From Waste to Worth: Utilizing Agro-Residues in Climate-Smart Feed Systems to Reduce Nigeria's Agricultural Postharvest Losses

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Abstract

Agro-residue utilisation presents a transformative opportunity to reduce postharvest losses and improve livestock feed systems within climate-smart agriculture frameworks. This systematic literature review evaluates how crop by-products are repurposed for sustainable animal nutrition in Nigeria. Drawing from 75 publications screened between April and May 2025 across Scopus, JSTOR, ScienceDirect, and institutional repositories (FAO, ILRI, FMARD), the review synthesises evidence published between 2015 and 2025. Thematic analysis followed Braun and Clarke's six-step approach, with triangulation applied to balance peer-reviewed sources and grey literature. The review identified five core themes: types and regional availability of agro-residues, nutritional composition and processing innovations such as fermentation and urea-ammoniation, socioeconomic benefits including feed cost reduction and rural employment, environmental advantages such as reduced methane emissions and soil enrichment, and policy enablers and barriers shaping adoption pathways. Findings reveal that while cassava peels, maize stover, and legume haulms offer viable feed alternatives, adoption is constrained by weak infrastructure, fragmented policies, and limited access to affordable processing equipment. Recent innovations, such as community-based feed hubs and microbial detoxification, have shown measurable improvements in feed quality and climate resilience. The review recommends coordinated policy implementation, decentralised processing investments, and gender-inclusive extension systems to accelerate scale-up. These strategies are essential for embedding agro-residue valorisation into Nigeria's livestock value chain and advancing food system sustainability.

Introduction

Agriculture remains a cornerstone of Nigeria's socioeconomic framework, contributing nearly 25% to the national Gross Domestic Product (GDP) and engaging over 70% of the rural population (National Bureau of Statistics [NBS], 2022). However, systemic inefficiencies, particularly postharvest losses (PHL), threaten food security and economic stability. Studies indicate that Nigeria loses 40–50% of fresh produce at postharvest, amounting to ₦3.5 trillion annually, exacerbating food inflation and rural poverty (USAID, 2024; Ugese, 2024; BusinessDay, 2025). These losses exacerbate food insecurity and contribute to environmental degradation through inefficient biomass disposal.

Simultaneously, Nigeria's livestock sector grapples with feed shortages, with feed costs comprising over 60% of total production expenses (ILRI, 2021[a]; Poultry News Africa, 2024; Nairametrics, 2025). Ironically, despite the vast surplus of agricultural residues discarded annually, livestock farmers face escalating feed costs and availability constraints. For instance, the price of a 25 kg bag of poultry feed surged to ₦27,800 in early 2025, making profitability nearly unattainable for smallholders (Nairametrics, 2025). As Nigeria's population is projected to exceed 230 million by 2050, the urgency

to establish sustainable solutions for food production and livestock systems has become increasingly apparent (FAO, 2025).

This review critically examines the potential of agro-residues, biomass left after crop harvesting and processing, as nutritional assets for livestock feed production, thereby transforming waste into value. By incorporating the principles of the circular economy (CE) and climate-smart agriculture (CSA), agro-residue utilisation presents a strategic pathway to promote feed security, reduce food losses, and nurture sustainable agricultural practices.

Despite the abundance of agro-residues in Nigeria, their utilisation in livestock feed systems remains limited and poorly integrated into national agricultural strategies. Postharvest losses undermine food availability, while livestock producers struggle with high feed costs and restricted access to affordable alternatives. The disconnect between CSA principles and agro-residue valorisation has resulted in missed opportunities for climate resilience, economic efficiency, and environmental sustainability. Moreover, the lack of a coherent framework linking agro-residue utilisation to Nigeria's feed supply chain has hindered policy development and farmer adoption. Without targeted interventions, Nigeria risks perpetuating a cycle of waste, food insecurity, and unsustainable livestock production.

