are rich in protein, fiber, and essential fatty acids. While papaya seeds are often discarded, they can be processed and used as an alternative protein source in dairy cattle feeds [52]. The nutritional value of papaya seed meal supports improved milk production, growth, and overall health in dairy cows. Incorporating this meal into dairy diets promotes sustainability by reducing waste from papaya processing and providing a cost-effective, nutrient-dense feed ingredient.

Passion Fruit Peel Meal

Passion fruit peel meal is made from the discarded peels of passion fruits, which are often left behind during fruit processing. Passion fruit peels are high in fiber and contain essential micronutrients that are beneficial for dairy cattle. After proper processing and fermentation, passion fruit peel meal can be

incorporated into dairy cattle diets to enhance fiber intake, improve rumen function, and increase overall feed utilization [53]. Utilizing this by-product reduces waste and offers a sustainable feed resource for dairy farming systems, especially in areas where passion fruits are widely cultivated.

Tamarind Seed Meal

Tamarind seed meal is produced by grinding the seeds of tamarind fruits, which are typically discarded after the pulp is extracted. The seeds are rich in protein, fiber, and essential fatty acids, making them a valuable feed resource for dairy cattle [54]. After proper processing to remove anti-nutritional compounds, tamarind seed meal can be included in dairy rations to support improved protein intake and overall milk production. By incorporating tamarind seed meal, dairy farmers can reduce waste, lower feed costs, and contribute to more sustainable farming practices.

Watermelon Rind

Watermelon rind is the outer, non-consumed portion of the watermelon fruit, which is typically discarded. The rind is rich in fiber, vitamins, and minerals, but it is often considered waste. However, after processing or fermentation, watermelon rind can be used as a supplemental feed ingredient for dairy cattle [55]. Its high fiber content aids in rumen health and digestion, while its mineral content supports overall animal health. Utilizing watermelon rind in dairy feeds helps reduce waste and provides a sustainable and economical feed source, especially in regions where watermelon is abundant.

INVASIVE AND UNDERUTILIZED PLANTS

Chromolaena odorata

Chromolaena odorata, commonly known as the Siam weed, is an invasive species found in tropical and subtropical regions. While it is known to disrupt local ecosystems, its leaves are rich in protein and essential minerals, making it a potentially valuable feed resource for livestock. When properly processed, *Chromolaena odorata* can be incorporated into dairy cattle diets to provide a cost-effective alternative to traditional forage. Its high growth rate and ability to thrive in marginal lands make it an attractive option for enhancing feed resources in areas with limited agricultural land.

Lantana camara

Lantana camara is a widely distributed invasive shrub in tropical and subtropical regions. Although considered a nuisance due to its toxic properties when consumed in large quantities, *Lantana camara* can be utilized as livestock feed once processed and detoxified [56]. Its leaves and stems contain essential nutrients, like fiber, protein, and minerals, which can be beneficial for dairy cattle when incorporated into balanced rations. Research on safe processing methods is essential to ensure the effective utilization of this plant, turning it from an environmental threat into a valuable feed resource.

Parthenium hysterophorus

Parthenium hysterophorus, also known as the Congress grass, is an invasive plant that spreads rapidly in tropical regions. While it is often regarded as a problematic weed, its leaves and stems contain nutrients that can be utilized in livestock diets. Proper processing and detoxification techniques can render *Parthenium hysterophorus* a viable feed option for dairy cattle, providing essential proteins and minerals. Integrating this plant into livestock feeding systems could help manage its spread and turn a destructive species into a beneficial feed resource.

***Prosopis juliflora* Pods**

Prosopis juliflora, a fast-growing invasive tree species, produces pods that are rich in carbohydrates, fiber, and protein. These pods can be utilized as an alternative feed resource for dairy cattle, particularly in arid regions where other feed resources may be scarce. The high fiber content of *Prosopis juliflora* pods can support rumen health, while the protein content can enhance milk production [57]. Harvesting and processing the pods into animal feed can help mitigate the spread of this invasive species while providing a sustainable feed option.

