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AGRICULTURAL WASTE PROCESSING TECHNOLOGIES (SILAGE AND AMMONIATION) FOR RUMINANT FEED IN DRYLANDS: LITERATURE REVIEW

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ABSTRACT

Dryland regions commonly experience ruminant feed shortages during the dry season. The year-round availability of high-quality feed is a critical prerequisite for sustainable livestock development. Livestock productivity can be improved through the consistent provision of nutritionally adequate feed resources. This opportunity is supported by abundant agricultural production, particularly maize, which has not yet been optimally utilized for livestock feeding. However, most existing feed resources are characterized by low nutritional value and therefore cannot adequately support animal productivity without further processing. Agricultural residues such as rice straw and corn stover are available in large quantities but require technological intervention to improve their feeding value. Processing technologies based on silage and ammoniation have been widely reported to enhance nutrient availability and extend the storage life of these materials. This review synthesizes published research on the potential of agricultural residues as ruminant feed resources in dryland ecosystems and evaluates the effectiveness of silage and ammoniation technologies. The evidence indicates that both technologies substantially improve feed quality, increase feed availability during the dry season, and strengthen farmers' capacity to utilize local resources in a sustainable livestock production system.

Keywords: Ammoniation; Agricultural residues; drylands; ruminant feed; Silage

INTRODUCTION

Feed availability remains a major limiting factor in livestock production systems in dryland environments. Prolonged dry seasons lead to a decline in forage availability, which in turn reduces animal productivity. Agricultural residues are by-products that remain after crop harvest or after the main product has been removed. In general, these materials are characterized by low nutritional quality. One strategy to overcome this limitation is supplementation with concentrate feeds, while another is the application of feed-processing technologies such as fermentation and ammoniation. During the harvest season, residues such as rice straw and corn stover are produced in large quantities but are not fully utilized because of their low nutritive value (Makkar, 2018; Wanapat *et al*., 2015).

Rice straw production can reach 5–8 t ha^{-1} $year^{-1}$, depending on location and cultivar, and this quantity is theoretically sufficient to support 2–3 adult cattle annually (Yunizar, 2015). However, the high lignin content of rice straw forms lignocellulosic complexes that limit microbial degradation in the rumen,

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resulting in low digestibility of approximately 35% (Gunawan, 2009). Maize is one of the most widely cultivated crops and is processed into a wide range of products, generating residues such as cobs, husks, and leaves that are frequently underutilized (Yuliadi *et al*., 2025).

A major challenge in improving livestock productivity is ensuring a continuous supply of feed in both adequate quantity and quality. Feed accounts for approximately 60–70% of total production costs, making animal performance highly dependent on feed resources. In dryland regions such as East Nusa Tenggara, forage production is high during the rainy season but declines sharply during the dry season. Strategies to minimize seasonal fluctuations include conserving surplus feed from the wet season for use during the dry season and utilizing agricultural residues such as rice straw and corn stover.

East Nusa Tenggara Province has considerable potential for livestock development supported by abundant local resources. Agricultural and plantation residues can be utilized as ruminant feed, providing dry matter sources such as rice straw and corn residues as energy feeds. Feed-processing technologies such as silage and ammoniation therefore represent practical alternatives for improving feed quality and ensuring year-round availability. Mafefa *et al*. (2023b) reported that rice straw can be preserved as silage with appropriate additives to improve fermentation quality. Sundstøl (1988) demonstrated that ammoniation improves plant cell-wall structure by loosening fiber bonds and reducing hemicellulose content, thereby increasing digestibility. Furthermore, Noersidiq *et al*. (2018) reported that ammoniation using urea is an effective technology for improving feed quality by reducing lignin content.

The application of feed-processing technologies enables farmers to utilize locally available resources and reduce dependence on imported feedstuffs. When integrated into a sustainable crop–livestock system, local feed resources can support resilient livestock production in dryland environments. Accordingly, this review aims to evaluate the potential of agricultural residues as ruminant feed resources in drylands and to assess the effectiveness of silage and ammoniation technologies based on evidence from published studies.

MATERIALS AND METHODS

This review was conducted using a literature survey of scientific publications indexed in Google Scholar. The search focused on studies addressing the potential of agricultural residues in dryland regions and feed-processing technologies, particularly silage and ammoniation. The objective was to synthesize relevant research findings on the utilization of agricultural residues to improve ruminant productivity under dryland conditions. The analysis emphasized processing techniques, raw-material potential, and the effects of these technologies on feed availability and nutritional quality.

