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Transforming Agricultural Waste into Opportunities: Crop Residues for Sustainable Livestock Feeding and Productivity

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Abstract

As global agricultural systems strive to meet the growing demand for livestock products while minimizing environmental impact, the sustainable utilization of crop residues has emerged as a key strategy for improving feed resource availability. In Bangladesh and many other developing regions, vast quantities of crop residues are produced annually, yet their potential as a valuable feed resource remains underutilized. This review evaluates the role of crop residues in livestock feeding, focusing on their nutritional value, limitations, and strategies for enhancing their digestibility and utilization. Innovative processing techniques, such as biological, chemical, and mechanical treatments, are explored to convert low-nutrient agricultural waste into nutritionally viable feed. Additionally, it addresses the environmental and economic benefits of integrating crop residues into feeding systems, including reduced feed costs, lower reliance on conventional feed ingredients, and mitigation of waste-related environmental challenges. By transforming agricultural waste into a sustainable feed resource, this approach not only contributes to enhancing livestock productivity but also aligns with broader goals of sustainable agricultural development and circular economy principles. This paper provides a comprehensive analysis of opportunities, challenges, and future directions for optimizing use of crop residue in livestock feeding to achieve sustainable and resilient food production systems by using neglected crop residues.

Keywords: Crop residues, livestock feeding, nutritional value, sustainable agriculture, waste utilization

INTRODUCTION

In the quest for sustainable agricultural practices, the management of crop residues presents both a challenge and an opportunity [1]. Globally, billions of tons of agricultural waste, primarily in the form of crop residues, are generated each year. In countries like Bangladesh, where agriculture remains a cornerstone of the economy, the potential for these residues to be transformed into valuable feed resources for livestock is significant [2]. Despite their abundance, crop residues are often underutilized, frequently burned or left to decompose, contributing to environmental pollution and the loss of potential nutritional benefits for livestock. The livestock sector is facing immense pressure to meet the increasing demand for protein-rich foods as global populations rise and dietary preferences shift. Traditional feed sources, such as grains and oilseeds, are becoming scarce and expensive, leading to a need for alternative feeding strategies

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that leverage locally available resources [3]. Crop residues, including rice straw, wheat straw, maize stover, and leguminous haulms, can serve as a crucial supplement in livestock diets, particularly in resource-constrained settings [4–6].

Utilizing crop residues not only addresses the economic challenges associated with livestock feeding but also aligns with sustainable agricultural practices. Integrating these residues into feeding systems can reduce dependence on commercial feed inputs, lower production costs, and enhance the overall resilience of farming systems [7]. Furthermore, converting agricultural waste into animal feed can help mitigate environmental issues, such as greenhouse gas emissions from open burning and nutrient runoff from decomposing residues [8–10]. However, the nutritional value of crop residues is often limited due to their high fiber content and low digestibility. To maximize their potential, innovative processing techniques, such as ensiling, urea treatment, and fermentation, must be employed to enhance nutrient availability and improve digestibility.

This review aims to explore the multifaceted role of crop residues in livestock feeding, assessing their nutritional profiles, the environmental and economic benefits of their utilization, and the technological advancements that can facilitate their incorporation into livestock diets. The novelty of this study lies in its comprehensive analysis of crop residues as underutilized feed resources in livestock production, specifically within the context of Bangladesh. By integrating innovative processing techniques and exploring sustainable feeding strategies, this study highlights the potential of transforming agricultural waste into high-quality feed. It further addresses the dual benefits of enhancing livestock productivity and promoting environmental sustainability. Additionally, the review identifies gaps in current research and presents actionable recommendations for optimizing crop residue utilization, contributing to the development of more resilient and sustainable livestock systems in the face of growing global food demands.