Studies bolster the plausibility of agro-residue appreciation. Akinola et al. (2015) indicate that farmers allocate a substantial proportion of crop residues to livestock feed, with legume residues comprising 64% of feed allocation and cereal residues having 26%. Similarly, findings from Kwara State demonstrated that agropastoral households actively utilise crop residues for feeding livestock and organic manure, highlighting the potential for circular agricultural practices (Ogan et al., 2024). Additionally, studies on agro-industrial by-products emphasise their untapped potential in enhancing ruminant nutrition, which could significantly reduce Nigeria's animal protein deficit (Mogaji et al., 2023). Agro-residue valorisation (converting crop by-products into functional materials) aligns with national food security objectives, environmental sustainability, and rural economic development. By reframing "waste" as "worth," this review positions agro-residue utilisation as a transformative strategy for mitigating postharvest loss, alleviating feed scarcity, and promoting resilience within Nigeria's agricultural sector. Further, it underscores the necessity of policy interventions, farmer education, and investment in agro-residue processing technologies to maximise the benefits of climate-smart feed systems.

This review aims to explore agro-residue's transformative potential in Nigeria's livestock feed systems through the lens of climate-smart and circular agriculture. The specific objectives are to: assess the extent of postharvest losses in Nigeria's agricultural sector, particularly in relation to feed scarcity and environmental degradation; evaluate the feasibility of agro-residues as alternative feed inputs for livestock; and examine the integration of CSA and circular economy frameworks in promoting sustainable feed systems and reducing greenhouse gas emissions.

Conceptual framework
Incorporating climate-smart feed systems with the principles of the circular economy

The discussions on postharvest losses have evolved significantly over the past decade, shifting beyond food spoilage concerns to a broader focus on resource efficiency, economic viability, and environmental sustainability (Affognon et al., 2015). Within this expanded perspective, the circular economy framework provides a practical strategy for converting agricultural residues into valuable assets rather than waste. According to the Ellen MacArthur Foundation (2013), the circular economy seeks to preserve the usefulness of biological materials within a closed-loop system, emphasising reuse, regeneration, and sustained value across agricultural supply chains. In Nigeria's agri-food systems, this approach is particularly relevant. Studies have shown that Nigeria generates millions of metric tons of agricultural residues annually, with huge untapped potential for feed, bioenergy, and industrial conversion (Kolawole et al., 2024; Jonathan et al., 2025). Agricultural by-products like cassava peels, maize cobs, sorghum stalks, rice bran, and oil palm fronds can be transformed into nutrient-rich animal feed using affordable processing methods (AgroNigeria, 2025). This reduces environmental hazards from indiscriminate burning and landfill dumping, while addressing persistent feed shortages (Poultry News Africa, 2024).

Climate-smart feed systems, a climate-smart agriculture (CSA) division, seek to enhance resilience, ameliorate productivity, and minimise greenhouse gas emissions via sustainable feed management strategies (Lal, 2016). These systems recycle nutrients, ensuring crop residues are reintegrated into the livestock production cycle instead of going to waste. For instance, fermented cassava peels, which are a common leftover in the South-West and Middle Belt

regions of Nigeria, can significantly improve digestibility for ruminants while also cutting down methane emissions, a major contributor to agricultural greenhouse gases (Pelemo et. al., 2024). Similarly, treating maize and sorghum stover with urea-ammoniation enhances their protein content and reduces reliance on costly synthetic feed inputs (Abubakar & Bello, 2016). This treated stover is particularly beneficial in Northern Nigeria, where dry conditions make fresh forage scarce for much of the year. By adopting these innovative practices, farmers can create more sustainable and cost-effective feeding solutions for livestock. Through such improvements, nutrient spirals are restricted, and soil luxuriance can be amplified via the return of enriched compost to croplands.
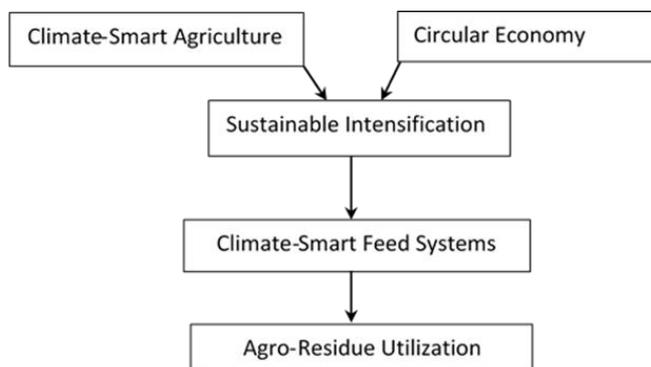

