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FROM WASTE TO FEED: ENHANCING SUSTAINABILITY IN RUMINANT NUTRITION THROUGH CASHEW APPLE UTILIZATION – A REVIEW*

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Abstract

Growing global demand for livestock products has intensified the need for sustainable feed resources in ruminant nutrition, particularly in developing regions. With feed costs comprising up to 75% of production expenses, exploring alternative feed sources can offer both economic and environmental benefits. This study explored the potential of cashew apple (CA) as a novel and sustainable by-product for ruminants by reviewing relevant articles from databases such as Scopus, Web of Science, PubMed, and Google Scholar. CA has an average proximate composition (dry matter basis) of 130 g/kg crude protein, 71.7 g/kg crude fibre, 61.2 g/kg ether extract, 49.3 g/kg ash, 640 g/kg nitrogen free extract, and 2973 kcal/kg metabolizable energy, making it a valuable addition to ruminant diets. It can reduce reliance on traditional and high-cost feed sources and mitigate environmental pollution by reducing waste and contributing to circular agricultural practices. However, limitations such as high moisture content in fresh cashew fruit, seasonal availability, and rapid spoilage necessitate effective processing methods. There is a knowledge gap on the use of CA in ruminant diets, and there is a need to assess its impact on ruminal pH, short-chain fatty acids production, ammonia production, other rumen fermentation profiles, and animal performance. Based on the quantitative data of this study about the proximate composition of CA and some animal studies, it could be a viable and eco-friendly supplement to the ruminant diets. Addressing its storage and preservation challenges can unlock its potential in diversified, eco-friendly ruminant systems.

Key words: ruminant nutrition, alternative feedstuff, cashew apple, cashew pulp, sustainability

Livestock production has gained increased attention due to the rising demand for livestock products driven by population growth, urbanization, and socioeconomic development (Thornton, 2010; Ojediran et al., 2025). The livestock business is progressively organized into large market chains that engage at least 1.3 billion people worldwide and directly support the livelihoods of at least 600 million impoverished smallholder farmers in developing nations (Khade et al., 2021). With the human population projected to reach 9.8 billion by 2050, with an estimated range of 7.96 to 10.46 billion (United Nations, 2017), there is growing emphasis on increasing the productivity of the enterprise. While livestock production is receiving increasing attention, feeding cost remains one of its major limitations, accounting for 65 to 75% of the total cost of production (Okonkwo et al., 2022). The identification of low-cost feed ingredients and sustainable feedstuffs for livestock is one potential solution to the nutritional challenges facing the livestock production industry (Benoit and Mottet, 2023). The key grains used as feedstuffs are tremendously facing strong competition from human nutrition and the biofuel industry, highlighting the need to explore unconventional and drought-resistant alternatives, such as cashew (*Anacardium occidentale*) and its by-products, because of its deep root system and its water-storing ability (Costa et al., 2021).

Cashew apple (CA), often known as cashew pulp, is derived from the edible portion of the fruit after the juice

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processing industries extract the liquid (Ojediran et al. 2024 a). This fleshy fruit of the cashew tree has traditionally been considered waste and discarded (Aslam et al., 2024). The pulp, skins, and other leftover fruit components from CA comprise most of this waste (Dao et al., 2021). Due to its high moisture content when freshly harvested, CA waste can present environmental issues such as water and soil pollution, if not handled appropriately (Aslam et al., 2024; van Walraven and Stark, 2024). However, recent studies have demonstrated this by-product as a potential feedstuff for livestock due to its good nutritional value, containing crude protein, crude fat, minerals (calcium, magnesium, potassium), and vitamins such as C (Oliveira et al., 2020; Akyereko et al., 2023). In addition, CA has a low lignin composition (de França Serpa et al., 2020), making it highly digestible and palatable, especially in ruminant feeding. Despite its potential as a feedstuff for livestock, CA faces several challenges, including seasonality, short shelf life, and high moisture content, which can lead to spoilage and fermentation (Akyereko et al., 2022). Nevertheless, developing new processing techniques, such as dehydration and ensiling, has shown promising results in preserving the nutritional quality of CA and increasing its shelf life (Liu et al., 2023).

Using CA as a ruminant feedstuff could provide a new source of feed for ruminants, promoting sustainable agricultural practices. Moreover, such by-products can constitute one of the alternative feed components in ruminant nutrition during droughts in arid and semi-arid regions where they are available. Therefore, this review explored the potential of CA as a viable commercial feedstuff for ruminants by assessing its nutritional value, benefits, and the challenges associated with its use in ruminant nutrition. A focused literature search was carried out using databases and academic search engines such as Scopus, Web of Science, PubMed, and Google Scholar. Although no formal systematic review protocol was followed, a deliberate effort was made to gather relevant studies that specifically or indirectly addressed the use of CA in animal nutrition, particularly in ruminant feeding. The search strategy was designed to capture a broad yet relevant range of studies, using combinations of keywords such as "cashew apple", "cashew pomace", "cashew pulp", "cashew by-products", "ruminant, animal feed", and "animal nutrition". Boolean operators (AND/OR) and truncation symbols were applied as appropriate for each database (for example, "cashew apple" AND "ruminant feed", "cashew" AND "animal nutrition"). These were used in various permutations across databases to capture a broad spectrum of research. The selection of articles was based on relevance to the topic rather than predefined criteria. Emphasis was placed on studies discussing the nutritional composition, processing methods, feeding trials, and potential applications of CA in animal diets. The search yielded approximately 85 articles, from which six studies indexed in Scopus directly addressed the use of CA in ruminant diets. A broader search in Google Scholar identified 8–10 articles of partial relevance, while about 32 articles examined CA in the context of general animal nutrition, particularly monogastric species. These findings formed the core basis of our critical analysis, helping to identify both the potential and limitations of CA as feedstuff for ruminants.

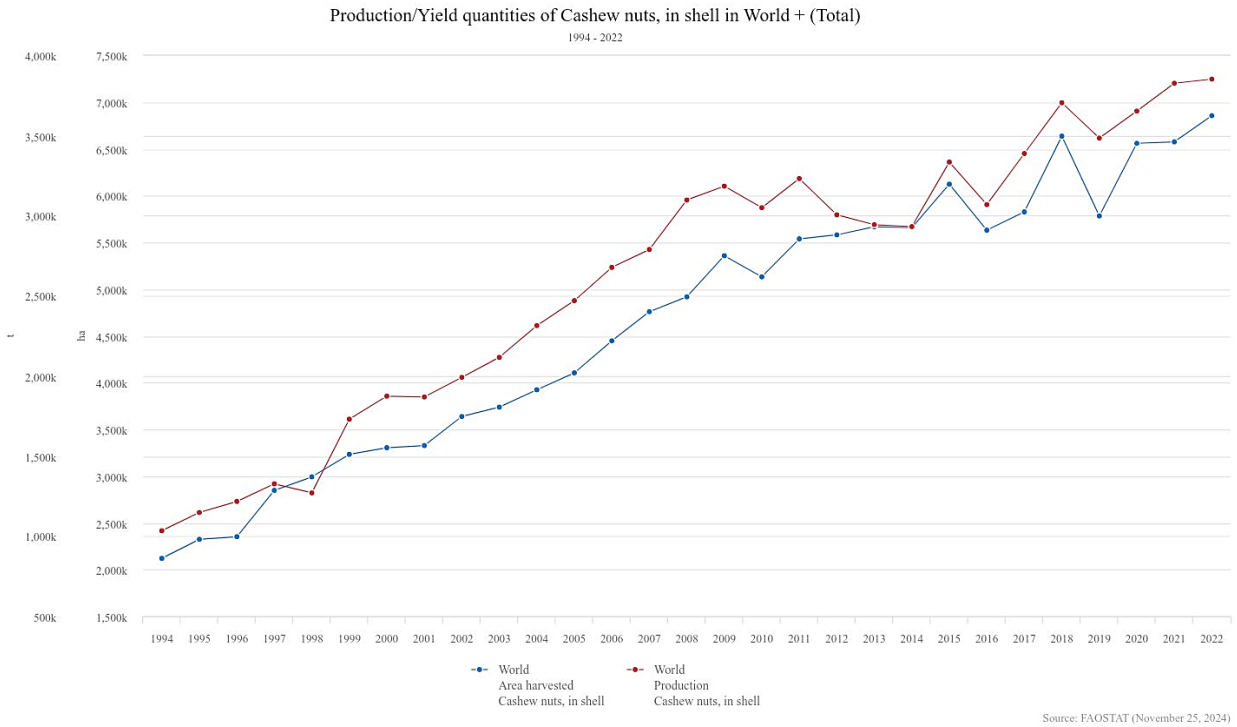


Figure 1. World production of cashew nuts between 1994 and 2022. T – tons produced; ha – hectares utilized for production; k – hundred thousand. Source: FAOSTAT, 2024