Sida acuta

Sida acuta, or the wireweed, is an invasive plant commonly found in tropical and subtropical regions. This plant contains protein, fiber, and various micronutrients that can be beneficial in livestock diets. When properly processed, *Sida acuta* can be used as an alternative source of roughage for dairy cattle. Its ability to grow in poor soils and harsh conditions makes it a useful feed resource in areas with limited access to traditional forage crops, contributing to improved feed sustainability.

Tithonia diversifolia

Tithonia diversifolia, known as the Mexican sunflower, is an underutilized plant that is widely distributed in tropical regions. Its leaves are rich in proteins, minerals, and fiber, making it a valuable addition to livestock diets. *Tithonia diversifolia* can be used as a green forage, silage, or dried feed for dairy cattle [58]. The plant's rapid growth and ability to thrive in marginal soils make it an excellent resource for enhancing livestock feed supply, particularly in areas where other forage crops may be scarce.

Urochloa (Brachiaria) spp.

Urochloa, commonly referred to as *Brachiaria*, is a genus of grass species known for its drought tolerance and high productivity in tropical regions. While some species are cultivated for forage, others are considered invasive in certain environments. *Urochloa* species can be incorporated into dairy cattle diets to improve protein intake and enhance overall animal performance [59]. The ability of *Urochloa* to grow in poor soils and withstand harsh environmental conditions makes it a valuable feed resource for sustainable livestock farming in tropical climates.

Vernonia amygdalina

Vernonia amygdalina, commonly known as bitter leaf, is an underutilized plant that grows in tropical regions. The leaves of this plant contain essential nutrients such as protein, vitamins, and minerals. Despite its bitter taste, when properly processed, *Vernonia amygdalina* can be used as a valuable feed resource for dairy cattle. It has been shown to have beneficial effects on animal health and can help improve milk production when incorporated into livestock diets [60]. Promoting the use of this plant as animal feed can contribute to more sustainable farming practices.

Wild sunflower (*Tithonia spp.*)

Wild sunflower, or *Tithonia spp.*, is a member of the Asteraceae family, native to tropical and subtropical regions. Its leaves are high in protein, vitamins, and minerals, making them a beneficial feed source for dairy cattle. Although often regarded as a weed, *Tithonia spp.* can be utilized as a valuable forage resource when properly processed. It offers a sustainable alternative to conventional forages, particularly in regions where land is underutilized or where other feed sources are scarce.

***Ziziphus mauritiana* Leaves**

Ziziphus mauritiana, commonly known as the Indian jujube or ber, is a drought-tolerant tree that produces nutritious leaves, fruits, and seeds. The leaves of *Ziziphus mauritiana* are rich in protein and fiber, making them suitable for use as livestock feed [61]. In tropical regions where this tree thrives, *Ziziphus mauritiana* can be incorporated into dairy cattle diets to improve protein intake and overall nutrition. This underutilized plant can serve as a valuable feed resource, particularly in areas facing feed scarcity or poor soil conditions.

CONCLUSION

This study highlights the untapped potential of neglected tropical dairy feeds as viable alternatives to conventional feed resources. The findings demonstrate that these alternative feeds, such as agro-industrial by-products, wild forages, and leguminous species, offer significant nutritional, economic, and environmental benefits. Integrating these feeds into dairy farming systems can reduce feed costs, enhance sustainability, and minimize reliance on imported inputs. Furthermore, the study underscores the need for further research into the digestibility, bioavailability, and long-term effects of these feeds

on dairy cattle performance. By unlocking the full potential of these underutilized resources, the dairy industry in tropical regions can achieve improved productivity and resilience, ultimately contributing to sustainable dairy development.