Figure 1: Conceptual Framework integrating Climate-Smart Feed Systems with the Principles of Circular Economy

Methodology

This study adopts a systematic literature review approach, informed by the PRISMA 2020 Statement, to explore how agro-residue utilisation can reduce postharvest losses and support climate-smart livestock feed systems in Nigeria. The review integrates evidence from peer-reviewed journal articles, institutional reports, and high-quality grey literature to construct a balanced and multidisciplinary perspective. The search process was conducted between April 1 and May 28, 2025, using databases including Google Scholar, ScienceDirect, Scopus, and JSTOR, alongside institutional repositories from FAO, ILRI, IITA, and Nigeria's Federal Ministry of Agriculture and Food Security.

The search strings combined thematic keywords and Boolean operators such as "agro-residues AND livestock feed AND Nigeria," "climate-smart agriculture AND animal nutrition," "circular economy AND feed systems," and "postharvest losses AND feed innovation." Eligible publications were limited to English-language sources published between 2015 and 2025, emphasising Nigerian agriculture and Sub-Saharan African analogues. Studies were included based on relevance to agro-residue valorisation in livestock feed systems. At the same time, documents lacking scientific validation, narrowly focused on industrial or energy applications, or offering redundant findings were excluded. An initial set of 140 papers was retrieved from credible sources, including Google Scholar, Scopus, and ILRI. These records underwent a rigorous screening process beginning with title and abstract evaluation to determine relevance. Following this, 65 records were excluded due to a non-feed or energy-centric focus, duplicate or redundant content, and an emphasis on industrial or agro-energy uses unconnected to livestock feed. The remaining studies were assessed through full-text review, retaining 75 publications deemed suitable for thematic synthesis. A PRISMA flow diagram (Figure 2) illustrates the step-by-step breakdown of this selection process, from identification to final inclusion.

Triangulation was applied across three source categories to ensure analytical robustness: peer-reviewed journal articles, institutional reports and policy briefs, and grey literature, including NGO publications and technical bulletins. Grey literature was assessed using the AACODS checklist, evaluating authority, accuracy, coverage, objectivity, date, and significance to determine its reliability and relevance. Peer-reviewed sources were weighted more heavily in thematic synthesis, though grey literature was crucial in capturing emerging innovations and field-level practices not yet reflected in academic publishing. Cross-source validation was applied within each theme to verify consistency, and reflexive interpretation ensured careful handling of conflicting findings.

Thematic analysis followed Braun and Clarke's six-step approach: familiarisation with the data, initial coding, identifying and refining themes, theme definition, and final synthesis. Inter-coder reliability checks were conducted to validate coding consistency, and reflexivity was maintained throughout to mitigate bias and enhance objectivity. Five core themes emerged from the synthesis: types and availability of agro-residues, nutritional composition and processing technologies, socioeconomic impacts on farmers, environmental sustainability and climate mitigation benefits, and policy frameworks that support or hinder adoption. These themes collectively frame the review's insights into how strategic agro-residue utilisation can strengthen Nigeria's livestock feed supply chain, reduce postharvest losses, and promote sustainable agricultural development.