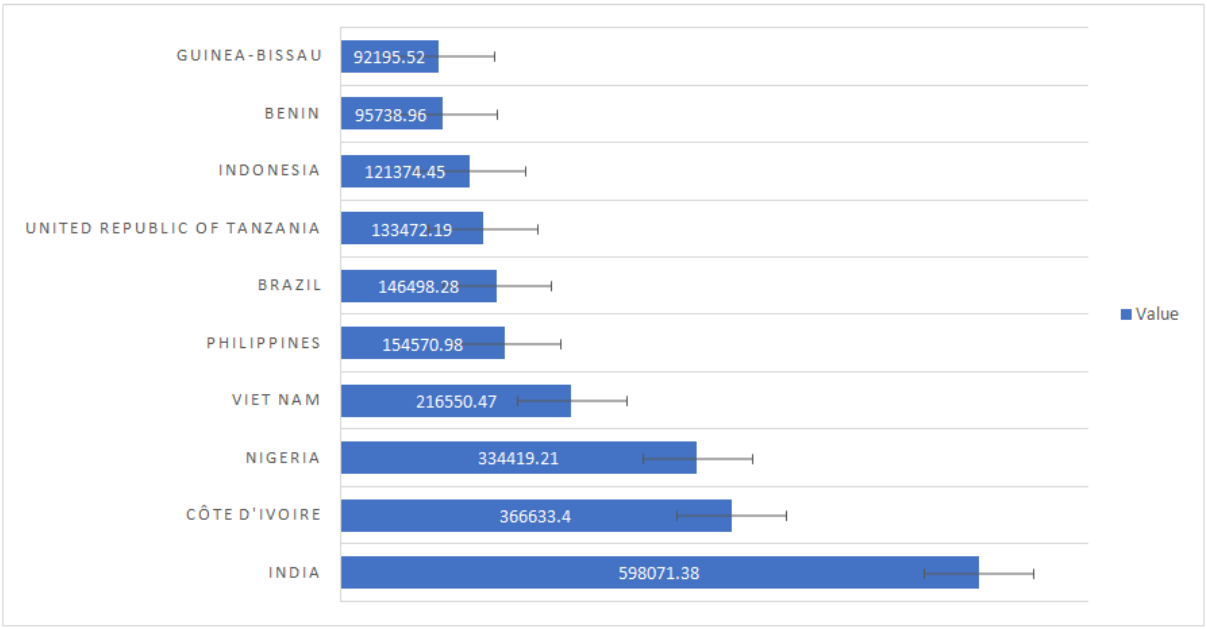


Figure 2. Top 10 producers of cashew nuts between 1994 and 2022. Source: FAOSTAT, 2024

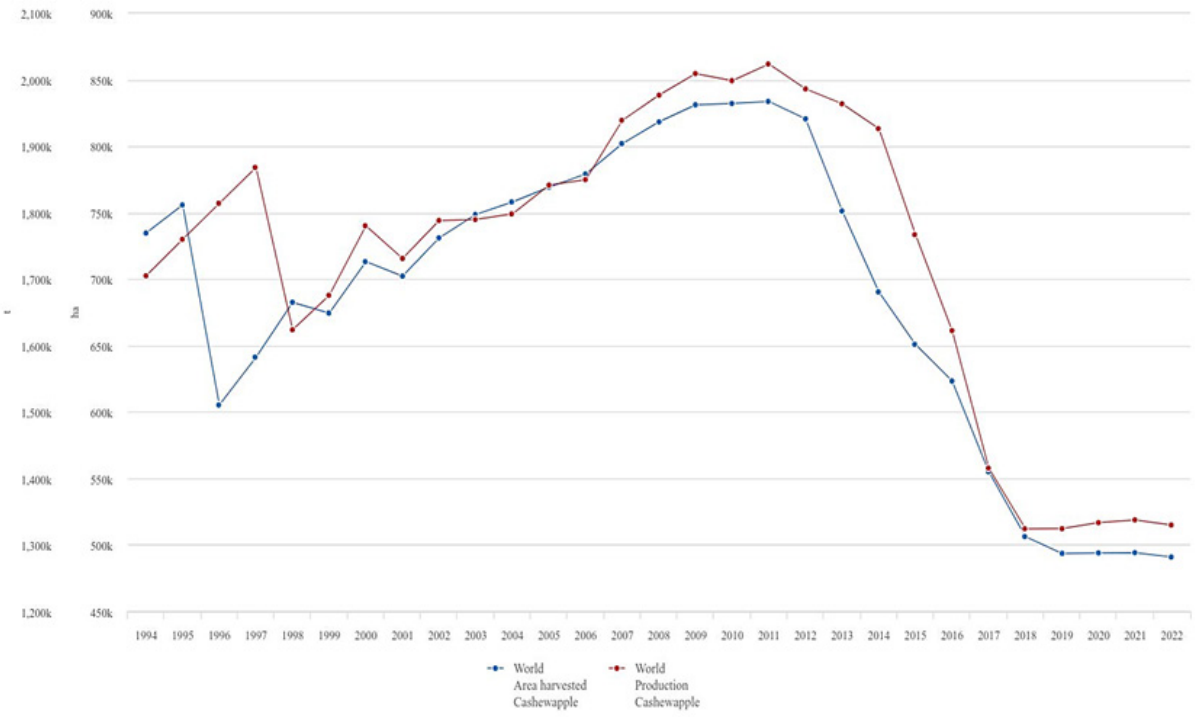


Figure 3. World production of CA between 1994 and 2022. T – tons produced; ha – hectares utilized for production; k – hundred thousand. Source: FAOSTAT, 2024

Production trend of CA and the nut

Cashew nut production has been steadily increasing worldwide (Danso-Abbeam et al., 2021), with several countries across different regions contributing significantly to this trend. The leading producers of cashew nuts are India, Nigeria (Adeigbe et al., 2015; Agboola-Adedoja et al., 2022), Côte d'Ivoire (Bassett, 2017), and Vietnam (Mothé et al., 2017). Figures 1 and 2 show the production trend and the top 10 producers of cashew nuts between 1994 and 2021, respectively. Between 1994 and

2021, the top 3 producers of cashew nuts were India, Côte d'Ivoire, and Nigeria, producing 57.5% of the total production, while other countries produced the remaining 42.5%. By region, Africa is the top cashew nut-producing continent in the world with an average production of 49.20% (1,259,566.51 tons), followed by Asia, producing 44.40% (1,134,951.93 tons) and Americas, 6.40% (164,158.75 tons) (FAOSTAT, 2024). Nigeria and Côte d'Ivoire have significantly contributed to the production of cashew nuts in Africa, whereas India and Vietnam in Asia (Bojang and Gibba, 2021).

The production trend of CA differs from that of cashew nuts. Between 1994 and 2022, the majority of the CA production came from the Americas (89.10% – 1,561,988.02 tons) and Africa (10.10% – 190,947.29 tons) (FAOSTAT, 2024). Figures 3 and 4 show the production trend and top CA producers between 1994 and 2021. Brazil was the top producer of CA, followed by Mali, Madagascar, and Guyana. The decline in CA production, compared to cashew nuts, could be attributed to selective harvesting, market demand, and agricultural priorities. The rising demand for cashew nuts may lead farmers to prioritize harvesting them, as they are more commercially valuable than CA (Bojang and Emang, 2024; Olubode et al., 2018). In regions where cashews are grown primarily for their nuts, the apples may be left to rot or discarded during nut harvesting, leading to reduction of the recorded production of CAs.

Nutrition value of CA in ruminant nutrition

While cashew nut meal is highly valued in global markets and used in animal nutrition and livestock production, CA, which constitutes approximately 90% of the cashew fruit by weight (Akyereko et al., 2022), is a promising alternative in ruminant nutrition. The potential of CA in ruminant diets stems from its nutrient composition, comprising valuable carbohydrates, proteins, vitamins, minerals, and bioactive compounds such as anacardic acid, flavonoids, leucoanthocyanins, tannins, alkaloids, saponins, sterols, naphthoquinones and anthraquinones, and carotenoids (Cruz Reina et al., 2022).

