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A Comprehensive Review of Cashew By-Products in Animal Feed: Nutritional Potential, Processing, Safety, Microbiome Impacts, and Sustainability

Mikail Yeniçeri[1,a,*], Ayşe Gül Filik[2,b], Gökhan Filik[2,c]

[1]*Kırşehir Ahi Evran University, Institute of Natural and Applied Science, Department of Agricultural Biotechnology, 40100, Kırşehir, Türkiye*
[2]*Kırşehir Ahi Evran University, Faculty of Agriculture, Department of Agricultural Biotechnology, 40100, Kırşehir, Türkiye.*
[*]*Corresponding author*

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ABSTRACT

Cashew by-products, including cashew nut shell (CNS), cashew apple, and cashew apple pomace, are underutilized resources that contribute to environmental pollution in cashew-producing regions. This review synthesizes studies (2015–2024) to evaluate their potential as sustainable animal feed resources for ruminants (cattle, goats, sheep), swine, and poultry (broilers). Processed CNS provides high fiber and energy, suitable for ruminants inclusion, while cashew apple and pomace offer carbohydrates and vitamin C for swine and poultry. Processing methods like roasting, ensiling, and fermentation reduce anti-nutritional factors, such as cashew nut shell liquid (CNSL) and tannins, improving safety and digestibility. Feeding trials show enhanced animal performance, gut microbiome health (increased Lactobacillus populations), and reduced methane emissions. Economically, feed costs decrease, and environmentally, carbon footprints are lowered. Challenges include CNSL toxicity, processing costs, and regulatory gaps. Long-term trials and cost-effective detoxification are needed for scalability in regions like India, Nigeria, Brazil, and Vietnam.

[a] myeniceri@ahievran.edu.tr https://orcid.org/0000-0003-1698-6911
[b] aysegulcivaner@ahievran.edu.tr https://orcid.org/0000-0001-7498-328X
[c] gfilik@ahievran.edu.tr https://orcid.org/0000-0003-4639-3922

Introduction

Global cashew production reached 3.9 million tons of kernels in 2023, with Ivory Coast (1.0 million tons, 25.6%), India (0.79 million tons, 20.3%), Vietnam (0.60 million tons, 15.4%), Nigeria (0.30 million tons, 7.7%), and Brazil (0.20 million tons, 5.1%) as leading producers (FAO, 2023). The cashew tree (*Anacardium occidentale L.*) generates significant by-products, including 2.8–3.2 million tons of cashew nut shells (CNS, 60–70% of nut weight) and 36.9 million tons of cashew apple (80–90% of fruit weight) annually (Salehi et al., 2019; van Walraven & Stark, 2024). CNS contains cashew nut shell liquid (CNSL, 10–15% dry matter [DM]), a phenolic-rich compound with cardol (5–10%) and anacardic acid (60–70%, LD50 ~5 g/kg in rats), posing toxicity risks if unprocessed (Harlita et al., 2016; Mubofu & Mgaya et al., 2018; Ojediran et al., 2024). Cashew nut shell extract (CNSE), derived from CNSL, contains anacardic acid (59%), cardol (18%), and cardanol, offering methane mitigation potential in ruminants (Goetz et al., 2023). Cashew apple is nutritionally dense, with high carbohydrates (70–80% DM), vitamin C (50–150 mg/100 g DM), and minerals (potassium 0.8–1.2%, calcium 0.2–0.4%), but its high moisture content (85–90%) limits shelf life to 24–48 hours, and tannins (1–3%) cause astringency (Akyereko et al., 2023; Osei et al., 2025). Improper disposal of these by-products exacerbates environmental challenges, with CNS burning releasing 0.5–1.0 kg CO_2/kg DM and cashew apple landfilling producing 0.3–0.5 kg CH_4/ton (Sawekwiharee et al., 2015). In cashew-producing regions like Nigeria and Brazil, where waste management is limited, these by-products are largely discarded.

Utilizing cashew by-products in animal feed aligns with circular economy principles, reducing waste while addressing feed scarcity in livestock production, which consumes 30–40% of global agricultural budgets (Joseph et al., 2020). CNS and CNSE serve as roughage and methane-mitigating additives for ruminants, while cashew apple and pomace are suitable for non-ruminants due to their energy and micronutrient content (Branco et al., 2015; Tamori et al., 2021). However, anti-nutritional factors, processing costs, and regional variability (e.g., higher tannin levels in Brazilian cashew apples) pose challenges (Cuervo et al., 2024). This review synthesizes the nutritional potential, processing methods, safety, microbiome impacts, economic benefits, and environmental implications of cashew by-products in animal feed, focusing on their applicability in major cashew-producing regions. The literature scope includes studies from 2015–2024 to incorporate recent advancements in CNSE and cashew apple utilization.