Figure 2: PRISMA-style Flowchart
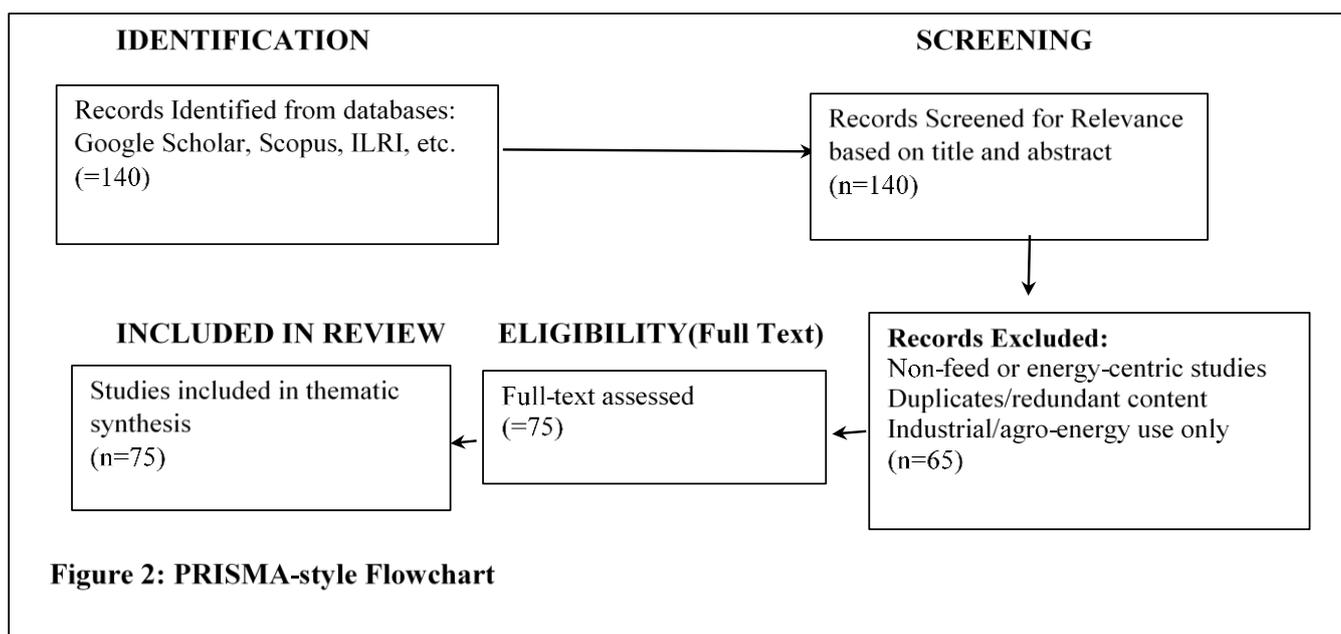
Findings
Recent research in Nigeria highlights the growing economic and environmental benefits of integrating agro-residues into livestock feed systems. Initiatives led by the International Livestock Research Institute (ILRI), in partnership with the Federal Ministry of Agriculture and Food Security (FMA&FS), have expanded access to nutrient-rich livestock feed, particularly in cassava-producing states such as Oyo, Ogun, and Benue (ILRI, 2019). These programs have strengthened smallholder farming and helped reduce reliance on costly commercial feeds.

Tehinloju & Fasina (2024) further reveal a significant shift among Nigerian farmers toward climate-smart feed alternatives, driven by escalating feed prices and climatic disruptions. Their study highlighted increased use of cassava and maize residues in livestock nutrition, with participating farmers reporting improved feed efficiency, fewer seasonal feed shortages, and higher animal productivity. Beyond Nigeria, experimental evidence from Ghana and Kenya underscores the scalability of circular feed models. Buabeng et al. (2024) show that integrating postharvest residues into livestock feed systems has reduced feed costs by up to 40%, supporting stable livestock production and improving food security. These findings highlight the scalability of agro-residue utilisation and reinforce the case for its broader institutional adoption in Nigeria

Types and regional availability of agro-residues
The diverse agricultural landscape of Nigeria produces a wide variety of crop residues, each with distinct nutritional properties and biochemical compositions. Despite their potential, many agro-residues remain underutilised or discarded, even though they could significantly enhance sustainable livestock feeding. Recognising and understanding the diversity of these residues enables farmers to improve feed efficiency, enhance animal health, and contribute to a more resilient agricultural sector. Scaling up their use reduces feed costs and promotes environmental sustainability by minimising agrarian waste.

