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Livestock Feeding Challenges, Alternative Strategies, and Waste-to-Feed Innovations in the Nepalese Livestock Sector: A Review

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ABSTRACT

Nepal's livestock sector plays a vital role in ensuring food security, supporting rural livelihoods, and driving economic growth; however, feed shortages, rising costs, and inefficient waste management remain significant challenges. This review explores the potential of waste-to-feed innovations as a sustainable strategy within a circular bioeconomy approach. It outlines the current status of feed resources and explores opportunities to transform agro-industrial by-products, food waste, and animal by-products into nutritionally valuable feed ingredients. Advanced methods such as microbial fermentation, insect-based protein production, and enzymatic conversion of lignocellulosic biomass are discussed for their roles in enhancing feed quality and decreasing reliance on traditional feed sources. Emerging thermal and non-thermal processing technologies, along with their environmental advantages and socio-economic impacts, including cost savings, waste valorization, and employment creation, are also explored. Policy and institutional support from the Ministry of Agriculture and Livestock Development, the Department of Livestock Services, and the Nepal Agricultural Research Council is vital in this aspect; however, challenges related to safety regulations, quality assurance, and research data gaps remain. Therefore, the adoption of waste-to-feed technologies in Nepal represents a transformative opportunity to reduce environmental burdens and foster sustainable rural entrepreneurship. Coordinated policies, research partnerships, and capacity-building are essential to realizing a resilient, circular livestock production system.

Keywords: Circular economy, Feed innovation, Livestock sustainability, Waste valorization

सारांश

नेपालको पशुपालन क्षेत्र खाद्य सुरक्षा, ग्रामीण जीविकोपार्जन तथा राष्ट्रिय अर्थतन्त्रको महत्त्वपूर्ण आधार रहेको छ। यस क्षेत्रमा दाना अभाव, बढ्दो लागत, आयातमा निर्भरता, जैविक फोहोरहरूको उचित व्यवस्थापन जस्ता समस्याहरू महत्त्वपूर्ण चुनौतीहरू बनेका छन्। यस सन्दर्भमा, फोहरलाई दानामा रूपान्तरण गर्ने नवीन प्रविधिहरू (waste-to-feed innovations) दिगो कृषि—अर्थतन्त्र निर्माणका लागि प्रभावकारी विकल्पका रूपमा विकसित हुँदैछन् । यस अध्ययनले नेपालमा दानाका स्रोतहरूको वर्तमान स्थिति, कृषि तथा एग्रो—उद्योगजन्य उपउत्पादन, घरेलु तथा बजार फोहर, र पशु उप-उत्पादनहरू उपयोग सम्बन्धी प्रविधि र सम्भावनाको विश्लेषण गरेको छ । सूक्ष्मजीवीय तथा कीराको लार्भाबाट (e.g. Black Soldier Fly) प्रोटिन उत्पादन, र लिग्निनयुक्त बाली अवशेषहरूको एन्जाइम तथा ढुसीजन्य जैव—रूपान्तरण प्रविधिहरूले दानाको पोषण सुधार गर्दै वातावरणीय प्रभाव घटाउन मद्दत गर्दछन्। साथै, विभिन्न प्रशोधन प्रविधिहरू जस्तै सौर्य सुकाइ प्रणाली र पेलेट प्रविधि साना तथा मध्यम उद्यमीका लागि व्यवहारिक समाधानका रूपमा रहेका छन्। फोहरलाई दानामा रूपान्तरण गर्ने प्रणालीले दाना लागत घटाउने, ग्रामीण रोजगार सिर्जना गर्ने, फोहर पुनःप्रयोगद्वारा वातावरणीय प्रदूषण घटाउने र हरितगृह ग्यास उत्सर्जन न्यूनीकरणमा योगदान पुर्‍याउने देखिएको छ । यस्ता प्रविधिहरू कृषि तथा पशुपन्छी विकास मन्त्रालय, पशु सेवा विभाग, र नेपाल कृषि अनुसन्धान परिषद्का नीतिगत पहलहरूसँग सहकार्यमा लागू गर्न सकिने सम्भावना देखिन्छ । तथापि, सूक्ष्मजीवजन्य जोखिम नियन्त्रण, गुणस्तर प्रमाणीकरण, र प्रभावकारी नियमनका क्षेत्रहरूमा अझ सुधार आवश्यक छ । त्यसैले, फोहर—आधारित दाना प्रविधिको कार्यान्वयनले नेपालमा दिगो, स्वावलम्बी र वातावरण—मैत्री पशुपालन प्रणाली स्थापना गर्न योगदान पुर्‍याउनेछ । यसका लागि नीतिगत समन्वय, अनुसन्धान—आधारित निर्णय, र क्षमतावृद्धि अपरिहार्य छन् ।

INTRODUCTION

The livestock sector in Nepal plays a crucial role in the national economy, significantly contributing to agricultural output, food security, and rural livelihoods. Beyond its economic significance, livestock farming is deeply embedded into Nepal's social and cultural systems, supporting household resilience and poverty reduction. The sector accounts for about 11.5% of the country's gross domestic product (GDP) and remains a vital source of income for smallholder and subsistence farmers, who constitute nearly two-thirds of the population (Ghimire & Chapagain, 2020; Khanal et al 2024). Among its various subsectors, dairy production alone accounts for nearly two-thirds of livestock GDP, highlighting the increasing dependence on animal-based foods (Subedi & Kattel, 2022). Livestock ownership also enhances food and nutritional security by providing households with income stability and diverse diets (Moucheraud et al 2019).

Despite its significance, Nepal's livestock sector faces complex challenges, including climate vulnerabilities, disease outbreaks, and economic limitations (Khanal et al 2022; Khanal et al 2024). Policy measures such as the National Livestock Policy (Pradhanang et al 2015) aim to improve productivity, inclusivity, and equity within the sector, but structural barriers remain. Although national policies aim to boost productivity and inclusiveness, constraints such as limited pasture resources, reliance on imported feed ingredients, and socio-cultural restrictions, such as the no-slaughter policy for sacred cattle, continue to limit sectoral efficiency (Ojo et al 2022). Therefore, ensuring long-term sustainability requires innovative, resource-efficient strategies that improve feed availability and environmental performance (KC et al 2025).

Feed scarcity remains a major constraint to livestock productivity in Nepal and presents both national and regionally uneven implications. National feed balance report shows a 31% dry-matter (DM) deficit and a 20% total digestible nutrient (TDN) gap, with regional disparities, Mid-Hill (−24%), Terai (−18.9%), and High Mountain (−12%) shortages (Singh & Singh, 2019; Shrestha et al 2023; Shah et al 2019).These deficits intensify during the dry season when pasture regeneration declines and farmers rely on low-quality residues. As feed accounts for 60–70% of total production costs, dependence on imported maize, soybean meal, and mineral ingredients exposes producers to currency fluctuations, price volatility, and supply chain disruptions (Mat et al 2021; Bor, 2024). Climate-related reductions in forage availability and the absence of coordinated feed resource planning further compound these pressures (Suhendro et al 2025). At the same time, substantial quantities of agro-industrial and organic waste including crop residues, brewery by-products, and market waste, remain underutilized or are discarded through open dumping or burning, contributing to nutrient loss, greenhouse gas emissions, and localized pollution (El-Ramady et al 2020; Budihardjo et al 2023). Strategically valorizing these materials as feed inputs presents a practical pathway to improve national feed security while mitigating environmental burdens.