MAJOR CROP RESIDUES

Aquatic Plant Residues

Aquatic plant residues are increasingly recognized as valuable feed resources for livestock, particularly in regions with abundant water bodies. Key examples include water hyacinth, duckweed, coontail, azolla, and salvinia. These plants are typically high in protein and essential amino acids, making them a suitable supplement for ruminant diets [11–16]. For instance, duckweed is known for its rapid growth and can contain protein levels comparable to soybean meal, making it an excellent feed alternative. Moreover, azolla has been shown to improve soil fertility through nitrogen fixation when used as green manure. However, while these residues are rich in nutrients, they may also pose challenges. For example, water hyacinth can become invasive, leading to ecological imbalances in water bodies. Additionally, some aquatic plants may contain anti-nutritional factors or toxins that require careful management. Overall, the sustainable use of aquatic plant residues in livestock feeding can help improve productivity while addressing environmental concerns related to waste management.

Cereal Crop Residues

Cereal crop residues are among the most abundant agricultural by-products in Bangladesh, playing a crucial role in livestock nutrition [5, 17, 18]. Common examples include rice straw, wheat straw, maize stover, sorghum stover, barley straw, millet stover, paddy husk, rice bran, wheat bran, and oat straw. These residues are primarily composed of fibrous material, which provides bulk and promotes rumination in ruminants [19–24]. While they help maintain gut health and prevent digestive disorders, cereal crop residues are generally low in protein and energy content, necessitating supplementation with higher-quality feed sources to meet the nutritional needs of livestock. Additionally, their low digestibility can limit their effectiveness as a primary feed source. Despite these limitations, cereal residues are economically advantageous, readily available, and represent a sustainable feeding strategy to reduce reliance on expensive commercial feeds, especially in resource-constrained settings.

Distiller's Dried Grains

Distiller's Dried Grains (DDGs) are valuable byproducts of ethanol production, offering unique nutritional profiles beneficial for livestock. Corn Distiller's Dried Grains contain 30–35% protein and significant fat, providing a cost-effective energy source. Barley DDGs have about 25–30% protein and higher fiber content, supporting rumen health. Wheat DDGs offer a balanced profile for growth, while Sorghum DDGs provide 25–30% protein but may pose challenges due to anti-nutritional factors. Rye DDGs typically contain 20–25% protein, while Rice DDGs are suitable for various livestock with similar protein levels. Sugarcane DDGs contain 20–25% protein, promoting digestive health, and Potato DDGs enhance feed efficiency with 25–30% protein. Molasses DDGs are high in sugars (15–20% protein), and Mixed Grain DDGs offer a balanced nutrient profile. Together, these DDGs represent sustainable strategies for livestock feed and agricultural waste reduction [25–29].

Fodder Crop Residues

Fodder crop residues are specifically grown for animal feed and can significantly enhance livestock nutrition. Key examples include Napier grass stalks, para grass stubble, guinea grass stubble, Sudan grass stover, hybrid sorghum stover, alfalfa stems, berseem clover stems, lucerne stems, Rhodes grass stover, and stylosanthes stover. These residues typically have high fiber content and are beneficial for ruminants, helping maintain rumen health and promote digestion. Fodder crop residues are often rich in nutrients and can be used as primary feed sources [13, 30–34]. However, their availability can be seasonal, influenced by cropping patterns, and may require proper storage to prevent spoilage. Moreover, incorporating these residues into livestock diets can reduce feed costs and promote sustainable livestock production by efficiently utilizing agricultural by-products, enhancing the overall sustainability of the livestock sector in Bangladesh.

Fruit and Vegetable Residues

Fruit and vegetable residues, generated during the harvesting and processing of crops, offer a sustainable source of nutrition for livestock. Examples include mango peels, banana pseudostems, tomato vines, pumpkin leaves, and papaya waste. These residues are often rich in vitamins, minerals, and dietary fiber, contributing to improved animal health [22, 35, 36]. For instance, banana pseudostems are high in potassium and can serve as a valuable source of roughage, promoting healthy digestion in ruminants. Similarly, pumpkin leaves are known for their nutritional benefits and can enhance the palatability of animal diets. However, the high moisture content in many fruit and vegetable residues can lead to rapid spoilage, necessitating careful management and storage. Moreover, some residues may contain anti-nutritional factors that require processing before feeding. Effectively utilizing fruit and vegetable residues can reduce waste, enhance feed diversity, and contribute to more sustainable livestock production practices.