Table 1 shows a comparison of the dry matter (DM), crude protein (CP), crude fibre (CF), ether extract (EE), ash, nitrogen free extract (NFE), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), and metabolizable energy from eleven studies sourced from Web of Science and Google Scholar. The DM content of CA varies significantly across studies, revealing that the moisture level can be influenced by several factors, including the state (fresh or dried) and processing method. For instance, Gerpacio and Castillo (1979) reported DM values around 86.9% and 85.3%, which suggest a relatively low moisture content, making CA potentially stable and suitable for storage. A dry feed ingredient is less prone to microbial spoilage, enhancing its shelf life and reducing the risk of mould formation or nutrient degradation during storage. On the other hand, Fanimo et al. (2003) observed a DM content of 100%, indicating a fully dehydrated sample, making it more convenient for transport and inclusion in dry rations. However, the high DM of dried CA could also reduce palatability and intake compared to fresh or ensiled CA, as reported by La Van Kinh and Phuong (1997), with a much lower DM content of 22.5%. The DM content has important implications for developing effective ruminant feeding strategies. Greater DM content, as observed in dried forms, improves the feasibility of CA for year-round feeding, particularly in areas where fresh feed supply is seasonal or inconsistent.

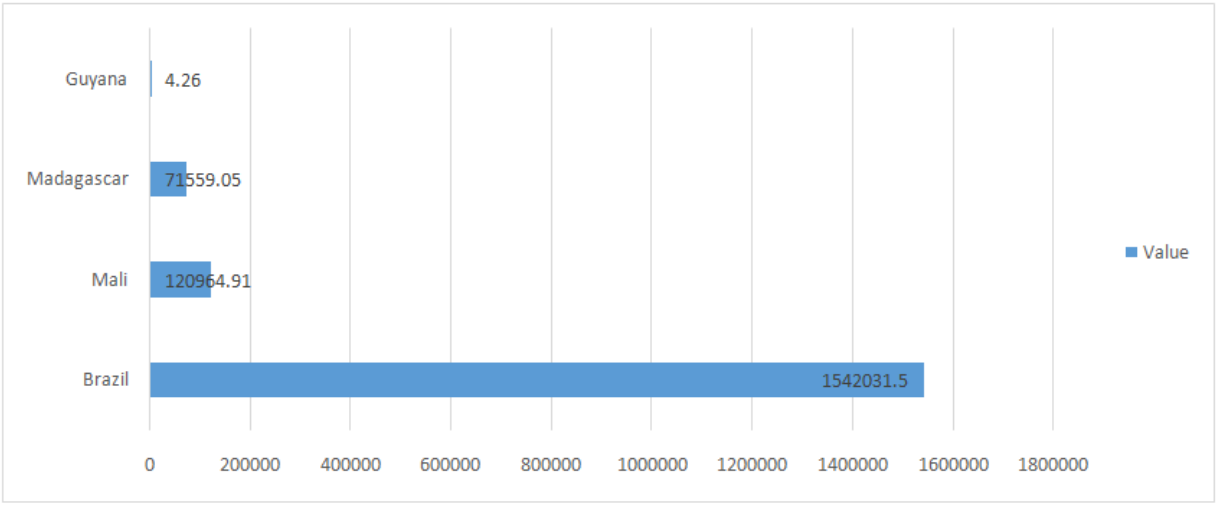


Figure 4. Top producers of CA between 1994 and 2022. Source: FAOSTAT, 2024

Table 1. Comparison of nutrition value composition (dry matter basis) of CA

Parameters (g/kg DM)	A	B	C	D	E	F	G	H	I	J	K	Average
Dry matter (%)	86.9	85.3	22.5	100	81.0	88.8	89.2	81.0	93.6	96.0	87.8	82.4
Crude protein	89.3	101	137	187	86.0	155	190	106	139	56.8	239	130
Crude fibre	76.5	68.7	118	84.0	38.0	75.6	79.6	46.9	Nd	69.3	130	71.7
Ether extract	44.9	68.7	Nd	24.0	99.6	119	117	123	20.3	31.3	19.4	61.2
Crude ash	41.7	31.8	10.0	54.0	38.0	32.1	27.8	46.9	13.9	26.0	198	49.3
NFE	736	708	Nd	651	548	617	586	676	Nd	817	423	640
NDF	Nd	Nd	Nd	Nd	207	Nd	Nd	Nd	687	Nd	Nd	447
ADF	Nd	Nd	Nd	Nd	122	Nd	Nd	Nd	476	Nd	Nd	299
ADL	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	223	Nd	Nd	223
ME** (Kcal/kg DM)	2875	2938	Nd	3197	Nd	3315	3326	3070	Nd	3228	2187*	2973

Nd – not determined, NFE – nitrogen free extract, NDF – neutral detergent fibre, ADF – acid detergent fibre, ADL – acid detergent lignin, and ME – metabolizable energy; A – Gerpacio and Castillo (1979) (wet CA); B – Gerpacio and Castillo (1979) (dried CA); C – La Van Kinh and Phuong (1997); D – Fanimo et al. (2003); E – Armah (2008); F – Okpanachi et al. (2016 a) (yellow varieties); G – Okpanachi et al. (2016 a) (red varieties); H – Ahaotu and Ihekoronye (2019); I – Lopes et al. (2018); J – Boateng et al. (2021); K – Oluwatosin et al. (2022); * – reported metabolizable energy; ** – estimated metabolizable energy using Pauzenga equation as reported by Ojediran et al. (2024 b) (37 × %CP + 81 × %EE + 35.5 × %NFE).

Regarding CP content in CA, the values vary across studies, ranging from 56.8 to 239 g/kg DM. CA may not entirely replace high-protein ingredients like soybean meal or other protein-rich feedstuffs. However, its CP content offers an economical option for supplemental protein intake, especially in regions where conventional protein sources are costly or scarce. Furthermore, Meneguelli et al. (2023) reported that the protein in cashew nuts is soluble, therefore suggesting that the protein of CA may be readily degraded by rumen microorganisms, allowing for microbial protein synthesis, which is a crucial source of amino acids for ruminants. Also, CA may be useful to supplement low-quality forages for enhanced fibrolytic bacterial activity, leading to improved forage utilization.

The variation in CF content of CA, ranging from 38 to 118 g/kg DM, can be attributed to several interrelated factors, including cashew variety, climatic conditions, stage of fruit maturity, agronomic practices, harvest time, and post-harvest processing methods. For example, younger or immature fruit typically contains more soluble sugars and less fibre, while mature or overripe fruits may have increased cell wall content (hemicellulose and cellulose), influencing overall CF concentration (Schumann et al., 2020). Additionally, sun-drying, mechanical pressing, or fermentation of CA can alter its fibre composition by breaking down or concentrating fibrous components (Radojčin et al., 2021). Fibre in CA comprises mainly cellulose, hemicellulose, and pectin, with minimal lignin content (Veena and Shweatha, 2024). These fractions, especially neutral detergent fibre (NDF) and acid detergent fibre (ADF), are critical for modulating rumen function, feed fermentation dynamics, and digestive efficiency in ruminants. While CA is not excessively fibrous, its moderate fibre levels may still contribute positively to rumen motility by stimulating chewing and saliva secretion. This, in turn, enhances salivary buffering, which is essential for stabilizing ruminal pH, especially when CA is included alongside fermentable carbohydrates or high-sugar feeds (Castillo-Lopez et al., 2021). This buffering effect is crucial as it helps counteract the rapid fermentation of the simple sugars and maintains a stable pH (not less than 6.0) within a range that supports cellulolytic bacterial activity (Russell and Wilson, 1996). However, while CA has the potential to support pH stabilization, it should ideally be fed in combination with high-NDF roughage sources within a balanced diet to prevent fermentation imbalance and maintain optimal rumen health.

In addition to influencing rumen function, the moderate and variable fibre content of CA also has important implications for its energy contribution in ruminant diets. While highly fibrous feedstuffs can dilute dietary energy density due to slower digestion and lower fermentability, the relatively moderate CF levels in CA suggest that it can supply digestible energy without significantly compromising overall dietary energy balance (Weimer, 2022). This is particularly relevant considering the metabolizable energy (ME) values of CA, which range widely from 2187 to 3315 kcal/kg DM. Such variation in ME reflects differences in chemical composition (especially sugar, starch, and fat content), variety, maturity at harvest, and processing methods.