Adopting a circular economy model offers a promising way to address both feed shortages and waste management challenges simultaneously. Circularity encourages the reuse, recycling, and valorization of agricultural and food system by-products (Rao & Rathod, 2018). Studies have shown that agricultural residues can be turned into biofertilizers, bioplastics, or livestock feed components, creating both economic and ecological benefits (Varghese et al 2023). Waste-to-feed technologies such as microbial fermentation, insect-based protein production, and enzymatic bioconversion offer promising opportunities to produce safe, nutrient-rich feed while reducing environmental impacts (Nath et al 2023; Iskakov & Sugirbay, 2023). Such innovations closely align with the Sustainable Development Goals (SDGs), especially SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Repurposing food and agro-waste into animal feed decreases landfill pressure and emissions while supporting nutrient recycling and circular agriculture (Hasan & Lateef, 2023; Ogwu, 2025). These systems promote economic resilience by reducing feed costs, creating rural jobs, and encouraging green entrepreneurship (Georganas et al 2023). In this context, building a sustainable bioeconomy that combines food production, waste utilization, and environmental conservation is vital for Nepal's livestock sector. Waste-to-feed innovation offers an important opportunity to turn the country's waste problems into sustainable feed solutions. Therefore, this review examines the potential, challenges, and policy aspects of waste-to-feed technologies in Nepal, highlighting their role in improving feed security, protecting the environment, and supporting circular livestock production.

Methodology

This review employed a structured literature screening and evidence-synthesis approach. Relevant studies were identified from Scopus, Web of Science, Science Direct, Springer Link, PubMed, and Google Scholar, along with sources such as NepJOL and institutional reports from the Nepal Agricultural Research Council (NARC). Search strings combined terms including waste-to-feed, circular nutrition, agro-industrial by-products, organic waste valorization, and livestock feed systems in Nepal. Sources were screened for relevance, clarity, and data reliability, with priority given to peer-reviewed publications, government or institutional reports. Articles lacking non-livestock industrial waste studies were excluded. Extracted findings were narratively synthesized to identify thematic patterns across technological pathways, socio-economic outcomes, environmental implications, and regulatory considerations.

Feed Resource Status and Challenges in Nepal

Nepal's feed resource landscape is defined by strong ecological gradients, highly fragmented smallholder production systems, and uneven market access, creating regional disparities in the quantity and quality of available feed. These structural constraints limit the supply of nutritious fodder and concentrate feeds, directly affecting livestock productivity and income. Despite livestock's central role in rural food security, national feed availability remains below requirement, and shortages persist across most agro-ecological zones (Khanal et al 2020; Shrestha et al 2023). Much of the livestock diet comes from crop by-products and residues, making up about 47% of daily nutrition. However, the country faces a shortfall in the dry matter (DM) required for livestock, with roughly 31% of DM unavailable nationwide (Shrestha, Kanu, GC, & Baskota, 2023). National assessments indicate an overall feed deficit of about 20% in total digestible nutrients (TDN), with the mid-hills experiencing the most significant shortages (−24%) and the Terai at (−18.9%) (Singh & Singh, 2019). These shortages are especially severe during the dry season, when reliance on low-quality residues results in poor animal performance (Shah et al 2019). Tree fodders like *Ficus semicordata*, *Bauhinia variegata*, and *Artocarpus lakoocha* are important protein sources during lean periods. Meanwhile, integrated crop–livestock–agroforestry systems show promise in increasing fodder supply and nutrient use efficiency (Tamang et al 2020; Khanal et al 2020). Climate variability further affects forage availability and nutritional value, pushing farmers to adopt adaptive strategies such as growing climate-resilient species, adjusting sowing times, and diversifying livestock holdings (KC et al 2025). Additionally, competition for resources with wildlife in buffer zones near protected areas has increased, as both domestic herds and wild herbivores depend on the same limited pasturelands (Kafle et al 2024).

A growing reliance on imported feed ingredients, such as maize, soybean meal, and mineral premixes, raises feed costs and exposes the livestock sector to market fluctuations and foreign-exchange risks. Besides quantity shortages, challenges also exist in the quality and sourcing of feed ingredients. Nepal's livestock and poultry industries rely heavily on imported maize, soybean meal, and mineral premixes, which make producers vulnerable to market volatility and foreign exchange risks. In Nepal, the poultry feed sector consumes about 3,000 metric tons of feed daily, with roughly half of the formulation consisting of maize. Over 80% of the maize used in feed is imported, at a cost of over USD 100 million annually (CIMMYT, 2022). Similarly, Nepal depends heavily on imported soybean and soybean meal to supply its feed industry. In 2022, Nepal imported roughly 135,993 metric tons of soybeans valued at USD 96.6 million (World Integrated Trade Solution [WITS], 2024). A recent report by the U.S. Soybean Export Council showed that soybean and soybean meal imports totaled around 271,000 metric tons during 2023/24, highlighting the country's increasing reliance on foreign protein sources for livestock feed (U.S. Soybean Export Council [USSEC], 2025). This dependence not only affects the economic stability of smallholders but also raises concerns about the long-term sustainability of national feed security. Developing locally available, nutrient-rich feed alternatives from crop residues, fodder trees, and agro-industrial by-products is crucial to building resilient, self-sufficient livestock production in Nepal.

Agro-industrial By-products and Alternative Feed Resources in Nepal

Agro-industrial by-products are an essential yet underutilized part of Nepal's livestock feed resources. The rapid growth of agro-processing industries, such as rice milling, oilseed extraction, breweries, and sugar production, has produced a variety of nutrient-rich residues that can partially replace traditional feed ingredients. Incorporating these by-products into livestock diets offers opportunities to reduce feed costs, increase resource efficiency, and promote circular agricultural practices. Among cereal-based by-products, rice bran, wheat bran, and maize gluten meal are common sources of energy and protein. Rice bran, rich in essential fatty acids and B-complex vitamins, is widely used in poultry and dairy feeds, though its high oil content needs stabilization to prevent rancidity (Khanal et al 2020). Similarly, wheat bran and maize by-products are valuable parts of concentrate feeds, especially during times of limited grain supply. Oilseed cakes from mustard, soybean, linseed, and sesame supply high-protein supplements that boost milk production and growth performance when properly processed to remove antinutritional factors (Shah et al 2019; Tamang et al 2020).

Brewer's spent grains, molasses, and sugarcane bagasse also hold significant potential as affordable feed resources. Brewer's grains provide digestible fiber and crude protein suitable for ruminant diets. At the same time, molasses serves as an excellent source of fermentable energy, enhancing palatability and rumen microbial activity (KC et al 2025). Similarly, bagasse and other fibrous residues can be improved through microbial fermentation or urea–molasses treatment to boost digestibility and nutrient absorption (Poudel et al 2020). Animal by-products such as blood meal, bone meal, and feather meal also offer nutrient-rich supplements, containing 70–85% protein and essential minerals when processed safely (Khiari, 2022; Prüter et al 2020). Fishery residues, high in protein and omega-3 fatty acids, can be efficiently transformed into fish meal or silage to support aquaculture and livestock feed (Alvarado-Ramírez et al 2023). Ensuring biosecurity through proper sterilization, pathogen monitoring, and heavy-metal control is essential to protect food safety (Cheli et al 2013; Hua et al 2019). Seasonal fluctuations in supply and transportation issues further hinder consistent use, especially in remote areas. Variations in nutrient composition arise from processing techniques, ingredient quality, and agronomic factors influencing raw material characteristics. **Table** 1 summarizes the dry matter, crude protein, fibre, lipid, and mineral values from validated feed tables and institutional references.