Fruit Processing Plant Wastes

Fruit processing generates significant waste, which can be categorized into various types that offer valuable resources for animal feed, composting, and bioenergy production. Common byproducts include peels from fruits like mangoes and oranges, which are rich in fiber and nutrients. Pulp remains after juice extraction and is suitable for ruminant feed due to its high fiber content. Seeds from fruits, such as grapes and apples can be processed for oils or antioxidants. Discarded stems and cores can also be utilized for animal feed or composting. Overripe fruits not fit for sale can be transformed into juices or jams, minimizing waste. Additionally, wastewater from processing may contain nutrients that can be treated for use as organic fertilizer. Residues from making concentrates and syrups, as well as drying residues, can serve as beneficial fiber sources for livestock [22, 35, 36]. By effectively utilizing these byproducts, fruit processing facilities enhance sustainability and reduce environmental impact.

Horticultural Crop Residues

Horticultural crop residues consist of the leftover parts of fruits and vegetables, which can provide moisture and fiber to livestock diets. Key examples include banana stems, banana leaves, banana

peels, mango leaves, papaya leaves, jackfruit leaves, coconut leaves, coconut husk, guava leaves, and pineapple leaves. These residues are often rich in vitamins and minerals, making them beneficial for animal health. Their high moisture content can help improve hydration and overall feed intake, particularly in dry seasons [37–43]. However, the seasonal nature of horticultural production can lead to variable availability, and these residues can spoil quickly, limiting their usability. Proper storage and processing techniques can extend their shelf life and enhance their nutritional value. Incorporating horticultural crop residues into livestock diets can also contribute to reducing food waste, promoting sustainable practices, and providing an economical alternative to conventional feed sources.

Legume Crop Residues

Leguminous crop residues are an important source of protein and essential nutrients for livestock. Examples of these residues include lentil straw, chickpea straw, black gram [mashkalai) haulms, mung bean (moong dal) haulms, grass pea (khesari) straw, pigeon pea (arhar) straw, cowpea haulms, soybean stover, groundnut haulms, and pea straw. These residues are richer in protein and mineral content compared to cereal residues, making them valuable for enhancing the overall nutritional profile of livestock diets [44–47]. The incorporation of legume residues can lead to improved animal health and productivity while also contributing to soil fertility through nitrogen fixation. However, the availability of leguminous crop residues can be limited by seasonal production cycles, and some residues may contain anti-nutritional factors that can adversely affect digestibility. Proper processing and blending with other feed components can help mitigate these issues and optimize the use of legume residues in livestock feeding.

Medicinal Plant Residues

Medicinal plant residues, derived from plants known for their therapeutic properties, can play a significant role in livestock nutrition. Examples include aloe vera leaves, neem leaves, tulsi (basil) stalks, mint stems, and turmeric leaves. These residues often possess unique phytochemicals and antioxidants that can enhance animal health and productivity [48–52]. For instance, neem leaves are renowned for their anti-parasitic and antibacterial properties, potentially reducing the incidence of diseases in livestock. Similarly, aloe vera leaves contain compounds that may improve gut health and enhance nutrient absorption. However, while these residues provide health benefits, they may also have limitations; some medicinal plants can possess strong flavors that may affect palatability, making them less appealing to livestock. Additionally, the variability in nutrient composition can impact their effectiveness as a feed resource. Utilizing medicinal plant residues in livestock diets can promote sustainable practices by maximizing the use of available agricultural resources and enhancing animal welfare.