The non-fibrous carbohydrate fraction (NFE; 423 to 817 g/kg DM) indicates a considerable source of readily available carbohydrates, which can quickly be metabolized to provide energy. This makes CA a valuable energy-dense feed ingredient, especially useful in regions where alternative carbohydrate sources, such as grains, might be expensive. The high NFE also implies that CA can enhance diet ME energy density and support high-energy ruminant demands during productive phases, such as lactation or rapid growth.

CA is naturally rich in soluble sugars, which are rapidly fermented in the rumen to produce short-chain fatty

acids (SCFAs). These SCFAs, particularly propionate, are vital for gluconeogenesis and energy supply in high-demand phases such as lactation or growth (Wang et al., 2023). Unlike bulky, high-fibre by-products, CA's energy profile allows it to function more like a concentrate feed than a roughage source. This characteristic makes it particularly suited for inclusion in intensive dairy or beef systems, where high-energy diets are required to support efficient feed conversion. However, the lower end of the ME range (e.g., 2187 kcal/kg DM) may reflect CA that has undergone nutrient losses during processing or storage or contains higher levels of fibre and less fermentable carbohydrate.

Building on this, another contributor to CA's energy profile is its ether extract (EE) content, which, while generally moderate, adds to its caloric value. EE levels range from 19.4 to 123 g/kg DM, depending on variety, maturity stage, extraction method, and residual oil content following juice processing. Although not exceptionally high, this EE content can enhance energy density without reaching levels that could disrupt rumen fermentation or microbial balance. This makes CA a safe and beneficial energy source that, when combined with other energy-dense feeds, can contribute to the overall caloric intake of the animal.

On the other hand, the crude ash content in CA ranges widely from 10 to 198 g/kg DM. A higher ash content implies a richer mineral composition, essential for bone development, metabolic function, and general health. Minerals are vital for supporting enzymatic processes, immune function, and milk production, making CA's mineral content beneficial for overall animal health.

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Furthermore, fibre fractions of CA (NDF, ADF, and ADL) can significantly influence digestibility and overall feed efficiency in ruminants. Reported values show considerable variation; for example, Table 1 presents NDF values ranging from 207 to 687 g/kg DM and ADF from 122 to 476 g/kg DM, indicating substantial discrepancies across studies. These differences may stem from varietal characteristics, stage of fruit maturity, environmental growing conditions, and particularly processing methods as it has earlier been discussed.

Sreekutty et al. (2019) reported CA fibre fractions of 587 g/kg NDF, 352 g/kg ADF, and 185.2 g/kg ADL, while Araújo et al. (2022) observed even higher values: 687 g/kg NDF and 476 g/kg ADF. Such high NDF values may reduce voluntary intake due to longer rumen retention times and slower digestion (Harper and McNeill, 2015), whereas lower ADF and ADL values – observed in other studies – suggest better digestibility and higher energy contribution (Stypinski et al., 2024). The hemicellulose and cellulose content, derived from the difference between NDF and ADF, also plays a central role in microbial fermentation, supporting short-chain fatty acid (SCFA) production and maintaining rumen health (Weimer, 2022).

Additionally, the sugar composition of CA depends on the cashew variety and environmental factors affecting fruit development. Araújo et al. (2022) reported that the sugar content of CA is 10.5% on a wet basis, Dao et al. (2021) documented a range of 8–10%, and Adou et al. (2021) reported that fresh CA is made up of 8.5% of sugar. This sugar content gives CA a naturally sweet flavour, enhancing their palatability for ruminants. These soluble sugars are beneficial in ruminant nutrition as they provide a readily available energy source (Campos et al., 2020). In the rumen, rumen microorganisms rapidly ferment complex carbohydrates like cellulose, hemicellulose, and starch into short-chain fatty acids (SCFAs) – acetate, propionate, and butyrate. These SCFAs serve as the primary energy sources for ruminants (Dijkstra, 1994), supporting maintenance, growth, milk production, and other metabolic functions. Additionally, propionate plays a crucial role in gluconeogenesis (Wang et al., 2023), the metabolic pathway that enables ruminants to produce glucose. The nitrogen-free extract content of CA (average 661 g/kg DM) can lead to greater production of SCFAs, particularly propionic acid. However, excessive SCFAs accumulation (Dijkstra et al., 2012) may lower ruminal pH, increasing the risk of rumen acidosis. To mitigate this, it is important to balance energy-protein ratio in the rumen by incorporating more readily degradable protein from other components of the diet (Huang et al., 2022; Szulc et al., 2023).

Considering the amino acid profile of CA in detail, it could be advantageous in ruminant nutrition, mostly as a diet component, particularly when considering its availability, feeding cost, and environmental impact when left as waste. CA in the yellow and red varieties contain a range of amino acids that contribute to their overall nutritional value (Table 2). The study by Okpanachi et al. (2015) offers insight into the amino acid composition of these varieties, showing a slight variation between the yellow and red types.

Lysine plays one of the main roles in improving animals' feed efficiency and productivity (Liao et al., 2015). Therefore, ruminant diets often benefit from lysine supplementation, as it is typically limited in forages (Kircher and Pfefferle, 2001; Mok and Urschel, 2020; Xue et al., 2011). The lysine content in CA is 1.84 g/100 g protein for the yellow variety and 2.22 g/100 g protein for the red variety. While this is low compared to soybean meal, incorporating CA into ruminant diets can still help address lysine deficiencies when paired with other protein-rich feed ingredients.

Table 2. Amino acid profile of CA (Okpanachi et al., 2015) compared with soybean meal

Amino acids	Yellow variety	Red variety	Soybean meal **
Essential amino acids (g/100 g protein)			
threonine	1.41	1.93	4.01
cysteine	0.40	0.60	1.42
valine	2.20	2.61	4.98
methionine	0.49	0.63	1.35
isoleucine	1.65	1.97	4.87
leucine	nd	nd	7.79
tryptophan	nd	nd	1.44
phenylalanine	1.87	1.94	5.11
histidine	0.76	1.04	2.54
lysine	1.84	2.22	6.32
Non-essential amino acids (g/100 g protein)			
arginine	1.47	1.90	7.26
aspartic acid	3.32	3.97	nd
proline	2.24	2.65	nd
glutamic acid	3.64	4.24	nd
serine	1.79	1.52	nd
alanine	1.99	2.28	nd

**Amino acid profile from the global PNE database as reported by Oviedo-Rondón et al. (2024); nd – not determined.

Like lysine, methionine is often limited in forage-based diets. The methionine content in CA is comparatively low, at 0.49 g/100 g protein in the yellow variety and 0.63 g/100 g protein in the red variety, compared to soybean meal with methionine levels of approximately 1.35 g/100 g protein. This indicates that while CA can contribute to dietary methionine intake, additional supplementation with sulphur-containing amino acids may be necessary to optimize productivity, particularly in young and lactating ruminants.

The amino acid profile of CA indicates that it should be used as a supplementary feedstuff rather than a sole protein source in ruminant diets due to its relatively low amino acid content compared to high-quality protein sources like soybean meal. However, its moderate levels of essential amino acids – such as lysine, threonine, valine, and methionine – can contribute to growth and productivity, particularly in regions where conventional protein sources are scarce or costly. As shown in Table 2, soybean meal contains significantly higher concentrations of essential amino acids, highlighting a clear nutritional gap. This suggests that CA alone may not meet the complete amino acid requirements of ruminants and should be used in combination with other protein sources to ensure a balanced diet.

Beyond macronutrients and amino acids, CA is also rich in micronutrients, especially vitamin C (Akyereko et al., 2023; Dakuyo et al., 2023), a powerful antioxidant that plays a role in immune support and overall health. The content of vitamin C (200–241 mg/100 g) in the CA is about 3–5 times higher than citrus (Oliveira et al., 2020). Studies have shown that the yellow variety of CA contains a higher concentration of vitamin C (241 mg/100 g) compared to the red variety (222 mg/100 g) (Gbohaïda et al., 2015; Leite et al., 2021; Oliveira et al., 2002). This indicates that the yellow CA might be a better source of ascorbic acid, a potent antioxidant that supports immune function and skin health (Carr and Maggini, 2017). Vitamin C neutralizes free radicals that can damage cells, proteins, and DNA (Lobo et al., 2010). In stressful situations like heat, disease challenges, or high production demands, vitamin C can help to alleviate these situations (Chambial et al., 2013). Supplementing with CA could provide an additional antioxidant boost, reducing the burden of oxidative stress (Tan et al., 2018), which is known to negatively affect milk yield, growth, and overall animal health. Although vitamin C is generally not essential for ruminants, as they can synthesize it endogenously, the presence of natural antioxidants can still confer health benefits (Akinmoladun, 2021).