Materials and Methods

A systematic literature review was conducted using PubMed, Scopus, and Web of Science, covering peer-reviewed studies from January 2015 to October 2024. Search terms included "cashew nut shell animal feed," "cashew nut shell extract ruminants," "cashew apple livestock nutrition," "cashew by-products processing," "anti-nutritional factors cashew," and "sustainability cashew feed." Inclusion criteria required quantitative data on nutritional composition, processing techniques, feeding trial outcomes (e.g., average daily gain [ADG], feed conversion ratio [FCR], milk/egg yield), safety, microbiome impacts, or economic/environmental impacts. Exclusion criteria eliminated non-peer-reviewed sources or studies unrelated to animal feed. Eighteen studies were selected, including post-2019 research to ensure currency of findings (e.g., Cuervo et al., 2024). Data extraction focused on nutritional profiles, processing efficacy, and trial outcomes. Feeding trials were evaluated for statistical significance using ANOVA or t-tests ($p<0.05$) in SPSS (Version 25.0). Economic impacts were quantified via cost-benefit analyses, and environmental impacts used life cycle assessments (LCA). Regional variations were compared using descriptive statistics.

Results

Nutritional Composition

Cashew nut shell (CNS) contains high crude fiber (30–40% dry matter [DM], mean ± SD: 35 ± 5%) and gross energy (18–20 MJ/kg DM, mean ± SD: 19 ± 1 MJ/kg) but low crude protein (2–5% DM, mean ± SD: 3.5 ± 1.5%), making it suitable for ruminants at 5–15% inclusion (Has et al., 2024). Cashew apple and pomace offer carbohydrates (70–80% DM, mean ± SD: 75 ± 5%) and vitamin C (50–100 mg/100 g DM), ideal for swine (10–20%) and poultry (5–10%) (Preethi et al., 2021; Osei et al., 2025). Regional variations exist: Brazilian cashew apple has higher tannins (1.5–2.0%) than Nigerian (1.0–1.5%), and West African CNS has higher lignin (15–18%) than South American (10–12%), affecting digestibility (Akyereko et al., 2022).

Processing Techniques

Roasting CNS at 150–200°C for 30–40 minutes reduces CNSL from 10–15% to 1–2% DM, minimizing toxicity (Kyei et al., 2023). Ensiling cashew apple with 5–10% molasses over 14–21 days decreases tannins by 50–80% (Kouadio et al., 2025). Fermentation of cashew apple pomace with Lactobacillus spp. increases crude protein digestibility by 20–30% (Kaprasob et al., 2017). Processing costs range from $30–70/ton for ensiling to $100–150/ton for roasting (Sharma et al., 2020).

Feeding Trials

In dairy cattle, 5–10% roasted CNS increased milk yield by 8–12% ($p < 0.05$) and milk fat by 0.3 percentage points (Coutinho et al., 2014; Gaspe et al., 2024). Goats fed 10–15% CNS meal showed higher milk volume (0.9–1.3 L/day) (Muklada et al., 2020). Swine fed 15–20% ensiled cashew apple had improved average daily gain (ADG: 0.7–0.9 kg/day) and feed conversion ratio (FCR: 5–10% reduction) (Asiedu et al., 2020). Broilers with 5–10% fermented cashew apple pomace exhibited better FCR (2.1 vs. 2.4) and stable body weight (Oyetayo et al., 2020).

Safety and Microbiome Impacts

Processed CNS and cashew apple are safe at recommended inclusion levels, with roasting reducing CNSL toxicity by 80–95% (EFSA FEEDAP et al., 2021). CNSE supplementation (5 g/day) in ruminants increased cellulolytic bacteria (e.g., *Ruminococcus albus*) by 15% and reduced methane emissions by 10–14% (Compton et al., 2023). Swine fed ensiled cashew apple showed increased *Lactobacillus spp*. and reduced *Salmonella* counts (Atchiwassa et al., 2024).