Future Directions

Future research should focus on exploring the optimal processing techniques for neglected tropical dairy feeds to enhance their digestibility, nutrient bioavailability, and palatability. Studies on improving feed preservation methods, such as fermentation or ensiling, could further expand their potential use. Additionally, evaluating the long-term effects of these alternative feeds on dairy cattle performance, health, and milk quality is essential for determining their practical applications. Research into the integration of these feeds within mixed or rotational grazing systems could also offer insights into maximizing feed utilization while reducing environmental impact. Moreover, exploring the potential of local knowledge in utilizing indigenous feed resources, along with collaborative efforts from farmers, researchers, and policymakers, could accelerate the adoption of these alternative feeds. Comprehensive assessments of the economic viability and scalability of these feed options are critical for ensuring their widespread implementation in sustainable dairy systems across the tropics.

REFERENCES

1. Wales WJ, Kolver ES. Challenges of feeding dairy cows in Australia and New Zealand. *Anim Prod Sci.* 2017;57(7):1366–1383.
2. Halmemies-Beauchet-Filleau A, Rinne M, Lamminen M, Mapato C, Ampapon T, Wanapat M, Vanhatalo A. Alternative and novel feeds for ruminants: Nutritive value, product quality and environmental aspects. *Animal.* 2018 Dec;12(s2):s295-309.
3. Chisoro P, Jaja IF, Assan N. Incorporation of local novel feed resources in livestock feed for sustainable food security and circular economy in Africa. *Front Sustain.* 2023;4:1251179. doi: 10.3389/frsus.2023.1251179.
4. Gebeyew K. Review on the nutritive value of some selected Acacia species for livestock production in dryland areas. *Adv Dairy Res.* 2015;3(2). doi: 10.4172/2329-888X.1000139.
5. Lata M, Mondal BC. Uses of tree leaves as alternative feed resources for ruminant animals. *J Entomol Zool Stud.* 2021;9(1):2239–2247.
6. Altamirano-Gutiérrez W, Molina-Botero IC, Fuentes-Navarro E, Arango J, Salazar-Cubillas K, Paucar R, Gómez-Bravo C. Bamboo forage in Peruvian Amazon: a potential feed for cattle. *Tropical Animal Health and Production.* 2023 Oct;55(5):288.
7. Tuwei PK, Kang'Ara JNN, Mueller-Harvey I, Poole J, Ngugi FK, Stewart JL. Factors affecting biomass production and nutritive value of *Calliandra calothyrsus* leaf as fodder for ruminants. *J Agric Sci.* 2003;141(1):113–127.
8. Mwangi, F.W., Suybeng, B., Gardiner, C.P., Kinobe, R.T., Charmley, E., Malau-Aduli, B.S. and Malau-Aduli, A.E., 2022. Effect of incremental proportions of *Desmanthus* spp. in isonitrogenous forage diets on growth performance, rumen fermentation and plasma metabolites of pen-fed growing Brahman, Charbray and Droughtmaster crossbred beef steers. *Plos one*, 17(1), p.e0260918.
9. Kassa A, Tadele Y, Mekasha Y. *Ficus sycomorus* (Sycamore Fig or Shola) leaf, a potential source of protein for ruminants: A review. *J Fish Livest Prod.* 2015;3:152.
10. Cherdthong A. An overview of alternative protein sources for ruminants in the tropical area. *Ann Anim Sci.* 2025;25(1):103–118.
11. Mathison GW. Forage tree legumes in tropical agriculture. CAB International; 1997. doi: 10.1016/S0377-8401(97)00023-0.
12. Valdivié M, Martínez Y. *Hibiscus rosa-sinensis* forage as a potential feed for animals: A review. *Animals (Basel).* 2022;12(3):288.
13. Gunun N, Kaewpila C, Khota W, Polyorach S, Kimprasit T, Phlaetita W, Cherdthong A, Wanapat M, Gunun P. The effect of indigo (*Indigofera tinctoria* L.) waste on growth performance, digestibility, rumen fermentation, hematology and immune response in growing beef cattle. *Animals.* 2022 Dec 26;13(1):84.