The mineral composition of CA from five studies (Cruz Reina et al., 2022; Gawankar et al., 2018; Gbohaïda et al., 2015; Lowor and Agyente-Badu, 2009; Singh et al., 2019) is summarized in Table 3. CA contains various essential macro- and micro-minerals required for maintaining metabolic functions, structural development, and immune competence in ruminants. Among these, calcium, potassium, magnesium, phosphorus, sodium, iron, and sulphur are particularly notable. Calcium (Ca) is crucial for bone formation, muscle contraction, and nerve transmission, especially in growing and lactating animals (Wild et al., 2021). The red variety of CA contains more calcium (6.01 mg/100 g) than the yellow variety (1.20 mg/100 g), which may make it slightly more beneficial for bone-related functions and milk production. Potassium (K), another abundant mineral in CA – especially in the red variety (43.6 mg/100 g) – helps maintain electrolyte balance, osmotic regulation, and cardiac muscle function, playing a key role in heat stress adaptation and acid-base balance in ruminants.

Magnesium (Mg), higher in the yellow variety (4.13 mg/100 g), is essential for enzyme activation, particularly in reactions involving ATP metabolism, and also supports nerve impulse transmission and muscle relaxation. Phosphorus (P), found in comparable amounts in both varieties (around 2.15–2.21 mg/100 g), supports energy transfer via ATP, cell membrane integrity (via phospholipids), and bone mineralization. It also plays a vital role in rumen microbial growth and efficiency, which affects overall digestibility and feed conversion. Sodium (Na), though present in relatively small quantities, contributes to osmotic pressure regulation, nutrient transport across cell membranes, and nerve conduction. The red variety has a slightly higher sodium content (2.34 mg/100 g), which may marginally enhance electrolyte balance in hot climates or under water restriction conditions. Iron (Fe) levels are nearly equal between the two varieties (approximately 0.35–0.37 mg/100 g), and though mod-

est, still contribute to haemoglobin synthesis, oxygen transport, and immune function. Sulphur (S), present at around 0.45–0.46 mg/100 g in both varieties, is essential for the synthesis of sulphur-containing amino acids (methionine, cysteine), vitamins (biotin, thiamine), and microbial protein in the rumen.

Additionally, the red variety of CA contains slightly higher levels of polyphenols (271 mg/100 g) and anthocyanins (226 mg/100 g) compared to the yellow variety. These bioactive compounds possess antioxidant and anti-inflammatory properties, which may help reduce oxidative stress and improve immune response, particularly under environmental or physiological stress conditions.

Table 3. Vitamins, minerals, and micronutrient composition of CA (Cruz Reina et al., 2022; Gawankar et al., 2018; Gbohaïda et al., 2015; Lowor and Agyente-Badu, 2009; Singh et al., 2019)

Component (mg/100 g)	Yellow variety	Red variety
Vitamin C	241	222
Total polyphenols	266	271
Anthocyanins	211	226
Potassium	36.1	43.6
Magnesium	4.13	1.22
Calcium	1.20	6.01
Sodium	2.18	2.34
Iron	0.37	0.35
Phosphorus	2.15	2.21
Sulphur	0.45	0.46
Manganese	0.20	0.03

These parameters are expressed on a dry matter (DM) basis. Values were obtained by aggregating data from five references, which analysed the amino acid composition of CA using different methodologies. The reported values represent an average of these studies, ensuring consistency in comparisons.

Bioactive compounds in CA

CA contains various bioactive compounds, including flavonoids, tannins, saponins, and polyphenols (Okpanachi et al., 2016 a), which influence ruminal fermentation, microbial activity, and overall digestion. These compounds can enhance feed efficiency by modulating microbial populations (Rashid et al., 2020) but may also present anti-nutritional effects at high concentrations. Okpanachi et al. (2016 a) reported that sun-dried red cashew pulp contains 0.0701%, 0.0877%, 0.0438%, 0.3661%, and 0.0327% of saponin, tannin, flavonoid, phytate, and oxalate, respectively; while sun-dried yellow cashew pulp contains 0.1568%, 0.0621%, 0.0767%, 0.3159%, and 0.0287% of each, respectively.

Flavonoids, a class of polyphenols that are known for their antioxidant and antimicrobial properties, can influence fermentation efficiency and microbial composition in the rumen (Olagaray and Bradford, 2019). Flavonoids selectively promote fibrolytic bacteria, such as *Fibrobacter succinogenes* and *Ruminococcus* spp., enhancing fibre digestibility and overall fermentation efficiency (Li et al., 2022; Seradj et al., 2014). This bioactive compound can inhibit methanogenic archaea, thereby reducing methane emissions and improving energy utilization in ruminants (Kim et al., 2015; Oskoueian et al., 2013). Increased propionate production has been observed when flavonoids are included in ruminant diets, improving glucose availability and overall energy metabolism (Seradj et al., 2014). However, excessive flavonoid concentrations can potentially inhibit certain ruminal bacteria, leading to reduced fibre degradation and fermentation imbalances (Li et al., 2022).

Tannins, naturally occurring polyphenolic compounds in CA, have both positive and negative effects on ruminant nutrition. This bioactive compound binds to dietary proteins (Ojo, 2022), reducing ruminal protein degradation and allowing more amino acids to be absorbed post-ruminally, thereby improving protein efficiency (Wang et al., 2022). They contribute to nitrogen utilization efficiency by reducing ruminal ammonia production, lowering nitrogen losses, and improving microbial protein synthesis (Fonseca et al., 2024; Martello et al., 2020). However, tannins can also inhibit cellulolytic enzyme activity, negatively affecting fibre digestibility and reducing voluntary feed intake (Wang et al., 2022). Souza et al. (2020) observed decreased feed intake in cattle when CA meal replaced maize in the diet, likely due to tannin-induced astringency affecting palatability. To maximize benefits and minimize the negative impact of tannins, processing techniques such as ensiling, drying, or adding protein sources can mitigate tannin-induced anti-nutritional effects.

Saponins have bioactive properties that may enhance animal health by providing antioxidant, antimicrobial, and anti-inflammatory benefits (Roy et al., 2022). This bioactive compound has been known for its methanogenic inhibition, leading to reduced methane emissions and improved energy retention in ruminants (Yanza et al., 2024). Saponins can cause potential reduction in ruminal ammonia toxicity, which may be beneficial when CA is included in high-protein diets (Santoso et al., 2007; Yanza et al., 2024). However, excess saponins could disrupt microbial equilibrium, potentially leading to reduced fibre digestion and altered rumen fermentation dynamics (Patra and Saxena, 2009).

Given the presence of these bioactive compounds, CA inclusion must be carefully managed to optimize fermentation, microbial stability, and nutrient absorption. Using several processing methods (ensiling, drying, roasting, and blanching) can reduce anti-nutritional effects and enhance nutrient bioavailability (Anaemene and Fadupin, 2022; Samtiya et al., 2020).

Biologically, anaerobic fermentation with lactic acid bacteria (LAB) lowers pH (<4.5), which inhibits spoilage microbes and degrades ANFs. Tai et al. (2020) observed that ensiling CA with rice bran reduced oxalate content by 25% while enhancing lactic acid production. LAB strains like *Lactobacillus plantarum* can further degrade

saponins (Sedó Molina et al., 2024). Furthermore, fungal species (*Aspergillus niger*, *Rhizopus oligosporus*) produce enzymes (tannase, phytase) that hydrolyze tannins and phytate (Jatuwong et al., 2020). Lopes et al. (2018) reported a 60% reduction in tannins after 72 hours of SSF, improving CA's protein availability.

Fine grinding increases surface area, while soaking in water (1:5 w/v) for 24 hours leaches water-soluble ANFs like oxalate (Dao et al., 2021). Soaking CA in 1–2% sodium hydroxide (NaOH) or calcium hydroxide ($Ca(OH)_2$) solutions for 12–24 hours can hydrolyze tannins and phytate because NaOH treatment reduced phytate by up to 55% (Raboy, 2000). Polyethylene glycol (PEG) binds to tannins, forming insoluble complexes that prevent protein-tannin interactions. Seradj et al. (2014) noted that adding 1% PEG to tannin-rich diets increased crude protein digestibility by 20% in sheep.