Table 1. Nutrient composition of selected agro-industrial by-products used in animal feed

Feed resources	DM %	CP %	CF %	EE %	Ca %	P %	Source
Rice bran	90.2	12.7	16.3	14.4	0.07	1.38	Heuzé et al 2013 – Feedipedia; Sauvant et al 2004
Wheat bran	87.0	17.3	10.4	3.9	0.14	1.11	Sauvant et al 2004; Heuzé et al 2013
Maize gluten meal	90.6	63.7	2.0	4.5	0.07	0.56	Sauvant et al 2004 – Feed Tables
Mustard oilseed cake / Rapeseed meal	89.3	38.6	13.2	3.8	0.86	1.27	Heuzé et al 2013 – Rapeseed Meal Datasheet
Linseed cake	87.6	36.3	11.6	3.6	0.44	0.96	Heuzé et al 2013 – Linseed Meal Profile

Feed resources	DM %	CP %	CF %	EE %	Ca %	P %	Source
Brewer's spent grain (BSG), dried	89.0	17.1	14.8	1.0	0.25	1.92	Heuzé et al 2013 – Brewers Grain Datasheet
Sugarcane molasses	73.0	5.5	0.1	1.0	0.92	0.07	FAO, 2004; Heuzé et al 2013
Bagasse (raw, untreated)	92.5	2.0	46.4	1.0	0.18	0.08	Heuzé et al 2013 – Bagasse; FAO, 2004
Blood meal (spray-dried)	93.8	94.1	0.5	0.8	0.13	0.22	FAO, 2004; ICAR, 2013
Bone meal (defluorinated only)	95.0	13–15	<1	<2	24–30	10–14	ICAR, 2013; FAO, 2004 (Bone Meal standard)
Feather meal (hydrolyzed)	92.0	85.5	1.4	9.2	–	–	FAO, 2004; ICAR, 2013
Fish meal (commercial grade)	92.2	70.6	–	~10.0	4.34	2.79	Heuzé et al 2013 – Fish Meal Profile
BSFL meal (Black Soldier Fly Larvae, dried)	91.0	46.2	–	23.1	5.49	1.12	Crosbie et al 2020; Lu et al 2022 (Insects Journal)

DM = Dry Matter; CP = Crude Protein; CF = Crude Fiber; EE = Ether Extract, Ca= Calcium, P= Phosphorus

Utilization Constraints and Research Needs

Despite their abundance, the full potential of agro-industrial by-products in Nepal remains underused due to technological, logistical, and institutional constraints. Lack of standardized processing facilities, quality control systems, and awareness among smallholder farmers restricts their large-scale use (Dobermann et al 2019; Pratama et al 2019). Efficient drying, detoxification, and storage methods are essential to maintain nutritional quality and prevent microbial spoilage. Furthermore, creating region-specific feed formulations using locally available by-products can greatly cut feed costs and reduce dependence on imported ingredients. Additional research into the nutrition, safety, and digestibility of Nepalese by-products is also needed. Collaboration among research institutions, the private feed sector, and government agencies could help establish pilot processing units and promote sustainable feeding practices across various agro-ecological zones.

Circular Nutrition and Waste Valorization

The concept of circular nutrition emphasizes closing nutrient loops within the agri-food system by recycling organic waste into useful products. Waste valorization turns discarded materials into valuable inputs such as feed, fertilizer, or bioenergy, thereby helping reduce environmental impact and competition for resources (Dhiman et al 2024; Puglia et al 2021). For Nepal, this approach provides a way to address feed shortages and waste management challenges simultaneously. Fungal and microbial processing of lignocellulosic residues, for example, can produce enzymes, organic acids, and functional feed ingredients, enhancing both productivity and sustainability.

Innovative Waste-to-Feed Technologies

Nepal's livestock sector faces concurrent challenges of feed scarcity, rising input costs, and increasing volumes of unmanaged organic waste. Waste-to-feed (WtF) technologies provide a strategic solution by converting agricultural residues, food waste, and agro-industrial by-products into nutritionally usable feed resources. These systems integrate biological and mechanical processing to improve nutrient value, storage stability, and feed safety.

Figure 1. Circular bioeconomy pathway for waste-to-feed systems illustrating input sources, bioconversion technologies, benefits, and risk considerations (Source: *Notebook LM*)

Circular Nutrition and Waste Valorization

Circular nutrition focuses on retaining nutrients within the agri-food system by reintroducing organic waste materials into productive use. In this model, waste valorization converts discarded resources into feed, fertilizer, or bioenergy, thereby lowering environmental burdens and competition for conventional feed crops (Dhiman et al 2024; Puglia et al 2021). For Nepal, this dual benefit is particularly relevant, as feed shortages and waste mismanagement occur simultaneously. Processes such as fungal and microbial bioconversion of lignocellulosic residues (e.g., rice straw, bran, market waste) can enhance digestibility, produce value-added metabolites, and generate functional feed components that support animal performance. These practices are strongly aligned with circular bioeconomy principles and directly complement national priorities on sustainable livestock development.

Fermentation and Ensiling

Fermentation and ensiling are essential techniques for preserving feed and enhancing its quality. Lactic acid bacteria (LAB), especially *Lactobacillus plantarum* and *L. buchneri*, play vital roles in converting soluble sugars into lactic acid, reducing pH, and preventing spoilage microorganisms (Dunière et al 2017; Xu et al 2020; McAllister et al 2018). The resulting anaerobic environment boosts feed safety and extends storage life. The activity of yeasts like *Saccharomyces cerevisiae* further improves fermentation stability, nutrient availability, and flavor (Ávila et al 2010; Dunière et al 2015). In Nepal, indigenous starter cultures adapted to local climates and crops (such as maize and millet) are increasingly used to produce region-specific silage with better fermentation stability (Cheng et al 2022; Yang et al 2022). These methods not only conserve nutrients but also enhance digestibility and intake, thereby improving feed efficiency and livestock performance (Li et al 2021; Loi et al 2023; Bai et al 2022).

Microbial and Enzymatic Conversion

Microbial fermentation is among the most promising innovations for converting waste into feed. Through solid-state or submerged fermentation, agricultural residues such as rice bran, maize stover, and vegetable waste can be enriched with microbial biomass and bioactive metabolites that enhance digestibility and protein content (Nath et al 2023). Lactic acid bacteria, *Aspergillus niger*, and *Bacillus subtilis* are often used to break down cellulose and hemicellulose, thereby increasing fiber utilization and feed efficiency. Likewise, enzymatic bioconversion using ligninolytic enzymes—laccase, lignin peroxidase, and manganese peroxidase produced by white-rot fungi such as *Pleurotus ostreatus* helps break down lignin-rich substrates, making them safe for use in ruminant diets (Song et al 2020; Hu et al 2021).