14. De Angelis A, Gasco L, Parisi G, Danieli PP. A multipurpose leguminous plant for the Mediterranean countries: *Leucaena leucocephala* as an alternative protein source: A review. *Animals (Basel)*. 2021;11(8):2230.
15. Brar S, Haugh C, Robertson N, Owuor PM, Waterman C, Fuchs III GJ, Attia SL. The impact of *Moringa oleifera* leaf supplementation on human and animal nutrition, growth, and milk production: A systematic review. *Phytotherapy Research*. 2022 Apr;36(4):1600-15.
16. Mwai LM, Kingori AM, Ambula MK. Mulberry leaves as a feed source for livestock in Kenya: A review. *Int J Agric Res Innov Technol*. 2021;11(2):1–9.
17. Nambi-Kasozi J, Sabiiti EN, Bareeb FB, Sporndly E. Effect of feeding varying levels of banana peelings supplemented with maize bran, cotton seed cake and *Gliricidia sepium* on the performance of lactating dairy cows. *Afr J Agric Res*. 2014;9(8):720–727.
18. US10066089B2 - Coffee pulp preservation and extraction process - Google Patents [Internet]. Google.com. 2014. Available from: <https://patents.google.com/patent/US10066089B2/en>.
19. Vernlund SD, Harris B Jr, Van Horn HH, Wilcox CJ. Effect of Masonex and forms of cottonseed hulls on dairy cows. *J Dairy Sci*. 1980;63(12):2037–2043.
20. Prusty S, Gendley MK, Singh AK, Dubey M, Patil PV, Sharma VK. Jackfruit waste and peels: Potential as livestock feed. *Indian J Anim Sci*. 2024;94(5):395–400. doi: 10.56093/ijans.v94i5.136138.
21. Wachirapakorn C, Pilachai K, Wanapat M, Pakdee P, Cherdthong A. Effect of ground corn cobs as a fiber source in total mixed ration on feed intake, milk yield and milk composition in tropical lactating crossbred Holstein cows. *Anim Nutr*. 2016;2(4):334–338.
22. Lalramhlimi B, Mukherjee D, Chakraborty I, Ghosh N, Chattopadhyay A, Dey RC. Fruit and vegetable wastes as livestock feeds. In: *Fruits and Vegetable Wastes: Valorization to Bioproducts and Platform Chemicals*. Springer; 2022. p. 139–168.
23. Tahir Z, Khan MI, Ashraf U, Adan Ijaz RDN, Mubarik U. Industrial application of orange peel waste: A review. *Int J Agric Biosci*. 2023;12(2):71–76. doi: 10.47278/journal.ijab/2023.046.
24. Sukri SA, Andu Y, Sarijan S, Khalid HN, Kari ZA, Harun HC, Rusli ND, Mat K, Khalif RI, Wei LS, Rahman MM. Pineapple waste in animal feed: A review of nutritional potential, impact and prospects. *Annals of Animal Science*. 2023 Apr 1;23(2):339-52.
25. Oluodo LA, Huda N, Komilus CF. Potential utilization of rubber seed meal as feed and food. *Int J Eng Technol*. 2018;7:64–71.
26. Harrison MD. Sugarcane-derived animal feed. In: *Sugarcane-based Biofuels and Bioproducts*. 2016. p. 281–310.
27. Madzimure J, Musimurimwa C, Chivandi E, Gwiriri L, Mamhare E. Milk yield and quality in Guernsey cows fed cottonseed cake-based diets partially substituted with baobab (*Adansonia digitata* L.) seed cake. *Trop Anim Health Prod*. 2011;43:77–82.
28. Coppock CE, Lanham JK, Horner JL. A review of the nutritive value and utilization of whole cottonseed, cottonseed meal and associated by-products by dairy cattle. *Anim Feed Sci Technol*. 1987;18(2):89–129.
29. de Barros CR, Ferreira LMM, Fraga I, Mourão JL, Rodrigues MAM. Detoxification methods of *Jatropha curcas* seed cake and its potential utilization as animal feed. *Fermentation*. 2024;10(5):256.
30. Sohail M, Nauman-ul-Islam M, Shah IA, Raziq A, Ullah S, Shah AA. Effect of supplementing different levels of mustard seed cake on milk yield and milk composition of Achai cattle. *Meat Sci Vet Public Health*. 2017;2(1):2002–2005.
31. Saxena M, Ravikanth K, Kumar A, Gupta A, Singh B, Sharma A. Purification of *Azadirachta indica* seed cake and its impact on nutritional and antinutritional factors. *J Agric Food Chem*. 2010;58(8):4939–4944.
32. Abdeltawab AM, Khat tab MSA. Utilization of palm kernel cake as a ruminant feed for animal: A review. *Asian J Biol Sci*. 2018;11(4):157–164.
33. Pirlo G, Migliorati L, Abeni F, Degano L, Bruni A, Cabassi G, Povolito M. Effect of supplementing sunflower cake in dairy cow diet on milk production and composition. *Sci. E Tec. Latt. Casaria*. 2020;70:27-34.