Effects of CA's inclusion on rumen fermentation

The inclusion of CA in ruminant diets can modulate the rumen microbiome through its rich profile of bioactive compounds. Flavonoids present in CA have been shown to selectively stimulate fibrolytic bacteria (e.g., *Fibrobacter succinogenes*, *Ruminococcus* spp.), thereby enhancing fibre-degrading populations (Liu et al., 2025; Vasta et al., 2019). At the same time, these phytochemicals can suppress rumen methanogenic archaea and some protozoa, leading to lower methane-producing microbe counts (Króliczewska et al., 2023).

Saponins, likewise, are known to exert defaunating effects (reducing ciliate protozoa) and inhibit methanogens, which can further curb ruminal methane emission (Króliczewska et al., 2023). The net effect is often a more energy-efficient microbial ecosystem, as fewer nutrients are lost to methane. Moderate inclusion levels of CA appear to support rumen microbial protein synthesis – for instance, diets with CA have shown increased ammonia-N availability in the rumen (up to optimal ~15 mg/100 mL), which in turn can enhance microbial protein output (Anim-Jnr et al., 2025). This suggests that CA provides fermentable substrates and nitrogen that foster microbial growth. Importantly, studies report that CA addition has a minimal adverse impact on overall rumen microbial balance when fed at reasonable levels (Anim-Jnr et al., 2025). Even at relatively high inclusions (e.g., 75% of total mixed ration as silage), rumen function remains stable with only slight shifts, such as a minor increase in rumen pH and ammonia (within normal ranges) and no major disruption of microbial populations (Anim-Jnr et al., 2025).

Notably, diets incorporating CA typically yield abundant total SCFAs, reflecting active fermentation. The readily fermentable sugars tend to increase propionate production relative to acetate (Kim et al., 2015). This shift toward propionate is metabolically favourable, as propionate is a gluconeogenic SCFA that improves energy supply for growth and lactation. Flavonoid compounds from CA may reinforce this trend because flavonoid-rich supplements in ruminant diets have been shown to elevate propionate proportion while slightly reducing acetate and methane (Kim et al., 2024; Seradj et al., 2014), suggesting a redirecting of hydrogen away from methanogenesis toward propionate formation. In addition, ensiled or dried CA can influence butyrate levels (Anim-Jnr et al., 2025). An increase in butyrate (another key SCFA) is beneficial for rumen epithelium development and as an energy source for rumen wall cells (Diao et al., 2019). For example, Tai et al. (2020) observed that cattle fed a high proportion of CA silage had an elevated ruminal butyrate percentage, which was linked to efficient microbial protein synthesis and nitrogen utilization.

Crucially, rumen pH and ammonia dynamics under CA feeding stay within optimal ranges for fermentation. CA does not cause excessive acidification of the rumen; on the contrary, diets including up to ~30% CA have yielded terminal rumen pH values around 6.4–6.7, well within the ideal 5.5–6.9 zone for fibre digestion (Tai et al., 2020). High inclusion of cashew silage has even been noted to slightly increase mean ruminal pH (relative to a starch-rich control), likely due to dilution of rapidly fermentable starch and the buffering effect of fruit fibres (Tai et al., 2020). Rumen ammonia-N (NH_3-N) tends to rise with CA inclusion as it contributes additional protein and nitrates. In one study, ensiled CA mixed with maize cobs led to higher ruminal NH_3-N concentrations (within 12–16 mg/dL), thereby optimally supporting microbial growth (Ferreira et al., 2015). This indicates improved nitrogen availability for microbes, which can translate to greater microbial protein synthesis for the host animal.

Comparison of CA with other unconventional feedstuffs

Nutrient composition

The nutrient profile of CA, as earlier discussed, makes it an easily fermentable energy source with moderate protein value. By contrast, dried citrus pulp is lower in protein (typically 5–10% CP) but rich in fermentable fibre (high pectin, neutral detergent fibre ~20–30%, and very low lignin) (Tayengwa and Mapiye, 2018). Banana peels are also low in protein (usually 6–8% CP) and contain substantial cell-wall content (e.g. ~50% NDF in mature peels) with more lignified fibre than CA or citrus pulp, alongside considerable ash (mineral) content (~10% DM) (De Angelis, 2025). All three feeds are good energy sources; CA and citrus pulp are highly digestible due to soluble sugars and pectin, whereas banana peels have more structural fibre that yields slightly lower energy availability. Mineral profiles differ: citrus pulp is notably high in calcium (often 1.5–2% DM) but low in phosphorus, banana peels are exceptionally rich in potassium and contain tannins and micronutrients (De Angelis, 2025), and CA provides appreciable potassium, magnesium and vitamin C (Aslam et al., 2024; van Walraven and Stark, 2024). These compositional traits indicate that CA, like citrus pulp, can serve as a readily fermentable energy supplement, while banana peels act more as a fibrous filler unless supplemented with protein.

Rumen fermentation effects

Due to its high soluble carbohydrate and low lignin, CA ferments rapidly in the rumen, supporting robust SCFAs production. This can enhance total SCFA yield and potentially favour propionate if balanced with adequate fibre, though specific fermentation profiles of CA are not yet well-documented. Importantly, CA contains modest levels of tannins and antioxidants, which may moderately modulate rumen microbes – for instance, tannins could bind protein, reducing ammonia release and possibly dampening methanogen activity, but detailed studies in ruminants are limited. Citrus pulp's high pectin content yields a fermentation pattern of high acetate (and often butyrate) with relatively lower lactate, helping to maintain stable rumen pH. Moreover, citrus by-products carry essential oils (e.g. d-limonene) and polyphenols that can suppress methanogenic archaea and protozoa (Cobellis et al., 2016; Ohene-Adjei et al., 2008).

Consequently, diets with citrus pulp often show reduced methane emissions and a healthy microbial balance, as the readily fermentable fibre is efficiently utilized without causing acidosis. Banana peels ferment more slowly; their higher fibre and phenolics can slightly limit degradability but also confer rumen benefits in moderation. Tannins in banana peel, which decrease upon ripening, can protect dietary protein from excessive rumen degradation (Huang et al., 2024) – this increases bypass protein to the intestine, potentially improving milk protein yield. However, excessive tannins or fibre from peels might depress fibre digestion if inclusion is too high (Besharati et al., 2022). In general, across cattle, sheep, and goats, these unconventional feeds do not upset rumen function when used appropriately. Citrus pulp is noted to stabilize rumen fermentation when replacing grain, preventing pH drop (García-Rodríguez et al., 2020), while banana peel inclusion (especially ensiled or treated) can increase total SCFA production in sheep without harming microbial activity (Ramdani et al., 2019).

Cost and availability

CA is abundant in cashew-producing areas (West Africa, India, and Brazil), where millions of tons of cashew fruits are discarded after nut harvest. Utilizing CA thus turns waste into feed, reducing environmental pollution. However, its use is limited by seasonality and perishability – the fresh fruit is ~85% moisture and spoils within days. Citrus pulp is generated in large volumes by juice industries (over 14 million tons globally per year) (Tayengwa and Mapiye, 2018). It is commonly dehydrated and pelleted for use in cattle diets, especially in citrus-growing countries (e.g. Brazil, USA, Mediterranean Europe). Because of disposal challenges for processors, dried citrus pulp is relatively inexpensive; its price per unit energy or protein is often lower than that of cereals (Thornton, 2010). This makes it an economically attractive substitute in commercial rations, as long as transport from processing plants is feasible. Banana peels are freely available in tropical farming systems wherever bananas are grown or processed. Large plantations and banana chip/beer industries produce heaps of peels that smallholders can use as feed at minimal cost.

Overall, CA shares many qualities with other unconventional feeds, like citrus pulp and banana peel, in providing affordable nutrients for ruminants. It offers a higher protein and vitamin contribution than most fruit wastes and, similar to citrus pulp, is highly digestible, supporting efficient rumen fermentation. Banana peels and other fruit by-products (e.g. pineapple or apple pomace) likewise can be judiciously used – for instance, ensiled pineapple waste can replace 50% of forage in diets without harming digestibility (Kiatti et al., 2023) – underscoring that a range of agro-wastes can successfully complement ruminant nutrition. Across cattle, sheep, and goats, these feeds, when properly supplemented, maintain animal performance while lowering feed costs and enhancing sustainability in various regions of the world.