Insect-Based Bioconversion

Insect larvae, especially the black soldier fly (*Hermetia illucens*), offer an innovative way to convert organic waste into high-quality protein and lipids for poultry and fish feed. They are efficient in transforming food residues, livestock manure, and agro-industrial by-products into high-quality biomass rich in protein, lipids, and bioactive compounds. Pilot studies in South and Southeast Asia have shown that insect meal can replace 25–50% of traditional soybean or fish meal without compromising growth performance, making it an eco-friendly and cost-effective option for the growing feed industry (Iskakov & Sugirbay, 2023). The larvae typically contain 40–55% crude protein and 25–35% lipids, including medium-chain fatty acids such as lauric acid, which possess antimicrobial properties beneficial to animal health (Meneguz et al 2022). In addition, chitin and antimicrobial peptides produced by black soldier fly larvae (BSFL) have been shown to improve intestinal integrity and immunity while reducing the need for antibiotics (Adeniran et al 2023). In our context, integrating insect rearing into waste management systems could simultaneously address feed shortages and environmental burdens. Urban centres such as Kathmandu and Pokhara generate large volumes of organic waste suitable for BSFL production, offering a circular approach to nutrient recovery and waste minimization.

Thermal and Non-Thermal Feed Processing Innovations

Recent advances in thermal and mechanical feed processing, including pelleting, extrusion, dehydration, and compaction, have improved nutrient utilization and feed hygiene. Pelleting and extrusion help gelatinize starch, remove anti-nutritional factors, and enhance feed conversion efficiency. Additionally, solar and osmotic dehydration systems provide cost-effective preservation options for smallholder farms in Nepal's rural areas, using abundant solar energy to stabilize moisture-rich materials while maintaining nutrient content (Pendita et al 2014; Salehi et al 2023). New non-thermal technologies such as high-pressure processing (HPP), cold plasma treatment, and pulsed electric fields have proven effective in inactivating microbes and allergens without affecting nutrient content or sensory qualities (Knorr et al 2011; Nwabor et al 2022; Williams, 2024). These low-energy, minimal-heat methods are beneficial for creating high-quality, functional feed ingredients and additives. Incorporating these technologies into local feed systems can extend shelf life, improve safety, and enhance consumer confidence, while also advancing environmental sustainability efforts (Pereira & Vicente, 2010; Singh & Singh, 2019).

Safety, Quality, and Regulatory Concerns

Ensuring the safety and quality of recycled feed systems is a major challenge for sustainable livestock production in Nepal. While recycling food and agricultural waste into animal feed offers economic and environmental benefits, it also poses risks, including microbial contamination, chemical hazards, and weak regulatory oversight. Recycled feed ingredients can contain pathogens, antibiotic residues, mycotoxins, and heavy metals such as lead and cadmium, which can accumulate in animal tissues and pose a threat to public health (Nelson et al 2020). Limited awareness, insufficient laboratory capacity, and poor monitoring systems hinder adequate quality assurance (Khanal et al 2022; Yadav et al 2023). Informal trading of feed materials without proper testing or labeling further increases safety risks and undermines consumer trust (Dahal et al 2017). Aligning Nepal's feed regulatory framework with international guidelines from the Codex Alimentarius, FAO, and WOAH can enhance risk assessment, traceability, and good manufacturing practices (Timsina et al 2016; Menna et al 2020). In Nepal, the legal basis for regulating animal feed quality and safety is established by the Feed Act, 2033 (1976 AD) and its implementing Feed Regulation, 2041 (1984 AD), which empower the government to set standards, inspect feed mills, and conduct laboratory analysis to prevent adulteration and ensure product quality. These laws oversee ingredient definitions, contaminant limits, and testing procedures for manufactured feeds. Using digital monitoring tools for contaminant detection and antimicrobial resistance surveillance, along with strong collaboration among government agencies, private feed manufacturers, and cooperatives, can improve transparency and compliance (Yadav et al 2023). Strengthening laboratory capacity, enforcing feed safety regulations, and promoting stakeholder participation are essential to ensure recycled feed supports livestock productivity without endangering animal welfare, public health, or environmental sustainability.

Socio-Economic and Environmental Implications of Waste-to-Feed Systems

The adoption of waste-to-feed (WtF) systems in Nepal has significant social, economic, and environmental impacts, connecting sustainable livestock farming with circular resource use. Economically, recycled feed methods can significantly reduce production costs, since feed accounts for 60–70% of overall livestock expenses. Using locally available organic materials, such as food waste, crop by-products, and agro-industrial residues, can reduce reliance on imported raw materials, stabilize prices, and boost farm profits (Zikria et al 2025). Cost savings from WtF benefit not only commercial farms but also smallholder farmers, who are often the most affected by feed price fluctuations. Waste valorization also creates jobs and promotes local businesses. Activities such as waste collection, sorting, microbial fermentation, and insect farming build new value chains that support rural employment and boost local economies. Community recycling enterprises, especially in urban and peri-urban areas, provide sustainable livelihoods for youth and marginalized groups while helping to keep the environment clean. These green businesses uphold circular bioeconomy principles by managing waste and producing valuable feed resources (Engidaw et al 2025). Environmentally, adopting WtF systems can significantly reduce greenhouse gas (GHG) emissions by reducing organic waste decomposition in landfills and lowering methane emissions. Additionally, diverting biodegradable waste into productive use lessens landfill pressure and protects natural ecosystems. The reduced use of traditional feed crops such as maize and soybeans also helps prevent deforestation and land degradation, supporting Nepal's national climate goals and the global Sustainable Development Goals (SDGs 2, 12, and 13).

Findings from Nepal highlights how WtF systems can yield socio-economic and environmental benefits. Black Soldier Fly larvae (BSFL) reared on locally sourced organic biowastes in Nepal reached protein contents up to 32 %, indicating potential as a sustainable feed ingredient while diverting waste from landfill (Gautam et al 2025). Similarly, dairy buffalo in the Tarai region fed total mixed ration silage containing brewer's grains maintained or improved milk yield, demonstrating how agro-industrial by-products can reduce dependence on imported feed inputs (Sakai et al 2015). A national assessment of Nepal's waste biomass also underlined significant availability of residues suitable for conversion into feed or fertiliser, supporting rural value chains and reducing environmental pressure (Kafle et al 2024). Analyses of existing feed resources further emphasise the growing role of crop by-products and processed wastes in livestock feeding systems in Nepal (Osti, 2019).

However, realizing these benefits requires supportive policies, research, and investment frameworks that ensure feed safety, quality assurance, and stakeholder participation. Establishing decentralized processing hubs, fostering training programs, and encouraging private-sector investment can increase both social and environmental benefits. Essentially, the successful adoption of waste-to-feed technologies in Nepal has the potential to create a win–win situation, lowering feed costs, generating employment, and reducing environmental damage while helping the country move toward a more resilient and sustainable livestock system.

Policy and Institutional Framework for Sustainable Feed and Waste Management

A strong policy and institutional framework is crucial for integrating sustainable feed production and waste management into Nepal's livestock development plans. The Ministry of Agriculture and Livestock Development (MoALD), Department of Livestock Services (DLS), and Nepal Agricultural Research Council (NARC) are key organizations leading efforts to promote efficient resource use and circular bioeconomy principles. Recent initiatives have focused on valorizing agricultural residues and improving feed formulation strategies to boost productivity while reducing environmental impacts (Nath et al 2023; Ogwu, 2025). NARC, in particular, has conducted applied research on transforming agricultural by-products into safe, nutrient-rich feed ingredients, supporting the development of locally adaptable technologies (Carter et al 2024).