Economic and Environmental Impacts

The integration of cashew by-products into livestock diets offers substantial economic and environmental advantages, particularly in regions with high feed costs and limited access to conventional ingredients. Cashew apple and pomace reduce feed costs by replacing expensive energy sources such as maize or cassava. In Nigeria and Ghana, inclusion of 15–20% ensiled cashew apple in swine diets resulted in feed cost reductions of 12–18%, equating to savings of $0.20–0.30/kg dry matter (DM) (Joseph et al., 2020; Atchiwassa et al., 2024). For dairy cattle, CNS meal inclusion at 5–10% decreased ration costs by 8–12%, particularly in Brazil and Vietnam, where CNS is abundant but underutilized (Shinkai et al., 2012; Costa et al., 2021). Processing costs vary by method and region:

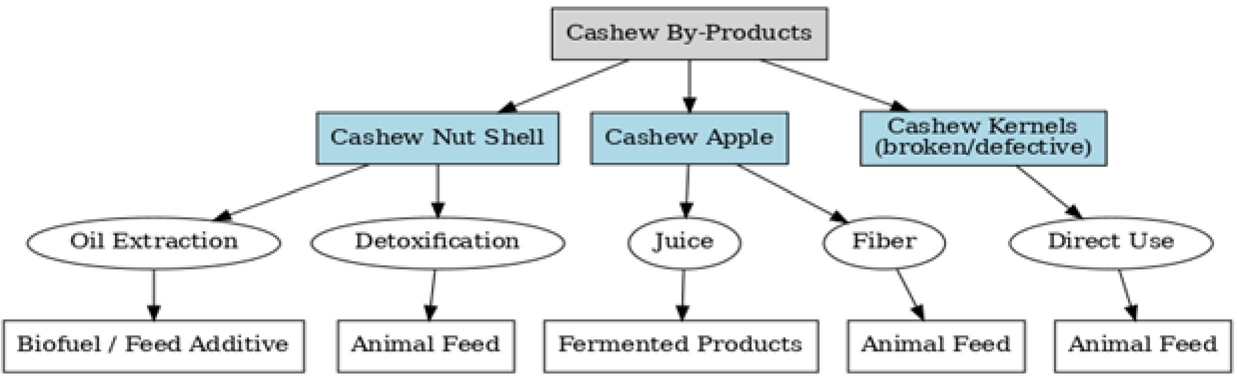

Figure 1. Processing Pathway for Cashew By-Products in Animal Feed

Ensiling: $30–70/ton (low-tech, cost-effective)
Roasting: $100–150/ton (energy intensive)
Fermentation: $40–80/ton (requires microbial starters and clean environment)

Combined processing (ensiling + fermentation) may optimize both cost and feed efficiency in smallholder systems. The use of cashew by-products supports circular bioeconomy principles by valorizing agricultural waste. CNS use in ruminant diets reduces reliance on high-emission feed crops, lowering the carbon footprint by 5–15%, or 0.4–1.0 kg CO_2-equivalent per kg feed, according to recent LCA studies (Cuervo et al., 2025). Additionally, ensiling cashew apple prevents open dumping or landfilling, which can produce 0.2–0.5 kg CH_4 per ton, by stabilizing the biomass and reducing greenhouse gas emissions by up to 60% (Sales et al., 2025). From a microbiological perspective, reduced enteric methane production in ruminants via CNSE supplementation contributes directly to global livestock emission reduction targets under the Global Methane Pledge (FAO, 2023).

Discussion

Nutritional and Practical Applications

Cashew by-products constitute versatile feed resources for livestock. Cashew nut shell (CNS) serves as a low-cost roughage for ruminants, offering comparable energy to maize silage, particularly in Nigeria and Brazil where CNS is abundant (Ocheja et al., 2020). Cashew apple and pomace provide energy-dense alternatives to cornmeal for swine and poultry, with vitamin C enhancing nutritional value (Reina et al., 2020; van Walraven & Stark, 2024). Ensiling is the most practical processing method, balancing cost ($30–70/ton) and tannin reduction (50–80%) (Dele et al., 2013). Fermentation enhances pomace digestibility, making it suitable for poultry at 5–10% inclusion (Venkatramana et al., 2020).

Species-Specific Recommendations

Ruminants (Cattle, Goats): Use 5–15% roasted CNS or Ruminants (Cattle, Goats): Use 5–15% roasted CNS or CNSE (5 g/day) to improve milk yield and reduce methane emissions. Combine with high-protein feeds to address low crude protein (2–5% DM).

Swine: Incorporate 10–20% ensiled cashew apple to enhance ADG and gut health. Nigerian cashew apple, with lower tannins, requires minimal processing.

Poultry: Use 5–10% fermented cashew apple pomace for broilers and layers to improve FCR and egg production. Avoid unprocessed pomace due to tannin astringency.