Innovative processing techniques for CA utilization in ruminant nutrition

To address the inherent challenges of utilizing CA as a ruminant feed, particularly its high moisture content in freshly harvested state – which can benefit animals in semi-arid regions but also accelerates spoilage – various processing techniques have been developed to enhance its preservation, palatability, and nutritional profile. Dehydration, for instance, is a prominent method that removes moisture content, thereby extending shelf life and preserving essential nutrients (Moutia et al., 2024). Studies have shown that dried CA retain substantial levels of protein, fibre, and minerals, making them comparable to fresh apples in nutritional value while being more accessible year-round (Oliveira et al., 2020; Sakhawat et al., 2022). This process has enabled the inclusion of CA in ruminant diets as a sustainable feed resource, with notable potential for regions aiming to reduce feed costs. However, further investigations are needed to explore animal acceptability, impacts on performance, and long-term health effects (Kiatti et al., 2024).

In addition to drying, ensiling offers an alternative preservation approach that maintains CA nutritional quality through anaerobic fermentation. This method not only stabilizes the nutrient composition but also enhances the palatability of the CA. Studies show that ensiled CA retain high protein and fibre levels, making them a viable feed option (Sahie et al., 2023). Tai et al. (2020) reported that for beef cattle, a silage mixture containing 75% CA, 12.5% maize cob, and 12.5% rice bran supported weight gain, demonstrating the economic and environmental benefits of CA silage in ruminant diets as a readily available ingredient. However, effective ensiling requires strict management to maintain silage quality and storage conditions to prevent spoilage (Costa et al., 2021).

Blending CA with other feed ingredients is another promising strategy to create balanced, nutrient-dense livestock diets. CA meal can be enriched with protein by combining it with ingredients like rice bran and urea,

improving its nutritional profile (Tai et al., 2020). This blending technique could allow flexibility in feed formulation, enabling producers to leverage the high-energy and fibre content of CA alongside other nutrient-dense additives to meet the dietary requirements of different livestock species (Moss et al., 2021). Collectively, these processing techniques hold significant promise in advancing CA utilization as an affordable, eco-friendly feed resource, with broad implications for sustainable livestock production.

Performance of animals fed CA

Studies have shown that CA can be incorporated into the diets of different livestock species. Just like other feedstuffs, the inclusion level varies depending on the species, growth stage, and animal physiological status (Cantalapiedra-Hijar et al., 2018). In a study by Araújo et al. (2022), the inclusion of dehydrated CA up to 33% level in the concentrate mixture improved the feed efficiency of sheep, and there was no adverse effect on their growth rate and nutrient utilization. Similarly, Okpanachi et al. (2016 b) reported that CA meal can be included in up to 30% of the goats' diet without any adverse effects on their performance. The high fibre content of CA makes it an excellent source of roughage in animal diets.

Growth and nutrient digestibility

Several studies have investigated the effect of CA inclusion in livestock diets on growth performance. Tai et al. (2020) evaluated the use of CA meal as a substitute for maize cob and rice bran in the diet of fattening cattle. The experimental diets were formulated into 3 groups – 100% maize silage (MSL), 75% CA + 25% maize cobs (CSL 2), and 75% CA + 12.5% maize cobs + 12.5% rice bran (CSL 3). The CA used in this study was ensiled with the other dietary ingredients according to the combination formula. Prior to ensiling, the CA were diced and subsequently compressed in layers within plastic containers, each with a capacity of 10 litres, to create three replicates per formula for ensiling durations of 30 and 60 days. The silage made from fresh CA became sour, very soft, and slightly smashed at the end of the 30- and 60-day ensilage process. This silage had pH values of 4.36 and 4.27 at the end of the 30 and 60 days, respectively. Considering the changes in the body weight gain of the cattle after 3 months of fattening, cattle fed maize silage alone had 0.72 kg/day weight gain, followed by those fed 75% CA + 12.5% maize cob + 12.5% rice bran (0.71 kg/day weight gain), and lastly, those fed 75% CA + 25% maize cob (0.69 kg/day weight gain). The cattle fed CSL 2 had the least dry matter intake (5.63 kg/day) and crude protein intake (783 g/day). The research concluded that CA may be ensiled and substituted for whole corn silage in the diets of fattening cattle without any detriment to weight increase, potentially decreasing feeding expenses and environmental pollution. The study also recommended the use of 75% CA + 12.5% maize cob + 12.5% rice bran. A summary of the effect of CA diets on growth performance and nutrient digestibility is presented in Tables 4 and 5.

Table 4. Growth performance of animals fed CA diets

Study	Animal type	CA inclusion level (%)	Weight gain (g/day)	Feed conversion ratio	Observations
Tai et al. (2020)	Cattle	75% CA silage	720 690 710	Not determined	Comparable to maize silage in fattening cattle
Okpanachi et al. (2016 b)	Goats	0 10 20 30	12.8 6.29 3.43 8.02	20.22, 37.76, 70.16, 30.66	Reduced weight

Table 5. Nutrient digestibility of CA diets

Study	Animal type	CA inclusion evel (%)	Dry matter digestibility (%)	Crude protein digestibility (%)	Crude fibre digestibility (%)	Ether extract digestibility (%)	Observations
Araújo et al. (2022)	Sheep	11 21 28 33	65.0 62.0 58.0 56.0	56.0 47.0 46.0 46.0	Not determined	Not determined	Reduced DM and CP digestibility
Okpanachi et al. (2016 b)	Goats	0 10 20 30	95.4 94.5 94.7, 91.1	55.0 50.6 52.2 48.5	61.8 61.4 52.3 58.4	73.2 66.6 67.2 72.4	Reduced DM and CP digestibility but increased EE digestibility
Pimentel et al. (2011)	Sheep	CA meal supplemented with concentrate (0, 10, 20, 30)	63.1 61.2 57.1 59.3	75.3 75.5 73.0 72.6	Not determined	59.5 64.1 72.0 83.3	Reduced DM digestibility but increased EE digestibility

Araújo et al. (2022) also evaluated the effects of feeding dehydrated CA in different grinding sizes on feed intake and nutrient digestibility in sheep. The CA was sun-dried for 15 days with DM content of 883 g/kg DM. Four total mixed rations (TMR) were formulated with the inclusion levels of 11%, 21%, 28%, and 33% of sun-dried CA. The result revealed that the inclusion of sun-dried CA up to 33% in the diet of sheep has no adverse effect on voluntary intake and growth performance. The study of Souza et al. (2020) also utilized dried CA (referred to dried cashew processing product in the study) as an alternative feedstuff for grazing beef cattle. The substitution of maize for dried CA did not affect the intake of forage; however, there was a reduction in the supplement DM intake. The reduced intake in the study was likely attributed to the condensed tannin content in the diet.

Another notable evaluation of CA on the growth performance and nutrient digestibility of animals is the study of Okpanachi et al. (2016 b) where the effect of feeding sun-dried cashew pulp-based diet was investigated in West African dwarf goats. The experimental diets were formulated to have dried CA incorporated in 0%, 10%, 20%, and 30%. According to the study, none of the performance parameters were significantly affected by the inclusion of sun-dried cashew pulp meal. There was a general decline in body weight gain, which was attributed to the health issues that goats undergo during the season, with those in 20% level being particularly affected. The study recommended that goat producers can use sun-dried yellow CA up to 30% level in the diet of goats. Furthermore, the digestibility coefficient of crude fibre and EE in the study of Okpanachi et al. (2016 b) was significantly affected due to inclusion of sun-dried cashew pulp, while the DM and CP digestibility values were not significantly affected. The increase in EE digestibility at 30% inclusion level was attributed to the very high crude fibre content of the experimental feeds. Similarly, Pimentel et al. (2011) evaluated the effect of CA meal on nutrient digestibility in sheep. The study revealed that including CA meal in the diet influenced digestibility by reducing dry matter, CP digestibility, and increased EE digestibility. The study by Araújo et al. (2022) earlier mentioned also found that dehydrated CA at 33% reduced the DM and organic matter digestibility when compared to the 11% diet.

Haematology and serum biochemistry

The inclusion of CA in livestock diets has been found to influence haematological and serum biochemical parameters in animals such as broilers and rabbits. However, research on its effects on the blood profile of ruminants – including sheep, goats, and cattle – remains limited compared to studies focusing on its impact on growth performance.