Municipal governments and local bodies are playing an increasingly important role in implementing WtF strategies at the community level. They can promote source segregation, waste collection, and partnerships among farmers, cooperatives, and recycling companies. Evidence from similar decentralized systems shows that effective coordination between waste generators and recyclers boosts resource efficiency and economic viability (Mendez et al 2022). In Nepal, including livestock-based enterprises within municipal waste management plans could greatly reduce landfill loads while supporting small-scale feed entrepreneurs.

The private sector and cooperatives also hold strong potential for innovation and investment. Agro-industries, feed mills, and cooperatives can engage in public–private partnerships (PPPs) to develop and commercialize sustainable feed products derived from agro-industrial residues. PPP models promote technology transfer, infrastructure sharing, and capacity-building while ensuring scalability and financial sustainability (Ramirez et al 2021). Cooperatives, on the other hand, can serve as intermediaries linking smallholder farmers to feed markets, thereby improving local ownership and participation (Mourad, 2016). To realize the full potential of a circular livestock economy, policy coherence is essential. Establishing feed quality standards, certification systems, and clear regulatory guidelines for recycled feed products will build trust among consumers and producers. Integrating circular economy concepts into national livestock policies and research agendas, alongside strengthening institutional collaboration between MoALD, DLS, NARC, municipalities, and private stakeholders, will be crucial for achieving feed security, environmental sustainability, and resilient livestock systems in Nepal.

Research and Knowledge Gaps

Despite increasing interest in sustainable feed innovation and circular bioeconomy practices, significant gaps in research and knowledge remain in Nepal's feed and waste management sector. These gaps hinder the development, adoption, and integration of WtF technologies, especially in areas such as nutrient profiling, safety assessment, and farmer adoption. A significant gap involves the complete characterization of feed resources derived from agro-industrial and food waste. Limited data on nutrient content, anti-nutritional factors, and the seasonal availability of residues hinder the development of nutritionally balanced and safe feeds (Zhang et al 2024). Baseline studies focusing on composition analysis and contamination levels, including heavy metals and microbial hazards, are crucial for ensuring quality and regulatory compliance.

Another crucial gap is the absence of pilot demonstration models tailored to Nepal's ecological and socio-economic conditions. While numerous global examples show the feasibility of recycled feed systems, localized studies validating these technologies within Nepalese contexts are limited. Creating small-scale pilot projects that combine feed production, waste segregation, and economic analysis would help identify scalable solutions and boost farmer confidence (Tanga et al 2022). Additionally, understanding the behavioral and socio-economic factors behind feed adoption is limited. Farmer perceptions, risk attitudes, and market incentives greatly affect the acceptance of WtF products. Research into these behavioral aspects can guide awareness campaigns, training programs, and participatory extension strategies to improve adoption at the grassroots level (Saxe et al 2018).

Institutionally, there is a need for interdisciplinary collaboration linking research institutions (e.g. NARC), universities, local governments, and private industries. Joint research frameworks should incorporate feed chemistry, microbiology, and economics to evaluate not only technical feasibility but also economic viability and environmental impact of WtF innovations. Strengthening public–private partnerships can promote technology transfer, infrastructure development, and long-term monitoring of feed safety and sustainability outcomes. Addressing these research and knowledge gaps will be crucial in building a reliable evidence base for policymaking and practical implementation. A coordinated effort that combines scientific research, field validation, and stakeholder participation can guide Nepal toward a resilient, resource-efficient, and environmentally responsible livestock feed system.

CONCLUSION

Nepal's livestock sector is constrained by structural feed deficits, evidenced by an estimated 31% national dry-matter shortage and regionally uneven TDN gaps reaching 24% in the mid-hills, compounded by rising dependence on imported maize and soybean meal. The findings indicate that locally available materials such as crop residues, fodder trees, brewer's grains, oilseed cakes, and other agro-industrial by-products can partially substitute commercial feed ingredients when appropriate processing and quality control are followed. Furthermore, emerging waste-to-feed technologies, including microbial fermentation, enzymatic bioconversion, and insect-based protein systems, consistently show potential to enhance nutrient availability, reduce feed costs, and improve resource circularity. These methods support circular bioeconomy principles by reducing waste, lowering emissions, and creating rural jobs. Ensuring their success will depend on proper nutrient analysis, feed safety verification, and adaptable demonstration models suited to local conditions. Incorporating these sustainable feeding strategies can make Nepal's livestock industry more productive, resilient, and environmentally friendly.

REFERENCES

Adeniran AE, II Yusuf, TT Femi-Adebayo and TN Nwagu. 2023. Gut health improvement and antimicrobial peptide potential of black soldier fly larvae meal in poultry feeding. *Animal Feed Science and Technology* **307**:115716. **DOI**: https://doi.org/10.1016/j.anifeedsci.2023.115716

Alvarado-Ramírez L, B Santiesteban-Romero, G Poss, J Sosa-Hernández, H Iqbal, R Parra-Saldívar, et al. 2023. Sustainable production of biofuels and bioderivatives from aquaculture and marine waste. *Frontiers in Chemical Engineering* **4**:1072761. DOI: https://doi.org/10.3389/fceng.2022.1072761

Ávila CLS, CEC Bravo Martins and RF Schwan. 2010. Identification and characterization of yeasts in sugarcane silages. *Journal of Applied Microbiology* **109**:1677–1686. **DOI**: https://doi.org/10.1111/j.1365-2672.2010.04796.x

Bai J, Franco M, Z Ding, H Lin, W Ke, M Wang, et al. 2022. Effect of Bacillus amyloliquefaciens and Bacillus subtilis on fermentation, dynamics of bacterial community and their functional shifts of whole-plant corn silage. *Journal of Animal Science and Biotechnology* **13(1)**:649-0. **DOI**: https://doi.org/10.1186/s40104-021-00649-0

Bor Ö. 2024. A fourier-based approach to understanding the impact of dairy farming on red meat prices: evidence from the Turkish case. *British Food Journal* **127(1)**:182-194. **DOI**: https://doi.org/10.1108/bfj-12-2023-1115

Budihardjo M, H Huboyo and D Kurniatama. 2023. Comparative study of the life cycle assessment model for agricultural solid waste management: case studies in East Ungaran and West Ungaran districts, Semarang. *IOP Conference Series Earth and Environmental Science* **1248(1)**:012013. **DOI**: https://doi.org/10.1088/1755-1315/1248/1/012013

Carter L, S Dennis, K Allen, P McKenna, X Chen, T Daniell, et al. 2024. Mitigating contaminant-driven risks for the safe expansion of the agricultural-sanitation circular economy in an urbanizing world. *ACS ES&T Water* **4(4)**:1166-1176. **DOI**: https://doi.org/10.1021/acsestwater.3c00803

Cheli F, R Gallo, D Battaglia and V Dell'Orto. 2013. EU legislation on feed related issues: an update. *Italian Journal of Animal Science* **12(2)**:e48. DOI: https://doi.org/10.4081/ijas.2013.e48