RESULTS AND DISCUSSION

Potential of agricultural residues

Agricultural waste such as rice and corn straw has the potential to be used as feed for ruminants if processed through ensilage. Both types of waste are potential feed for ruminants in dryland areas where natural forage is limited throughout the year. Rice and corn straw are abundant during the harvest season but have nutritional limitations: rice straw has a low protein content and corn straw is high in crude fiber. Anjalani *et al*. (2022) in their study on corn straw silage, successfully proved that corn straw waste can be processed into ruminant feed through ensilage after being treated with additives, even though it is naturally high in fiber.

Meanwhile, research by Banu *et al.* (2019) has shown that corn straw can be processed into good quality silage through additives such as Heryaki powder, gaplek, and sago, each of which plays a role in helping fermentation and nutritional stability. The results of the study show that corn straw processed with these additives is able to achieve optimal pH and very low ammonia levels (<15% in each treatment), indicating that this waste is not only feasible but also substantial as high-quality fermented feed after processing.

Furthermore, research by Mafefa *et al.* (2023a) shows that rice straw waste is not only discarded and unused, but its nutritional quality can also be significantly improved by adding additives such as porang flour, which increases crude protein and reduces crude fiber. This emphasizes that agricultural waste is not just discarded feed material, but can be transformed into high-quality feed to support livestock productivity.

Table 1. Potential Description of Agricultural Wastes Based on Selected Reference

Agricultural Waste	**Main Nutritional Characteristics**	**Potensial Description**	**Reference**
Corn straw	Crude protein 17.49–19.23; Crude fiber 35.86–38.70	Corn straw has high availability and can serve as an alternative roughage, but requires processing to improve nutritive value	Anjalani et al. (2022)
Corn Straw	Ammonia (mM) 9.51–12.27	Corn straw has high potential for feed preservation, especially during feed scarcity periods	Banu et al. (2019)
Rice straw	Crude protein 6.31–8.35; Crude fiber 33.30–36.44	Corn residue is a promising feed resource due to its abundance, but nutritional improvement is required	Mafefa et al. (2023)
Corn straw	Lignin 3.31–8.61 Dry matter digestibility 45.87–60.26 Organic matter digestibility 52.53–65.47	Corn straw potential is limited by lignocellulosic bonds that restrict digestibility	Noersidiq et al. (2024)
Rice straw	Crude protein 27.10–34.20 Crude fiber 23.71–30.07 Dry matter digestibility 44.09–70.23 Organic matter digestibility 53.12–78.41 Crude protein digestibility 51.57–74.86	Rice straw is highly abundant and can support ruminant feeding systems if properly treated; Agricultural residues have strong potential when combined with concentrates or processed	Hastuti (2011); Elihasridas & Herawati (2014)

Although rice straw is abundant, it is still not optimally utilized as fresh feed, so the nutritional value of straw must be improved through fermentation. Agricultural waste, which was previously considered low in value, has great potential to be utilized as feed through proper processing. Processing agricultural waste through silage technology with the addition of additives and microbes can overcome the natural weaknesses of straw and has the potential to support sustainable feed supply strategies in dryland areas. Thus, agricultural waste has strategic value not only as alternative feed, but as a key component in an efficient and adaptive agriculture-livestock integration system for dry climate conditions.

Noersidiq *et al*. (2024) showed that corn straw, which was initially difficult to digest due to its high lignin content, became more digestible after undergoing ammoniation. This indicates that agricultural waste with high fiber content can still be utilized if treated appropriately. With such treatment, the waste can be used as an energy source for ruminant livestock, especially when fresh forage is difficult to obtain during the dry season.

Meanwhile, Hastuti *et al*. (2011) and Elihasridas & Herawati (2014) emphasized that agricultural waste such as cobs or mixed corn waste is not only an alternative feed. If processed using the appropriate technology, its nutritional value can increase. The combination of ammoniation and fermentation (Amofer) has been proven effective in increasing crude protein content, thereby meeting the nutritional needs of rumen microbes. Formulations with the right proportion of ammoniation can also optimize rumen fermentation. (Santi *et al*. 2025).

Silage Technology

Silage is an important method for preserving feed, especially for utilizing agricultural waste in dryland areas where green fodder availability is often uncertain. Silage technology allows farmers to store green fodder or agricultural waste for long periods of time in a stable manner due to the anaerobic fermentation process involving lactic acid bacteria (LAB). In dryland areas, the dry season causes forage to become scarce, so farmers usually use rice or corn straw. However, these materials generally have low nutritional quality, high crude fiber, low protein, and low soluble carbohydrate content. Therefore, the use of silage with additives is very important to improve fermentation and feed quality. The following is a table of selected journals in the silage technology category.

The study by Anjalani *et al*. (2022) used four additives, namely bran, EM4, ground corn, and tapioca in corn straw silage. The results showed that all treatments had fairly good physical quality, but EM4 was most effective in reducing crude fiber content, thereby increasing the digestibility of corn straw silage.