Okpanachi et al. (2019) studied the effects of feeding sun-dried yellow CA diets on haematological and serum biochemical parameters in West African dwarf goats (Table 6). The experiment had four dietary groups with CA levels of 0%, 10%, 20%, and 30%. As the inclusion level increased, the white blood cell count significantly increased while the lymphocyte count was reduced. While not significantly influenced, the packed cell volume (PCV) of the goats increased as the inclusion level increased, such that the goats fed 30% level had the highest PCV (41.2%) while those fed 10% level had 37.7%. This study reported that the optimum PCV values suggested a minimum parasite challenge and better nutritional status. The observed level of haemoglobin showed that the nutritional supplementation did not lead to a lack of iron and other microminerals, which are necessary for the production of haemoglobin. The serum biochemistry did not show a detrimental effect of supplementing CA in the diets of West African dwarf goats. However, total protein, urea, and cholesterol levels were significantly affected. The goats fed 30% level diet had the most cholesterol and total protein levels, whereas the goats fed 20% level diet had the lowest levels. The urea values of the goats on 30% and 40% levels were the highest and lowest, respectively. Overall, this study found that sun-dried yellow cashew pulp may be fed to goats without causing any negative side effects. The study recommended including up to 30% inclusion level of CA in the diets of goats.

Limitations and variability in studies on animal performance with CA diets

While multiple studies have explored the potential of CA as a viable feedstuff for ruminants, their findings revealed notable variability due to differences in animal species, age, and CA preparation methods. Addressing these differences is essential for developing a more standardized understanding of the effects of CA on animal performance.

Table 6. Haematological and serum biochemistry of animals fed CA diets

Study	Animal type	CA inclusion level (%)	PCV (%)	Haemoglobin (g/L)	WBC (× 10^9/L)	Total protein (g/L)	Cholesterol (mg/dL)	Observations
Okpanachi et al. (2019)	Goats	0	39.6	207	6.57	15.8	108	No detrimental effect observed
		10	37.7	191	4.66	7.73	135	
		20	37.9	188	8.54	6.91	69.7	
		30	41.2	237	10.7	26.7	200	

PCV – packed cell volume, WBC – white blood cells.

Variability across animal species

The response to CA inclusion varies among different livestock species. Studies on sheep (Araújo et al., 2022), goats (Okpanachi et al., 2019, 2016 b), and cattle (Tai et al., 2020) indicate that CA can replace conventional feed ingredients at different inclusion rates. However, discrepancies in feed efficiency, weight gain, and digestibility may arise due to differences in digestive physiology, rumen fermentation dynamics, microbial activity, and metabolic efficiency. Small ruminants have a more efficient fibre digestion capacity due to their selective feeding behaviour (Lu, 1988), higher fermentation rate in the rumen, and faster passage rate through the digestive tract (Tsiplakou et al., 2011), which allows better utilization of fibrous feedstuffs like CA. However, the absence of direct comparative studies across different ruminant species makes it difficult to establish species-specific optimal inclusion levels, leading to inconsistencies in reported performance outcomes.

Processing and preparation methods

The method of CA preparation (fresh, dried, or ensiled) could significantly impact its nutritional profile and palatability. Fresh CA has a high moisture content, making it more prone to spoilage, whereas dried CA retains nutrients but may become less palatable due to reduced sugar content. Its high sugar content can lead to rapid ruminal fermentation, increasing the risk of acidosis if not balanced with adequate fibre sources. While drying improves shelf life and stability, it may reduce palatability due to the loss of volatile flavour compounds. Araújo et al. (2022) found that coarse grinding had no effect on the digestibility of sheep. Ensiling on the other hand is a promising method for long-term preservation, but variability in fermentation conditions (e.g., pH and microbial inoculation) could affect the final nutritional composition. The outcome of the study of Tai et al. (2020) showed no adverse effects on weight gain, but the specific fermentation dynamics need further investigation.

Variability in nutrient composition

The nutritional composition of CA is highly variable, which contributes to inconsistencies in reported feed efficiency and performance outcomes across different studies. Several factors, such as varieties, harvesting stage, and agronomic practices, influence its nutritional composition making it crucial to account for these variations when formulating ruminant diets.

Different cashew cultivars exhibit variations in their nutritional composition, which can impact their suitability as a feed ingredient. For instance, Okpanachi et al. (2015, 2016 a) observed significant differences between red and yellow CA varieties, with the red variety containing slightly higher fibre and energy content than the yellow variety. Such discrepancies affect digestibility, fermentation rates in the rumen, and overall nutrient utilization by ruminants. Furthermore, the maturity stage at which CA are harvested can influence their sugar, fibre, and moisture content.

Problems associated with using CA and solution

Problems associated with CA's utilization

The use of CA as a feed resource is associated with several challenges that need to be addressed to maximize their potential. These challenges include limited availability, short shelf life, and high moisture content.

Limited availability: The availability of CA as a feed resource is limited due to the seasonality of cashews (Akyereko et al., 2022), with a harvest period between January and May annually, depending on geographical location. Furthermore, CA have a short harvesting season, limiting their availability (Talasila and Shaik, 2015). Therefore, strategies like ensilage need to be developed to increase CA availability as a ruminant feed resource.

Short shelf life: CA have a short shelf life, typically lasting no more than two to three days after harvest (Nwosu et al., 2016; Oliveira et al., 2020; Talasila and Shaik, 2015). This is due to the high moisture content of CA in its fresh state, making it susceptible to spoilage and fermentation. CA, in its freshly harvested state, has a high moisture content (Singh et al., 2019), ranging from 77% to 88%, depending on the stage of ripeness (Aidoo et al., 2022; Rico et al., 2016).

High moisture: High moisture content in cashew fruit can lead to spoilage and fermentation, making it difficult to store for an extended period of time. Additionally, high moisture content can result in nutrient loss and reduced palatability of CA (Gawankar et al., 2018). Therefore, strategies to reduce the moisture content of CA need to be developed to enhance their storability and nutritional value.

Solutions

To address the challenges associated with using CA as a feed resource, several strategies can be implemented. This issue of high moisture content can be addressed by incorporating desiccating agents such as wheat bran, rice bran, wet corn, dehydrated citrus pulp, or ground grass or legume hay into fresh CA to create silage of a total mixed ration, enhancing both its storability and nutritional value. To overcome limited availability due to seasonality, techniques like ensilage can be explored to preserve CA and make it available year-round for ruminant feeding. To address the short shelf life, developing effective preservation methods, such as drying, fermentation, or the use of preservatives, can help extend the shelf life and maintain their nutritional quality. Sun-drying or oven-drying reduces moisture content (from ~85% to <15%), inhibiting microbial spoilage and stabilizing ANFs (Alp and Bulantekin, 2021). However, excessive heat (>60°C) may degrade heat-sensitive nutrients like vitamin C (Dakuyo et al., 2023). Dry-heat treatment at 120–150°C

for 15–20 minutes can denature tannins and saponins by breaking hydrogen bonds and hydrophobic interactions (Nikbakht Nasrabadi et al., 2021). Akyereko et al. (2023) reported a 40% reduction in tannins and improved palatability in roasted CA meal.

Conclusion

CA possesses significant potential as a sustainable feed resource for ruminants to enhance animal growth, health, and productivity while contributing to diversified and eco-friendly livestock production systems. Using CA in ruminant diets not only reduces feed costs and environmental waste but also offers an alternative income stream for farmers, particularly in cashew-producing regions. However, to fully realize this potential, key challenges such as seasonal availability, high moisture content, and perishability must be addressed through effective processing methods like sun-drying, ensiling, and blending with complementary feed ingredients. Integrating CA gradually into balanced rations, ensuring optimal energy-protein ratios, and avoiding anti-nutritional effects from bioactive compounds can help livestock farmers explore the potential of CA. Future research should prioritize both *in vitro* and *in vivo* studies to explore CA's impact on rumen fermentation, including ruminal pH, short-chain fatty acid profiles, ammonia concentrations, methane emissions, and microbial dynamics. Controlled feeding experiments across different ruminant species will be critical in determining optimal inclusion levels, potential health effects, and long-term implications for production performance and product quality. Moreover, economic assessments are needed to evaluate the cost-benefit ratio of CA-based feeding systems across varying scales of livestock enterprises.

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