Cheng Q, M Li, X Fan, Y Chen, H Sun, Y Xie, et al. 2022. Effects of epiphytic and exogenous lactic acid bacteria on fermentation quality and microbial community compositions of paper mulberry silage. *Frontiers in Microbiology* **13**:973500. **DOI**: https://doi.org/10.3389/fmicb.2022.973500

CIMMYT. 2022. From seed to feed: Maize constitutes half of poultry feed products in Nepal, with over 80% of maize feed being imported at a cost of ~USD 130 million. *International Maize and Wheat Improvement Center* (News article). https://www.cimmyt.org/news/from-seed-to-feed

Crosbie M, C Zhu, AK Shoveller and LA Huber. 2020. Standardized ileal digestible amino acids and net energy contents in full-fat and defatted black soldier fly larvae meal fed to growing pigs. *Translational Animal Science* **4(3**):txaa104. **DOI**: https://doi.org/10.1093/tas/txaa104

Dahal R, A Upadhyay and B Ewald. 2017. One Health in South Asia and its challenges in implementation from stakeholder perspective. *Veterinary Record* **181(23)**:626. **DOI**: https://doi.org/10.1136/vr.104189

Dhiman S, P Kaur, J Narang, G Mukherjee, B Thakur, S Kaur, et al. 2024. Fungal bioprocessing for circular bioeconomy: exploring lignocellulosic waste valorization. *Mycology: An International Journal on Fungal Biology* **1-26**. **DOI**: https://doi.org/10.1080/21501203.2024.2316824

Dobermann D, L Michaelson and L Field. 2019. The effect of an initial high-quality feeding regime on the survival of Gryllus bimaculatus (black cricket) on bio-waste. *Journal of Insects as Food and Feed* **5(2)**:117-123. **DOI**: https://doi.org/10.3920/jiff2018.0024

Du C, J Abdullah, D Greetham, D Fu, M Yu, L Ren, et al. 2018. Valorization of food waste into biofertiliser and its field application. *Journal of Cleaner Production* **187**:273-284. **DOI**: https://doi.org/10.1016/j.jclepro.2018.03.211

Dunière L, L Jin, B Smiley, Q Meng, W Rutherford, Y Wang, et al. 2015. Impact of adding Saccharomyces strains on fermentation, aerobic stability, nutritive value, and select Lactobacilli populations in corn silage. *Journal of Animal Science* **93(5)**:2322-2335. **DOI**: https://doi.org/10.2527/jas.2014-8287

Dunière L, S Xu, L Jin, C Elekwachi, Y Wang, K Turkington, et al. 2017. Bacterial and fungal core microbiomes associated with small grain silages during ensiling and aerobic spoilage. *BMC Microbiology* **17(1)**:94-0. **DOI**: https://doi.org/10.1186/s12866-017-0947-0

El-Ramady H, A El-Henawy, M Amer, AE Omara, T Elsakhawy, H Elbasiouny, F Elbehiry, D Abou Elyazid and M El-Mahrouk. 2020. Agricultural waste and its nano-management: a mini review. *Egyptian Journal of Soil Science* **60**:349–364. **DOI**: https://doi.org/10.21608/ejss.2020.46807.1397

Engidaw A, H Yu, Z Weikang and H Gong. 2025. Economic and social impacts of sustainable entrepreneurship: systematic review and bibliometric study of global evidence. *Sustainable Development* **33(4)**:5890-5903. **DOI**: https://doi.org/10.1002/sd.3440

FAO. 2004. Protein sources for the animal feed industry: expert consultation and workshop, Bangkok, 29 April–3 May 2002. FAO *Animal Production and Health Proceedings* No. 1, Rome, Italy. Available at: https://www.fao.org/4/y5019e/y5019e00.pdf

Franco P, I Shiraishi, R Dekker, A Barbosa-Dekker, D Borsato, K Angilelli, et al. 2023. Optimization of laccase production by Pleurotus ostreatus Florida and evaluation of metabolites generated during kraft lignin biotransformation. *Waste and Biomass Valorization* **14(8)**:2589-2597. **DOI**: https://doi.org/10.1007/s12649-022-02029-9

Georganas A, E Giamouri, A Pappas, E Zoidis, M Goliomytis and P Simitzis. 2023. Utilization of agro-industrial by-products for sustainable poultry production. *Sustainability* **15(4)**:3679. **DOI**: https://doi.org/10.3390/su15043679

Ghimire P and P Chapagain. 2020. Livestock movement in Gaurisankhar Valley, Dolakha, Nepal. *The Geographic Base* **7**:15-23. **DOI**: https://doi.org/10.3126/tgb.v7i0.34263

Hasan Z and M Lateef. 2023. Transforming food waste into animal feeds: an in-depth overview of conversion technologies and environmental benefits. *Environmental Science and Pollution Research* **31(12)**:17951-17963. **DOI**: https://doi.org/10.1007/s11356-023-30152-0

Heuzé V, G Tran, D Bastianelli, H Archimède and D Sauvant. 2013. Feedipedia: animal feed resources information. INRAE, CIRAD, AFZ and FAO, France. Available at: https://www.feedipedia.org

Hu M, L Yuan, Z Cai, J Zhang, D Ji and L Zang. 2021. Ammonia fiber expansion combined with white rot fungi to treat lignocellulose for cultivation of mushrooms. *ACS Omega* **6(47)**:31689-31698. **DOI**: https://doi.org/10.1021/acsomega.1c04388

Hua K, J Cobcroft, A Cole, K Condon, D Jerry, A Mangott, et al. 2019. The future of aquatic protein: implications for protein sources in aquaculture diets. *One Earth* **1(3)**:316-329. **DOI**: https://doi.org/10.1016/j.oneear.2019.10.018

ICAR. 2013. Nutrient requirements of livestock and poultry (3rd revised edition). *Indian Council of Agricultural Research*, New Delhi, India.

Iskakov A and A Sugirbay. 2023. Sustainable feed alternatives: potential of insect-based protein sources in developing countries. *Asian Journal of Agriculture and Biology* **11(1):**47–55. **DOI**: https://doi.org/10.35495/ajab.2022.10.544

Kafle S, M Gyawali, S Adhikari, J Kropp and P Pradhan. 2024. Possibilities and challenges for converting waste biomass into fuel, feed, and fertilizer in Nepal. *Regional Environmental Change* **24(3)**:2285-0. **DOI**: https://doi.org/10.1007/s10113-024-02285-6

KC V, A Dhungana, P Khand, R Upadhyaya, A Bhandari and M Baral. 2025. Farmers' perception about climate change, its impact on livestock health, and adaptation measures in Gandaki Province, Nepal. *Research Square (Preprint)*. **DOI**: https://doi.org/10.21203/rs.3.rs-6669581/v1

Khanal B, N Devkota, M Tiwari and N Gorkhali. 2020. Maximizing fodder yield of teosinte (Euchlaena mexicana) through sowing dates and mixed fodder cropping management. *Journal of Agriculture and Forestry University* **4(1)**:269-278. **DOI**: https://doi.org/10.3126/jafu.v4i1.47097

Khanal P, R Dhakal, T Khanal, D Pandey, N Devkota and M Nielsen. 2022. Sustainable livestock production in Nepal: a focus on animal nutrition strategies. *Agriculture* **12(5)**:679. **DOI**: https://doi.org/10.3390/agriculture12050679