34. Roy PS, Roy A, Pathak PK, Mandal N, Soren S, Kumar S. Effect of Azolla supplementation on milk yield and economics under farmers' field. *J Crop Weed*. 2018;14(2):77–80.
35. Goopy JP, Murray PJ. A review on the role of duckweed in nutrient reclamation and as a source of animal feed. *Asian-Australas J Anim Sci*. 2003;16(2):297–305.
36. Kusumah V, Pertiwi H. Potential of *Ipomoea aquatica* hay and its phytochemical to improve performance and health status in ruminants. *Ecol Environ Conserv*. 2022;28(1S):4–4. doi: 10.53550/eec.2022.v28i01s.004.
37. Sosa D, Alves FM, Prieto MA, Pedrosa MC, Heleno SA, Barros L, Feliciano M, Carochio M. Lemna minor: Unlocking the value of this duckweed for the food and feed industry. *Foods*. 2024 May 7;13(10):1435.
38. Alves SP, Mendonça SH, Silva JL, Bessa RJB. Nannochloropsis oceanica, a novel natural source of rumen-protected eicosapentaenoic acid (EPA) for ruminants. *Sci Rep*. 2018;8(1):10269.
39. Otto J, AEO MA. *Spirulina platensis* (Arthrospira spp.): A potential novel feed source for pasture-based dairy cows. *J Fish Livest Prod*. 2017;5(3). doi: 10.4172/2332-2608.1000253.
40. Tham HT. Water hyacinth (*Eichhornia crassipes*). *Acta Univ Agric Sueciae*. 2012;(2012:90).
41. Siddiqui SA, Elsheikh W, Ucak İ, Hasan M, Perlita ZC, Yudhistira B. Replacement of soy by mealworms for livestock feed: A comparative review between soy and mealworms considering environmental aspects. *Environ Dev Sustain*. 2024;1–44. doi: 10.1007/s10668-024-04874-1.
42. Makinde OJ, Makinde J. Maggot meal: A sustainable protein source for livestock production—A review. *Adv Life Sci Technol*. 2015;31:35–41.
43. Sheikh IU, Banday MT, Baba IA, Adil S, Nissa SS, Zaffer B, Bulbul KH. Utilization of silkworm pupae meal as an alternative source of protein in the diet of livestock and poultry: A review. *J. Entomol. Zool. Stud*. 2018;6(4):1010-6.
44. Halfen J, Carpinelli N, Del Pino FA, Chapman JD, Sharman ED, Anderson JL, Osorio JS. Effects of yeast culture supplementation on lactation performance and rumen fermentation profile and microbial abundance in mid-lactation Holstein dairy cows. *Journal of Dairy Science*. 2021 Nov 1;104(11):11580-92.
45. Lounglawan P, Khungaew M, Suksombat W. Silage production from cassava peel and cassava pulp as energy source in cattle diets. *J Anim Vet Adv*. 2011;10(8):1007–1011.
46. Jin SG, Li M, Liu W, Zhou Y. Effect of including different levels of palm kernel cake to dairy cow concentrate on milk production and composition. *J Anim Feed Sci*. 2007;16(2):566–570.
47. Chavda JA, Savsani HH, Murthy KS, Ribadiya NK. Utilisation of poultry excreta as a ruminant feed—A review. *Agric Rev*. 2014;35(2):136. doi: 10.5958/0976-0741.2014.00091.9.
48. Manlapig JJD, Matsui H. Production and utilization of fermented rice bran as animal feed. *Anim Sci J*. 2025;96(1):1–10. doi: 10.1111/asj.70037.
49. Ojedian T, Akande O, Emiola A. Cashew (*Anacardium occidentale* L.) products and byproducts: Nutrient constituents and nutritional benefits in livestock diets. *Hayv Bilim Urun Derg*. 2024;7(1):42–62.
50. Al-Farsi MA, Lee CY. Usage of date (*Phoenix dactylifera* L.) seeds in human health and animal feed. In: *Nuts and Seeds in Health and Disease Prevention*. Elsevier; 2011. p. 447–452.
51. Manju Wadhwa MW, Bakshi MP, Makkar HP. Waste to worth: fruit wastes and by-products as animal feed. *CABI Reviews*. 2015 Oct 14(2015):1-26.
52. Rivera JE, Villegas G, Chará J, Durango SG, Romero MA, Verchot L. Effect of *Tithonia diversifolia* (Hemsl.) A. Gray intake on in vivo methane (CH₄) emission and milk production in dual-purpose cows in the Colombian Amazonian piedmont. *Translational animal science*. 2022 Oct 1;6(4):txac139.
53. Hiep T, Tuan BQ, Phuong LV, Son NH, Ha LV, Trach NX. Passion fruit (*Passiflora edulis*) peel as feed for ruminants in Vietnam: Quantification, chemical composition and possibility to make silage. *Livest Res Rural Dev*. 2020;32(2).
54. Nunoi A, Wanapat M, Foiklang S, Ampapon T, Viennasay B. Effects of replacing rice bran with tamarind seed meal in concentrate mixture diets on the changes in ruminal ecology and feed utilization of dairy steers. *Trop Anim Health Prod*. 2019;51:523–528.