Oilseed Crop Residues

Oilseed crop residues serve as supplementary feed sources for livestock, providing moderate protein and essential fatty acids. Notable examples include mustard straw, mustard oil cake, sesame stalks, linseed straw, cottonseed hulls, sunflower stalks, sunflower heads, safflower stalks, castor plant residues, and flaxseed straw. These residues are often rich in fiber and can enhance the nutritional value of livestock diets when incorporated appropriately. They can also contribute to improved animal performance and health [53–56]. The oil extraction process leaves behind protein-rich residues that are particularly beneficial for ruminants. However, oilseed residues can be fibrous, which may affect palatability and digestibility. Ensuring proper processing, such as grinding or pelleting, can enhance their acceptance and nutrient availability. Additionally, the economic viability of using these residues as feed alternatives can help reduce feed costs while promoting sustainable livestock production practices in Bangladesh.

Pulse Crop Residues

Pulse crop residues are a significant source of protein, enhancing the nutritional quality of livestock diets. Examples include mung bean husk, black gram husk, lentil husk, pigeon pea pods, grass pea

pods, chickpea husk, pea husk, cowpea pods, soybean husk, and horse gram husk. These residues are particularly valuable for ruminants, as they contribute essential amino acids and minerals [57–59]. Additionally, pulse residues can improve soil fertility through nitrogen fixation, supporting sustainable agricultural practices. However, the availability of pulse crop residues can be limited by harvest periods, and some may contain anti-nutritional factors, which can reduce their digestibility. Appropriate processing methods, such as boiling or fermentation, can enhance their palatability and nutrient availability. Overall, incorporating pulse crop residues into livestock diets can improve productivity while promoting resource efficiency in Bangladesh's livestock sector.

Root and Tuber Crop Residues

Root and tuber crop residues are valuable sources of energy and fiber in livestock feeding systems. Common examples include sweet potato vines, potato haulms, yam haulms, taro (colocasia) leaves, cassava leaves, arrowroot leaves, beet leaves, turnip leaves, radish leaves, and carrot leaves. These residues contribute a significant amount of fibrous material, which aids in maintaining rumen health and stimulating digestion [60–66]. While they can provide some energy, their nutritional value varies, often requiring supplementation with protein-rich feeds to meet the dietary needs of livestock. The seasonal availability of root and tuber residues can be a challenge, as they are often produced in specific growing seasons. Additionally, certain residues may contain toxic compounds, necessitating careful management and processing to ensure safe feeding. Overall, incorporating root and tuber crop residues into livestock diets can promote sustainability by minimizing waste and utilizing available agricultural resources effectively.

Spice Crop Residues

Spice crop residues are valuable by-products derived from the cultivation of various spices, offering unique nutritional benefits for livestock feeding. Examples include ginger tops, garlic stalks, turmeric leaves, chili plant residues, and coriander stalks. These residues are often rich in essential oils, vitamins, and minerals, which can enhance the overall health of livestock. For instance, garlic stalks are known for their antimicrobial properties, potentially improving gut health and reducing disease incidence in ruminants [18, 67]. Additionally, turmeric leaves contain curcumin, which has anti-inflammatory and antioxidant effects that may benefit animal health. However, the nutritional value of spice crop residues can vary, with some residues being fibrous and less palatable for livestock. Proper processing methods, such as chopping or fermenting, can enhance their digestibility and acceptance. Utilizing spice crop residues in livestock feeding can promote sustainable practices by reducing waste and improving the nutritional diversity of animal diets.

Sugarcane Residues

Sugarcane residues are by-products of sugar production that offer valuable feeding options for livestock. Key examples include bagasse, sugarcane tops, sugarcane leaves, molasses, and press mud. Bagasse, the fibrous material left after juice extraction, serves as a roughage source rich in fiber but low in protein and energy. Sugarcane tops and leaves provide additional bulk in animal diets, containing some nutritional value despite being primarily fibrous [17, 68]. Molasses, a viscous by-product, is high in sugars and serves as an excellent energy supplement that enhances palatability and encourages feed intake. However, while these residues can be beneficial, they also have limitations; for example, high fiber content in bagasse may lead to lower digestibility. Additionally, the low protein content necessitates supplementation with higher-quality feed ingredients. Effectively utilizing sugarcane residues can contribute to sustainable livestock feeding practices by reducing waste and improving overall productivity.