Khanal S, U Tiwari and S Khanal. 2024. Willingness to pay for cattle insurance in Nepal: a double-hurdle model perspective. *Global Journal of Agricultural and Allied Sciences* **5(1)**:7-14. **DOI**: https://doi.org/10.35251/gjaas.2024.002

Khiari Z. 2022. Sustainable upcycling of fisheries and aquaculture wastes using fish-derived cold-adapted proteases. *Frontiers in Nutrition* **9**:875697. DOI: https://doi.org/10.3389/fnut.2022.875697

Knorr D, A Froehling, H Jaeger, K Reineke, O Schlueter and K Schoessler. 2011. Emerging technologies in food processing. *Annual Review of Food Science and Technology* **2(1)**:203-235. **DOI**: https://doi.org/10.1146/annurev.food.102308.124129

Li F, Z Ding, A Adesogan, W Ke, Y Jiang, J Bai, et al. 2020. Effects of class IIA bacteriocin-producing Lactobacillus species on fermentation quality and aerobic stability of alfalfa silage. *Animals* **10(9)**:1575. **DOI**: https://doi.org/10.3390/ani10091575

Li P, Y Lu, M Zhao, L Chen, C Zhang, Q Cheng, et al. 2021. Effects of phenyllactic acid, lactic acid bacteria, and their mixture on fermentation characteristics and microbial community composition of timothy silage. *Frontiers in Microbiology* **12**:743433. **DOI**: https://doi.org/10.3389/fmicb.2021.743433

Li X and Y Zheng. 2019. Biotransformation of lignin: mechanisms, applications and future work. *Biotechnology Progress* **36(1)**:2922-0. **DOI**: https://doi.org/10.1002/btpr.2922

Loi N, V Nguyên, P Anh, Q Tùng, T Hiep T An, et al. 2023. Effects of microbial inoculant on chemical compositions and in vitro digestibility of elephant grass-based silage. *Vietnam Journal of Biotechnology* **21(1)**:189-196. **DOI**: https://doi.org/10.15625/1811-4989/17406

Lu S, N Taethaisong, W Meethip, J Surakhunthod, B Sinpru, T Sroichak, P Archa, S Thongpea, S Paengkoum, RAP Purba and P Paengkoum. 2022. Nutritional composition of black soldier fly larvae and its potential use as an alternative protein source in animal diets: a review. *Insects* **13(9)**:831. **DOI**: https://doi.org/10.3390/insects13090831

Mat B, M Arikan, M Çevrimli, A Akın and M Tekindal. 2021. Factors affecting the price of raw milk in Turkey using panel data analysis. *Ciência Rural* **51(11)**:0-0. **DOI**: https://doi.org/10.1590/0103-8478cr20200937

McAllister T, L Dunière, P Drouin, S Xu, Y Wang, K Munns, et al. 2018. Silage review: using molecular approaches to define the microbial ecology of silage. *Journal of Dairy Science* **101(5)**:4060-4074. **DOI**: https://doi.org/10.3168/jds.2017-13704

Mendez G, C Mahler and S Taquette. 2022. Challenges of selective collection of household waste: a case study in a Brazilian metropolis. *Waste Management & Research: The Journal for a Sustainable Circular Economy* **41(3)**:733-739. DOI: https://doi.org/10.1177/0734242x221122545

Meneguz M, A Schiavone, F Gai, A Dama, C Lussiana, M Renna, L Gasco. 2022. Black soldier fly larvae meal as a sustainable protein source in poultry nutrition: a meta-analysis. *Sustainability* **14(6):**3428. **DOI**: https://doi.org/10.3390/su14063428

Menna F, J Davis, K Östergren, N Unger, M Loubiere and M Vittuari. 2020. A combined framework for the life cycle assessment and costing of food waste prevention and valorization: an application to school canteens. *Agricultural and Food Economics* **8(1)**:148-0. **DOI**: https://doi.org/10.1186/s40100-019-0148-2

Moucheraud C, R Chandyo, S Henjum, T Strand, M Ulak, W Fawzi, et al. 2019. Engagement in agriculture protects against food insecurity and malnutrition in peri-urban Nepal. *Current Developments in Nutrition* **3(1)**:nzy078. DOI: https://doi.org/10.1093/cdn/nzy078

Mourad M. 2016. Recycling, recovering and preventing food waste: competing solutions for food systems sustainability in the United States and France. *Journal of Cleaner Production* **126**:461-477. **DOI**: https://doi.org/10.1016/j.jclepro.2016.03.084

Nath P, A Ojha, S Debnath, M Sharma, P Nayak, K Sridhar, et al. 2023. Valorization of food waste as animal feed: a step towards sustainable food waste management and circular bioeconomy. *Animals* **13(8)**:1366. **DOI**: https://doi.org/10.3390/ani13081366

Nelson A, S Manandhar, J Ruzante, A Gyawali, B Dhakal, S Dulal, et al. 2020. High level of contamination of antimicrobial drug resistant non-typhoidal Salmonella enterica in commercial poultry and its surroundings in Chitwan, Nepal. *Research Square (Preprint)*. **DOI**: https://doi.org/10.21203/rs.3.rs-16336/v1

Nwabor O, H Onyeaka, T Miri, K Obileke, C Anumudu and A Hart. 2022. A cold plasma technology for ensuring the microbiological safety and quality of foods. *Food Engineering Reviews* **14(4)**:535-554. **DOI**: https://doi.org/10.1007/s12393-022-09316-0

Ogwu M. 2025. The piggy solution: harnessing food waste for sustainable hog farming. *Global Challenges* **9(8)**:0-0. **DOI**: https://doi.org/10.1002/gch2.202500073

Ojo K, J VanSickle and B Thapa. 2022. Nepal's sacred cattle: profitability analysis and policy implications. *Asian Journal of Agriculture and Development* **19(1)**:61-76. **DOI**: https://doi.org/10.37801/ajad2022.19.1.4

Pendita A, P Lim and H Junis. 2014. Development and experimental studies of a small-scaled solar-powered sago plant dehydrator. *International Journal on Advanced Science Engineering and Information Technology* **4(5)**:354. **DOI**: https://doi.org/10.18517/ijaseit.4.5.434

Pereira R and A Vicente. 2010. Environmental impact of novel thermal and non-thermal technologies in food processing. *Food Research International* **43(7)**:1936-1943. **DOI**: https://doi.org/10.1016/j.foodres.2009.09.013

Poudel U, U Dahal, N Upadhyaya, S Chaudhari and S Dhakal. 2020. Livestock and poultry production in Nepal and current status of vaccine development. *Vaccines* **8(2)**:322. **DOI**: https://doi.org/10.3390/vaccines8020322

Pradhanang U, S Pradhanang, A Sthapit, N Krakauer, A Jha and T Lakhankar. 2015. National livestock policy of Nepal: needs and opportunities. *Agriculture* **5(1)**:103-131. **DOI**: https://doi.org/10.3390/agriculture5010103

Pratama S, S Wajizah, A Jayanegara and S Samadi. 2019. Evaluation of agro-industrial by-products as potential local feed for ruminant animals: chemical composition, fiber fractions and in vitro rumen fermentation. *Animal Production* **20(3)**:155. **DOI**: https://doi.org/10.20884/1.jap.2018.20.3.715