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55. Agbana JA, Ete AO, Ojodomo MA, Ajala TO, Musa I. Ensiling improves the nutritive value of watermelon rinds (*Citrullus lanatus*) for use as livestock feed. *J Agric Rural Dev.* 2022;25(2):6468–6473.
 56. Ntalo M, Ravhuhali KE, Moyo B, Hawu O, Msiza NH. *Lantana camara*: Poisonous species and a potential browse species for goats in southern Africa—A review. *Sustainability.* 2022;14(2):751.
 57. Sawal RK, Ratan R, Yadav SBS. Mesquite (*Prosopis juliflora*) pods as a feed resource for livestock—A review. *Asian-Australas J Anim Sci.* 2004;17(5):719–725.
 58. Ribeiro RS, Terry SA, Sacramento JP, Silveira SR, Bento CB, da Silva EF, Mantovani HC, Gama MA, Pereira LG, Tomich TR, Maurício RM. *Tithonia diversifolia* as a supplementary feed for dairy cows. *PloS one.* 2016 Dec 1;11(12):e0165751.
 59. de Oliveira AF, Menezes GL, Goncalves LC, de Araujo VE, Ramirez MA, Júnior RG, Jayme DG, Lana AM. Pasture traits and cattle performance in silvopastoral systems with *Eucalyptus* and *Urochloa*: Systematic review and meta-analysis. *Livestock Science.* 2022 Aug 1;262:104973.
 60. Adugna W, Ayele S, Addis M. Different proportions of dried *Vernonia amygdalina* leaves and wheat bran mixture supplementation on feed intake, digestibility and body weight change of Arsi-Bale sheep fed with natural pasture hay as basal diet. *Vet Med Sci.* 2023;9(2):957–966.
 61. Abdu SB, Ehoche OW, Adamu AM, Bawa GS, Hassan MR, Yashim SM, et al. Effect of varying levels of *Zizyphus* (*Zizyphus mauritiana*) leaf meal inclusion in concentrate diet on performance of growing Yankasa ram lambs fed maize stover basal diet. 2012:323-330.