Vegetable Crop Residues

Vegetable crop residues are an important source of moisture and fiber, particularly in regions with abundant vegetable production. Notable examples include cabbage leaves, cauliflower leaves, spinach stems, bottle gourd vines, ridge gourd vines, cucumber vines, pumpkin vines, okra stems, tomato

vines, and eggplant vines. These residues can enhance feed intake due to their moisture content, providing hydration to livestock in dry seasons. Their high fiber content also supports digestive health, promoting effective rumination in ruminants [19, 23, 69]. However, vegetable residues can be perishable and may spoil quickly, leading to inconsistent availability. Additionally, they may require careful management to ensure they are free from pesticide residues and contaminants. Incorporating vegetable crop residues into livestock diets can help reduce food waste and provide a nutritious, cost-effective alternative to traditional feed sources, supporting sustainable livestock production in Bangladesh.

CONCLUSIONS

The effective utilization of crop residues presents a significant opportunity for enhancing livestock feeding practices in Bangladesh and beyond. By transforming agricultural waste into valuable feed resources, this study underscores the potential to improve livestock productivity while promoting sustainability and reducing environmental impacts. The integration of innovative processing techniques can enhance the nutritional quality of crop residues, making them viable alternatives to conventional feed ingredients. Moreover, this approach not only addresses the economic challenges faced by farmers but also aligns with the principles of a circular economy, minimizing waste and optimizing resource use. Future research should focus on developing region-specific strategies for residue processing and utilization, as well as exploring the socioeconomic impacts on farming communities. Embracing crop residues paves the way for a more sustainable and resilient livestock sector that will meet the growing global demand for animal products while safeguarding environmental health.

Limitations

The limitations of this study include the variability in the nutritional composition of crop residues, which can be influenced by factors, such as crop type, growth conditions, and processing methods, complicating the standardization of feed formulations. Additionally, many crop residues possess inherent digestibility challenges due to their high fiber content, necessitating further processing to enhance their feed value. Economic feasibility is another concern, as the costs associated with processing and utilizing crop residues may not be justifiable for all farmers, particularly in resource-constrained settings. Furthermore, cultural acceptance of new feeding practices can impede the adoption of crop residues as livestock feed, while geographic and climatic variations can lead to disparities in the availability and quality of residues. Lastly, a lack of extensive research on the long-term impacts of crop residue utilization on livestock health and productivity presents a need for further investigation to support effective implementation.

Future Directions

Future studies should focus on developing and optimizing innovative processing methods to enhance the nutritional quality and digestibility of crop residues, such as fermentation, urea treatment, and ensiling. Conducting region-specific research can provide insights into the local availability and nutritional profiles of different crop residues, allowing for tailored feeding strategies that meet the specific needs of livestock in various agro-ecological zones. Investigating the economic viability of utilizing crop residues in livestock feeding can help assess cost-benefit ratios, market dynamics, and the impact on farmers' incomes, which can encourage adoption among livestock producers.

Promoting integrated crop-livestock systems that incorporate crop residues into livestock diets can enhance resource use efficiency and sustainability. Comprehensive studies on the nutritional composition and palatability of various crop residues can help identify optimal combinations and formulations for livestock feeding, addressing the limitations of using crop residues as a sole feed source. Evaluating the long-term impacts of utilizing crop residues on livestock health, productivity, and environmental sustainability is essential for understanding the broader implications of this approach.

Developing educational programs and workshops for farmers can facilitate knowledge transfer regarding the benefits and practices of using crop residues in livestock feeding, promoting widespread adoption. Finally, advocating for supportive policies and regulations that promote the use of agricultural waste as livestock feed can help create an enabling environment for farmers, including incentives for adopting sustainable practices. By pursuing these future directions, researchers and practitioners can enhance the sustainable utilization of crop residues in livestock feeding, contributing to improved productivity and environmental stewardship in the agricultural sector.

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