Cereal crop residues, particularly maize and sorghum stovers, are highly prevalent in Northern Nigeria. Abubakar & Bello (2016) demonstrated that applying

urea-based pre-treatment improves digestibility and nitrogen content, an essential adaptation during the dry season when forage availability is low. According to Ajala et al. (2018), the generation of cassava peels in Nigeria is estimated to be 9 million metric tons annually. However, some of the estimates are higher depending on the processing capability. These are rich in residual starch, containing cyanogenic glycosides, posing toxicity risks if not adequately treated. Sogunle et al. (2020) emphasised that microbial fermentation and drying techniques are crucial for detoxification and nutrient enrichment, enhancing their safety for livestock consumption.

Legume residues, including groundnut haulms and cowpea vines, are especially vital during periods of forage scarcity. Trials conducted by the International Livestock Research Institute (ILRI, 2021b) confirmed their high protein content and palatability, making them integral components of adaptive feeding strategies in the semi-arid zone. Rice by-products, including rice bran and husks, are abundantly produced in states like Ebonyi and Kebbi. Ademola et al. (2018) found that rice bran contains appreciable crude protein when appropriately blended with complementary feed ingredients. Oil palm residues, such as fronds, fibre, and press cakes, are commonly found in Southern Nigeria. Akinfemi & Ogunwole (2012) observed that although these residues contribute valuable fibre and energy, their poor digestibility limits utility in livestock diets unless they undergo chemical or mechanical enhancement.

Nutritional composition and processing technologies

When adequately treated, agro-residues offer substantial nutritional value and serve as vital components of sustainable livestock feeding systems in Nigeria. These residues, derived from crops such as cassava, maize, sorghum, rice, legumes, citrus, plantain, and oil palm, provide digestible energy, fibre, and moderate protein but often require detoxification or mechanical enhancement to optimise their feed potential.

Cassava peels, abundant in the South-West, are rich in residual starch but contain cyanogenic glycosides that necessitate detoxification. Techniques such as yeast fermentation and effective microorganisms (EM) have proven effective; Gunun et al. (2023) reported a crude protein increase from 2.1% to 13.7% after 14 days of fermentation. Sogunle et al. (2020) and Egbune et al. (2023) further emphasised microbial and solid-state fermentation methods as critical for improving

digestibility and nutrient bioavailability. Maize and sorghum stovers, widely available in Northern Nigeria, are fibrous and low in protein. However, urea-based treatments significantly improve nitrogen content and feed conversion efficiency (Abubakar & Bello, 2016; Omunizua et al., 2023). These improvements promote their viability as feed during forage-scarce seasons.

Rice bran, a milling by-product, contains up to 15% crude protein and performs well when blended appropriately (Ademola et al., 2018). In contrast, rice husks contain high silica levels, presenting digestibility challenges unless pre-treated effectively (Unigwe & Mba, 2023). Legume residues, including groundnut haulms and cowpea vines, are highly palatable and protein-rich. ILRI (2021b) and Yusuf et al. (2022) confirmed their efficacy as dry-season feed supplements. Though rich in energy and fibre, oil palm by-products suffer from poor digestibility, a challenge addressable through chemical or mechanical processing (AU-IBAR, 2025).