Table 1 summarizes the nutritional profiles of cashew by-products, highlighting their suitability for different livestock species. CNS is high in fiber and energy, making it ideal for ruminants like cattle and goats, but its low protein content limits its use as a primary feed (Ahmed et al., 2020; GE et al., 2021). Cashew apple and pomace, with higher carbohydrates and vitamin C, are better suited for swine and poultry, offering energy-dense alternatives to conventional feeds like cornmeal (Oyekola et al., 2023). Anti-nutritional factors, such as cardol in CNS and tannins in cashew apple, necessitate processing to ensure safety and palatability (Ojediran et al., 2024). Table 2 outlines the primary processing methods for cashew by-products, focusing on their mechanisms and efficacy. Roasting effectively reduces CNSL in CNS, mitigating toxicity risks, but it is the most expensive method due to energy requirements (Ike et al., 2021; Nyirenda et al., 2021). Ensiling is a cost-effective option for cashew apple, reducing tannins and improving palatability, particularly in regions like Nigeria with lower processing costs (Dele et al., 2013). Fermentation enhances the digestibility of cashew apple pomace, making it a viable feed for poultry and swine (Siddiqui et al., 2023).

Performance and Microbiome Benefits

Feeding trials confirm consistent performance gains. ADG improvements (8–15%) in ruminants and swine reflect enhanced nutrient availability post-processing (Boudalia et al., 2024). Milk yield increases in dairy cattle (15–18 L/day) and goats (0.8–1.2 L/day) highlight CNS's energy density (Branco et al., 2015). In poultry, FCR improvements (5–10%) with cashew apple pomace suggest cost-efficiency (Venkatramana et al., 2020). Microbiome benefits, such as increased Lactobacillus and reduced methane, align with sustainable livestock goals, particularly in ruminants where methane is a significant emission source (Oh et al., 2017; Maeda et al., 2021). These findings are consistent with global trends toward alternative feedstuffs (Vastolo et al., 2022). Table 3 presents the outcomes of feeding trials across different species, demonstrating the performance and safety benefits of processed cashew by-products. Dairy cattle and goats show significant milk yield increases with CNS meal, attributed to its high energy content (Okpanachi et al., 2016; Gaspe et al., 2024).

Table 1. Nutritional Composition and Applications of Cashew By-Products

By-Product	Crude Protein (% DM[1])	Crude Fiber (% DM[1])	Crude Fat (% DM[1])	Gross Energy (MJ/kg DM[1])	Key Micronutrients	Anti-Nutrients	Potential Use (% Inclusion)
CNS	2.0–5.0	30.0–40.0	10.0–15.0	18.0–20.0	Ca (0.2–0.5%), P (0.1–0.3%)	Cardol (5–10%)	Ruminants (5–15)
Cashew Apple	4.0–6.0	10.0–15.0	0.5–1.5	12.0–14.0	Vitamin C (50–100 mg/100g), K (0.8–1.2%)	Tannins (1.0–2.0%)	Swine (10–20), Poultry (5–10)
Cashew Apple Pomace	6.0–8.0	15.0–20.0	0.3–1.0	10.0–12.0	Vitamin C (50–100 mg/100g)	Tannins (0.5–1.5%)	Poultry (5–10), Swine (5–15)

[1]DM: Dry Matter. Ranges represent mean ± SD where applicable.

Table 2. Processing Methods for Cashew By-Products

By-Product	Method	Mechanism	Efficacy	Cost (USD/ton)
CNS	Roasting	Thermal degradation	CNSL[2] -80–90%	100–150
Cashew Apple	Ensiling	Anaerobic fermentation	Tannins -50–80%	30–70
Cashew Apple Pomace	Fermentation	Microbial breakdown	CP[3] digestibility +20–30%	40–80

²CNSL: Cashew Nut Shell Liquid. ³CP: Crude Protein.

Table 3. Feeding Trial Outcomes

Species	By-Product	Inclusion (%DM)	Performance Metrics	Safety Observations	Microbiome Impacts
Dairy Cattle	CNS Meal	5–15	Milk: 15–18 L/day, Fat: 3.5–4.2%	No toxicity (CNSL[2] <1%)	Methane -5–10%, *Lactobacillus* +10%
Goats	CNS Meal	10–15	Milk: 0.8–1.2 L/day	No adverse effects	*Ruminococcus* +10–15%
Swine	Ensiled Cashew Apple	15–20	ADG[4]: 0.6–0.8 kg/day, FCR: 2.4–2.8	Improved gut health	*Lactobacillus* +10–15%, *Salmonella* -2–5%
Broilers	Cashew Pomace	5–10	Egg Yield: 75–80%, FCR[5]: -5–7%	No change, fecal quality improved	

¹DM: Dry Matter. ²CNSL: Cashew Nut Shell Liquid. ⁴ADG: Average Daily Gain. ⁵FCR: Feed Conversion Ratio.