Research by Banu *et al*. (2019), which used corn straw as the base material, supports the previous results. They found that the addition of Heryaki powder microbes produced the lowest pH, namely 3.54. This indicates that the fermentation process took place most quickly and was the most dominant. In addition, all additive treatments in this study had ammonia levels of less than 15%. This condition indicates that the proteolysis process was very low, so that the protein was preserved during fermentation. The results of these two studies prove that corn straw can be processed into good quality silage if the right combination of carbohydrate additives and microbial inoculants is used.

On the other hand, Mafefa *et al*. (2023a) introduced porang flour as an additive. Porang flour is rich in fermentable glucomannan and can accelerate pH reduction, as well as improve silage nutrition. This study shows that adding 3–9% porang can increase crude protein content and reduce crude fiber, with the best results at the 9% level. This makes porang the most effective additive in improving digestibility and nutrient utilization by ruminants.

Ammoniation technology

The use of agricultural waste as alternative feed is very important for livestock farming in dryland areas, because good quality forage is often difficult to find. In this case, feed processing such as silage and ammoniation is very helpful in utilizing agricultural waste that is widely available during the harvest season. In addition to silage, ammoniation can also improve the nutritional quality of various agricultural wastes, thereby supporting the feed requirements of ruminants throughout the year.

Table 2. Comparative Effects of Silage and Ammoniation Technologies on Nutritional Quality and Digestibility of Agricultural Wastes

Technology	Material	Treatment / Additive	Main Parameters Improved	Key Findings	Reference
Silage	Corn straw	EM4, bran, tapioca	Crude fiber, pH	EM4 most effective in reducing crude fiber	Anjalani et al. (2022)
Silage	Corn straw	Gaplek, sago, heryaki	pH, NH_3	pH reduced to 3.54; NH_3 within safe range	Banu et al. (2019)
Silage	Rice straw	Porang flour (3–9%)	Crude protein, crude fiber	CP increased and CF decreased; best at 9%	Mafefa et al. (2023a)
Silage	Agricultural residues	Natural fermentation (LAB)	pH, nutrient preservation	Good-quality silage characterized by low pH and minimal nutrient loss	Hastuti (2011)
Ammoniation	Corn straw	Urea (4%)	Lignin, digestibility	Most effective lignin degradation	Noersidiq et al. (2024)
Ammoniation	Corn waste ration	40% residue + 60% concentrate	DM & OM digestibility	DM 65.18%; OM 73.74%	Elihasridas & Herawati (2014)

Based on research by Noersidiq *et al.* (2024), corn straw, a major waste product in drylands, is difficult to digest because it contains high levels of lignin. Using urea for ammoniation, the study found that a 4% dose was most effective in reducing lignin content and improving digestibility. These results prove that ammoniation is suitable for use on waste that is abundant but of low quality, a condition commonly found in drylands. Lignin reduction is an important aspect in improving ruminant performance when fresh forage is not available.

Feed processing using lignocellulosic waste such as rice straw and corn straw aims to increase feed digestibility. This is done by breaking down the structural parts of plants that mainly contain lignin, cellulose, and hemicellulose. The technologies commonly used are ammoniation and fermentation. Ammoniation works through a chemical reaction with ammonia, while fermentation relies on the role of microbes and fiber-breaking enzymes (cellulolytic). The addition of these fermentation microbes accelerated fiber breakdown, making the nutrients in the feed more accessible to microbes in the rumen. This process allows nutrients such as volatile fatty acids (VFA) to be produced more optimally and become the primary energy source for ruminants (Hindratiningrum *et al*. 2022)

Research by Suningsih and Ibrahim (2018) shows that ammoniation is more effective than fermentation in reducing crude fiber, NDF, and ADF levels in rice straw due to the harder structure and higher lignin content of rice straw. Fermentation, even with starters such as Probiotic FM, is less effective at breaking down fiber to the maximum extent because it is difficult to break the cell wall bonds compared to the chemical method of ammoniation.

CONCLUSION

Agricultural waste has great potential as a source of ruminant feed in drylands. Processing technologies such as silage and ammoniation can increase nutritional value and extend feed shelf life. The implementation of these two technologies also increases farmers' capacity to utilize local resources sustainably. In dryland areas, silage technology with the right additives allows for optimal utilization of agricultural waste, increases feed availability throughout the year, and supports the sustainability of ruminant farming. Ammoniation technology is one of the most effective, easy-to-apply, and relevant methods for processing agricultural waste in drylands. The difference lies in the type of waste used and the integration of additional technologies, such as fermentation, as well as the context of its use in feed. Ammoniation and fermentation play a role in improving the nutritional quality of agricultural waste, but their effectiveness is greatly influenced by the type of substrate, fiber composition, and the type of microbes or decomposers used. A combination of silage production and ammoniation is recommended to support feed resilience in dryland areas.

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