Experimental validation studies in Table 1 reinforce the nutritional potential of these residues. Tona et al. (2015) highlighted how citrus pulp, bean waste, maize stover, and rice husk supply essential nutrients for ruminants and yield favourable fermentation profiles. Adedokun & Akuma (2015) demonstrated the viability of maize husk and plantain leaves as alternative feed inputs, with significant implications for cost savings and sustainable production. Yusuf et al. (2022) examined various crop residues' mineral content and dry matter composition across Northern Nigeria, verifying their utility under climate-smart systems. Proven techniques such as ensiling, sun-drying, and chemical treatment with urea and molasses can enhance storage stability, reduce anti-nutritional risks, and improve digestibility (Onwuka & Akinsoyinu, 2016). These innovations are essential for transforming agro-residues from waste into valuable feed inputs.

Technologies and innovations in feed processing

Technological innovations are steadily transforming agro-residues from waste by-products into viable and nutrient-rich components of livestock feed systems. These processing methods in Table 2 unlock latent nutritional potential while enhancing digestibility, storability, and overall feed efficiency. Among the most impactful innovations is urea-ammoniation, which chemically enriches fibrous residues such as maize stover. This method has increased crude protein by 30–50%, improving palatability and rumen utilisation (Gunun et al., 2023). In parallel, microbial

Table 1: Nutritional Profiles of Selected Agro-Residues Used in Livestock Feeding

Agro-Residue	Crude Protein (%)	Crude Fiber (%)	Metabolizable Energy (kcal/kg)	Key Anti-Nutritional Factors
Cassava Peels	4.67, 13.7 (fermented)	9.50	2850	Cyanogenic glycosides
Maize Stover	9.15	32.33	2700	Low digestibility
Rice Bran	15.00	12.00	2860	Silica (in husks)
Groundnut Haulms	8.61	24.33	2550	Phytates, tannins
Cowpea Vines	12.36	18.33	2650	Saponins, alkaloids
Citrus Pulp	6.50	10.00	2700	Pectin, limonene
Plantain Leaves	8.38	10.67	2600	Oxalates, tannins

Sources: Tona et al. (2015); NIAS Feed Ingredient Listing (2021); ILRI (2021); Yusuf et al. (2022)

fermentation of cassava peels using Saccharomyces cerevisiae or effective microorganisms (EM) has proven effective in detoxifying cyanide compounds and boosting nutrient density (Egbune et al., 2023; Aro et al., 2022). Pelletisation further enhances feed value by improving bulk density and reducing postharvest losses; recent infrastructure investments like Nutreco's 2024 feed facility in Ibadan reflect a growing commitment to localising pelletizing technology for fish and poultry sectors. Additionally, the emergence of community-based Feed Innovation Centres, championed by Heifer International (2021), has created decentralised hubs where cooperatives and micro-enterprises process agro-residues using accessible technologies such as choppers, mixers, fermenters, and pelletizers. These centres expand feed access and drive entrepreneurship and farmer capacity-building (Heifer International, 2021; AU-IBAR, 2025).

Despite these advancements, barriers persist: limited access to energy, unaffordable equipment, minimal technical training, and infrastructural deficits, especially in transport and rural electrification. FAO (2021) and AU-IBAR (2025) note that these bottlenecks constrain feed system scalability and food security outcomes. Overcoming these challenges requires inclusive public-private partnerships, targeted subsidies, expanded farmer training, and strategic investment in rural infrastructure. Unlocking these innovations for smallholders is critical to actualising climate-smart feed systems across Nigeria.