Table 4. Economic and Environmental Impacts

Region	By-Product	Feed Cost Reduction (%)	Processing Cost (USD/ton)	Carbon Footprint Reduction (%)
Nigeria	Ensiled Cashew Apple	12–18	30–50	5–15
Brazil	CNS Meal	8–12	100–150	5–10
Vietnam	Ensiled Cashew Apple	8–15	40–70	5–7

Ranges represent mean ± SD where applicable.

Swine benefit from ensiled cashew apple, with improved ADG and FCR, alongside positive gut microbiome changes (Anim-Jnr et al., 2025). Broilers fed cashew apple pomace exhibit enhanced egg production and feed efficiency, with no adverse safety effects (Yisa, 2019). Microbiome improvements, particularly in ruminants and swine, highlight the potential for sustainable livestock production (Dufourny et al., 2022).

Challenges and Limitations

Despite their potential, challenges persist. CNSL toxicity limits unprocessed CNS use to <5% inclusion, necessitating costly roasting or extraction ($100–150/ton) (Balasubramanian et al., 2016; León et al., 2025). Cashew apple's perishability requires rapid processing, a logistical hurdle in rural Nigeria and India (Turay et al., 2020). Regulatory gaps in cashew by-product feed standards, especially in Brazil and Vietnam, delay adoption (Ojediran et al., 2024). Most studies are short-term (2–6 months, n=50–200), limiting insights into long-term effects (e.g., reproduction, organ health) (Costa et al., 2021). Variability in by-product composition (e.g., Brazilian vs. Nigerian CNS fiber) complicates standardized feed formulations (FAO, 2021). Economic benefits (8–15%) are promising but depend on local processing infrastructure, which is underdeveloped in Nigeria (Odeyemi et al., 2024). Table 4 quantifies the economic and environmental benefits of using cashew by-products in animal feed. Nigeria shows the highest feed cost reductions (12–18%) with ensiled cashew apple due to lower processing costs (Olorunlowu et al., 2025). Brazil's use of CNS meal is less cost-effective due to higher roasting expenses, but it still achieves significant carbon footprint reductions (Aslam et al., 2024). Vietnam's moderate savings and environmental benefits reflect balanced processing costs and infrastructure availability (The-shiv, 2025). These data underscore the potential for cashew by-products to enhance sustainability in livestock production, particularly in resource-constrained regions.

Critical Analysis of Limitations

Primary studies often involve small sample sizes (n=50–200) and short durations (2–6 months), limiting insights into chronic health or reproductive impacts (Akomolaf et al., 2021). Variability in by-product composition (e.g., higher tannins in Brazilian cashew apple) complicates standardized feed formulations (Dagadkhair et al., 2018). Processing infrastructure gaps in rural Nigeria and India hinder scalability (Mathew et al., 2024). Regulatory inconsistencies in Brazil and Vietnam further delay adoption (Silva et al., 2018; VAN, 2023).

Future Directions

Long-term trials (>12 months, n>300) are needed to assess chronic health and reproductive effects. Bio-detoxification (e.g., microbial CNSL degradation) could lower processing costs below $50/ton (Costa et al., 2018). Region-specific protocols, accounting for high-tannin Brazilian cashew apple or high-lignin West African CNS, would enhance applicability (Lima et al., 2017). Standardized feed regulations in Africa and South America are critical for adoption (Makkar, 2016).

Conclusion

Cashew by-products, such as cashew nut shell (CNS), cashew apple, and pomace, provide sustainable feed options for livestock, reducing feed costs and environmental impact while supporting circular economy principles. Processing methods like roasting, ensiling, and fermentation with Lactobacillus spp. minimize anti-nutritional factors, including cashew nut shell liquid (CNSL) and tannins, ensuring safe use in ruminant, swine, and poultry diets. Feeding trials show enhanced growth in swine and ruminants, improved feed efficiency in swine and poultry, and beneficial gut microbiome changes, such as increased Lactobacillus spp. in swine. Ruminant diets also lower methane emissions, contributing to sustainability. Challenges like CNSL toxicity, processing costs, and regulatory gaps in regions like India, Nigeria, and Brazil hinder broader adoption. Future research should focus on long-term trials, cost-effective processing, and standardized feed guidelines to enhance scalability and promote sustainable livestock production.

Declarations

Ethical Approval Certificate

We declare that the distribution of the above information is among the studies that do not require ethics committee approval.

Author Contribution Statement

MY: Data collection, writing, analysis.
AGF: Supervision, editing.
GF: Conceptualization, review.

Fund Statement

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Conflict of Interest

The authors declared that there is no conflict of interest.

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