Table 2: Innovations and Their Impact on Agro-Residue Feed Value

Technology	Residue Targeted	Benefit
Urea-Ammoniation	Maize/Sorghum Stover	+30–50% Crude Protein
Microbial Fermentation	Cassava Peels	Detoxification + Protein Boost
Pelletization	Mixed Residues	Longer Shelf-Life, Bulk Storage
Community Processing	Multiple	Local Employment + Scale-Up

Source: Egbune et al. (2023); Gunun et al. (2023); Nutreco (2024); AU-IBAR (2025)

Socioeconomic impacts on farmers

Agro-residue valorisation is pivotal in strengthening rural economies, offering new income streams and employment opportunities, especially for women and youth through small-scale feed processing initiatives (Oladeji et al., 2021). These practices enhance livestock productivity and increase access to affordable animal protein in food-insecure regions by lowering feed costs. Community-led cooperatives and localised feed markets foster grassroots innovation and support inclusive enterprise development. Despite its potential, adoption is hindered by persistent structural barriers. Labour-intensive processing methods, limited mechanisation, and inadequate access to capital constrain scalability. Gender disparities further restrict women's participation in feed value chains due to unequal access to land, finance, and equipment. Poor transport infrastructure and weak aggregation systems impede market access, especially in remote areas (World Bank, 2022). Unlocking the full potential of agro-residue enterprises requires strategic investment in inclusive innovation, rural logistics, and gender-responsive agro-feed programs. Prioritising capacity-building and equitable policy implementation can ensure that marginalised communities benefit from the economic and nutritional value.

Environmental sustainability and climate mitigation benefits

Agro-residue utilisation contributes significantly to environmental sustainability by reducing greenhouse gas emissions and promoting regenerative agricultural practices. The open burning and landfill disposal of crop residues are significant sources of methane and carbon dioxide emissions in Nigeria. By redirecting these residues into livestock feed systems, farmers can mitigate climate burdens while improving resource efficiency (FAO, 2016; Pinotti, 2023). Residue-fed livestock produce nutrient-rich manure that enhances soil fertility and supports circular nutrient recovery. Composting agro-residues further enriches organic matter and soil structure, reinforcing the principles of climate-smart agriculture (Ade-Oluwa et al., 2020). These practices also reduce postharvest waste, which accounts for up to 40% of food loss in Nigeria's agricultural value chains.

Recent advances in feed detoxification technologies have expanded the safe use of residues previously considered hazardous. The European Food Safety Authority (EFSA, 2024) now provides scientific guidance for evaluating physical, chemical, and biological detoxification processes, including microbial fermentation and enzymatic hydrolysis, which are increasingly applied to cassava peels and oilseed by-products. In parallel, climate-smart feed trials have demonstrated measurable reductions in methane emissions and improvements in feed conversion efficiency. For example, Gunun et al. (2023) showed that yeast-fermented cassava peels reduced feed costs by 32% and increased crude protein content from 2.1% to 13.7%, lowering enteric methane output in goat trials. Similarly, Shah et al. (2025) emphasised that integrating feed efficiency with waste management, such as anaerobic digestion and composting, can transform livestock waste into biogas and organic fertiliser, reducing emissions and enhancing soil health. These innovations align with global efforts to decarbonise agriculture and support Nigeria's transition toward climate-resilient livestock systems. By adopting circular feed models and detoxification protocols, farmers can reduce environmental footprints while improving productivity and food security.

Institutional and policy landscape supporting agro-residue feed systems

The institutional and policy landscape underpinning agro-residue-based feed systems in Nigeria is gradually evolving. Yet, it continues to be hindered by fragmentation, limited inter-agency collaboration, and inconsistent policy implementation. Several government and non-governmental actors play strategic roles across the agro-feed value chain. The Nigerian Stored Products Research Institute (NSPRI) contributes through its postharvest loss reduction research and the dissemination of improved preservation and storage technologies to reduce spoilage and extend the usability of residues (Ibrahim et al., 2022). The Federal Ministry of Agriculture and Food Security (FMA&FS) anchors broader livestock development agendas, notably the National Livestock Transformation Plan and the Value Chain Development Programme. Although these programs do not directly target agro-residues, they support infrastructure upgrades and capacity-building efforts that indirectly benefit alternative feed initiatives (FMAFS, 2025).

Regulatory oversight by the National Agency for Food and Drug Administration and Control (NAFDAC) ensures compliance with feed safety standards and nutritional benchmarks for processed residues. Yet, its enforcement mechanisms remain weak, particularly at sub-national levels, where inspection systems are under-resourced and irregular. One of the most compelling collaborative efforts in recent years is the Cassava Peel Transformation Project, jointly implemented by the International Livestock Research Institute (ILRI), Synergos, and FMA&FS. This initiative exemplifies the power of public-private partnerships in scaling innovation, bridging gaps in adoption, and translating agro-residue technologies into commercially viable products across multiple states (ILRI, 2019).

However, several systemic gaps persist. The National Feed Policy (2019) explicitly identifies alternative feed sources such as agro-residues as priority areas. Nevertheless, its implementation has been sluggish, constrained by inadequate budgetary allocation, limited institutional capacity, and underdeveloped monitoring frameworks. Beyond these challenges, the lack of policy synergy between agriculture, environment, and rural development ministries has obstructed integrated execution and slowed the scale-up of climate-smart feed systems (FAO, 2021). This disjoint policy, combined with insufficient engagement of private-sector actors and extension services, undermines efforts to position agro-residues as central elements in sustainable livestock nutrition.

Addressing these barriers requires establishing a cohesive multi-stakeholder platform that bridges research institutions, policy bodies, private processors,

and community-level actors. Through harmonised strategy, transparent governance, and responsive policy action, Nigeria can unlock the full potential of agro-residue valorisation and embed it within a transformative, climate-adaptive livestock feed framework.

Limitations of the study and areas for further research

This review highlights the potential of agro-residue utilisation in Nigeria's livestock feed systems but notes several limitations. Reliance on secondary data limits empirical validation of feed efficiency and climate impact claims. Methodological inconsistencies across sources affect comparability, with most studies focused on cassava peels and maize stover, overlooking residues like millet stalks, yam peels, and oil-seed cakes. Data is skewed toward the South-West and North-Central zones, leaving other regions underrepresented. A lack of real-time data on farmer adoption and private-sector innovations hampers tracking of emerging trends.

Future research should prioritise field trials on nutrient recovery, methane reduction, and feed conversion using diverse residues. Evaluating decentralised feed hubs, gendered access to agro-feed technologies, and long-term impacts on soil and biodiversity will better inform inclusive and climate-smart agricultural policies.

Conclusion

Agro-residue utilisation represents a strategic pathway toward sustainable livestock nutrition and resource-efficient agriculture in Nigeria. Through innovative processing technologies, nutrient-rich residues once considered waste are now integral to climate-smart feed systems, supporting environmental sustainability, reducing postharvest losses, and fostering inclusive rural economies. However, scaling adoption requires coordinated policy action, infrastructural investment, and equitable engagement of farmers, especially women and youth. When positioned within a circular bioeconomy, agro-residues address feed scarcity and contribute to resilient food systems and long-term ecological balance.

Recommendations

Unlocking the full potential of agro-residue utilisation in Nigeria's livestock sector demands cohesive and inclusive strategies. First, stronger multi-agency coordination is vital, bringing together FMA&FS, NAFDAC, ILRI, NSPRI, and state-level actors to harmonise research, regulation, and policy implementation. Expanding decentralised feed processing hubs through cooperative-led models can enhance accessibility to pelletizers, fermenters, and drying equipment, especially for women and youth entrepreneurs. Training and extension services should be strengthened, and residue-based feed modules should be integrated into agricultural advisory systems and demonstration platforms. Operationalising the National Feed Policy requires timely budgetary allocations, measurable milestones, and embedded monitoring frameworks that prioritise rural uptake. Investment in climate-smart feed trials and circular nutrient systems can further advance Nigeria's emission-reduction goals while supporting adaptive livestock systems. Gender-responsive programming must provide women access to assets, leadership roles, and market opportunities across the value chain to ensure equity.

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