Prüter J, S Strauch, L Wenzel, W Klysubun, H Palm and P Leinweber. 2020. Organic matter composition and phosphorus speciation of solid waste from an African catfish recirculating aquaculture system. *Agriculture* **10(10)**:466. **DOI**: https://doi.org/10.3390/agriculture10100466

Puglia D, D Pezzolla, G Gigliotti, L Torre, M Bartucca and D Buono. 2021. The opportunity of valorizing agricultural waste, through its conversion into biostimulants, biofertilizers, and biopolymers. *Sustainability* **13(5)**:2710. **DOI**: https://doi.org/10.3390/su13052710

Ramirez J, B McCabe, P Jensen, R Speight, M Harrison, L Berg, et al. 2021. Wastes to profit: a circular economy approach to value-addition in livestock industries. *Animal Production Science* **61(6)**:541. **DOI**: https://doi.org/10.1071/an20400

Rao P and V athod. 2018. Valorization of food and agricultural waste: a step towards greener future. *The Chemical Record* **19(9)**:1858-1871. **DOI**: https://doi.org/10.1002/tcr.201800094

Sakai T, N Devkota, K Oishi, H Hirooka and H Kumagai. 2015. Evaluation of total mixed ration silage with brewers grains for dairy buffalo in Tarai, Nepal. *Animal Science Journal* **86(10)**:884-890. **DOI**: https://doi.org/10.1111/asj.12374

Salehi F, K Goharpour and H Kamran. 2023. Optimization of sonication time, edible coating concentration, and osmotic solution °Brix for the dehydration process of quince slices using response surface methodology. *Food Science & Nutrition* **11(7)**:3959-3975. **DOI**: https://doi.org/10.1002/fsn3.3382

Sauvant D, JM Perez and G Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, sheep, goats, rabbits, horses and fish. *Wageningen Academic Publishers*, Wageningen, The Netherlands. **DOI**: https://doi.org/10.3920/978-90-8686-668-7

Saxe H, L Hamelin, T Hinrichsen and H Wenzel. 2018. Production of pig feed under future atmospheric CO_2 concentrations: changes in crop content and chemical composition, land use, environmental impact, and socio-economic consequences. *Sustainability* **10(9)**:3184. **DOI**: https://doi.org/10.3390/su10093184

Shah M, B Tamang, B Dhakal, P Chaudhary, S Shrestha and N Chhetri. 2019. Nutritive values of fodders at different seasons and altitudes in Gandaki River Basin of Nepal. *Journal of Agriculture and Natural Resources* **2(1)**:109-126. **DOI**: https://doi.org/10.3126/janr.v2i1.26051

Shrestha A, S Kanu, B GC and N Baskota. 2023. Feeding status of indigenous buffalo in midhills of Gandaki Province, Nepal. *Nepalese Veterinary Journal* **38**:187-192. **DOI**: https://doi.org/10.3126/nvj.v38i1.55863

Singh SB and N Singh. 2019. Nepal livestock feed balance and strategies to address the feed deficit. *Journal of Agriculture and Forestry University* **3**:159-171.

Song Q, X Deng and R Song. 2020. Expression of *Pleurotus ostreatus* laccase gene in *Pichia pastoris* and its degradation of corn stover lignin. *Microorganisms* **8(4)**:601. **DOI**: https://doi.org/10.3390/microorganisms8040601

Subedi S and R Kattel. 2022. Determining factors and impact of household income on dairy cattle insurance in Nepal. *Journal of Agriculture and Forestry University* **5(1)**:229-238. **DOI**: https://doi.org/10.3126/jafu.v5i1.48469

Suhendro I, R Noor, J Jakaria, A Nurlatifah and A Furqon. 2025. Discriminating heat stress and feed scarcity in Bali cattle using multivariate trait analysis. *Research Square (Preprint)*. **DOI**: https://doi.org/10.21203/rs.3.rs-4904288/v1

Surendra KC, R Olivier, JK Tomberlin, R Jha and SK Khanal. 2023. Bioconversion of organic wastes into biodiesel and animal feed via insect farming. *Renewable Energy* **206**:677–689. **DOI**: https://doi.org/10.1016/j.renene.2023.01.075

Tamang B, Shah M, Dhakal B, Chaudhary P and Chhetri N. 2020. Participatory ranking of fodders in the western hills of Nepal. *Journal of Agriculture and Natural Resources* **3(1)**:20-28. **DOI**: https://doi.org/10.3126/janr.v3i1.27001

Tanga C, D Beesigamukama, M Kassie, J Egonyu, C Ghemoh, N Kiatoko, et al. 2022. Performance of black soldier fly frass fertiliser on maize (*Zea mays* L.) growth, yield, nutritional quality, and economic returns. *Journal of Insects as Food and Feed* **8(2)**:185-196. **DOI**: https://doi.org/10.3920/jiff2021.0012

Timsina K, Y Ghimire and J Lamichhane. 2016. Maize production in mid-hills of Nepal: from food to feed security. *Journal of Maize Research and Development* **2(1)**:20-29. DOI: https://doi.org/10.3126/jmrd.v2i1.16212

U.S. Soybean Export Council (USSEC). 2025. Marketing strategy for Nepal – FY 2025. https://ussec.org/wp-content/uploads/2025/04/USSEC_MS25-Nepal.pdf

Varghese S, H Pulikkalparambil, K Promhuad, A Srisa, Y Laorenza, L Jarupan, et al. 2023. Renovation of agro-waste for sustainable food packaging: a review. *Polymers* **15(3)**:648. **DOI**: https://doi.org/10.3390/polym15030648

Williams E. 2024. Assessment of food processing technologies on allergen reduction in United States. *International Journal of Food Sciences* **7(2)**:1-10. **DOI**: https://doi.org/10.47604/ijf.2540

World Integrated Trade Solution (WITS). 2024. Nepal soybean imports (HS code 120100). *World Bank*. https://wits.worldbank.org/trade/comtrade/en/country/NPL/year/2022/tradeflow/Imports/partner/ALL/product/120100

Xu D, N Wang, M Rinne, W Ke, Z Weinberg, D Mi, et al. 2020. The bacterial community and metabolome dynamics and their interactions modulate fermentation process of whole crop corn silage prepared with or without inoculants. *Microbial Biotechnology* **14(2)**:561-576. **DOI**: https://doi.org/10.1111/1751-7915.13623

Yadav S, L Shrestha, J Acharya, T Gompo, S Chapagain and R Jha. 2023. Integrative digital tools to strengthen data management for antimicrobial resistance surveillance in the "One Health" domain in Nepal. *Tropical Medicine and Infectious Disease* **8(6)**:291. **DOI**: https://doi.org/10.3390/tropicalmed8060291

Yang X, Y Bao, T Shao, W Wang, P Ma, W Wang, et al. 2022. Altitudinal distribution patterns of phyllosphere microbial communities and their contribution to silage fermentation of *Kobresia pygmaea* along the elevation gradient on the Tibetan Plateau. *Frontiers in Microbiology* **13**:874582. **DOI**: https://doi.org/10.3389/fmicb.2022.874582

Zhang X, Y Wang, E Davidson and B Gu. 2024. Shifting trade from feed to food reduces agricultural nitrogen loss and GHG emissions in U.S. and China. *Research Square (Preprint)*. **DOI**: https://doi.org/10.21203/rs.3.rs-4533060/v1

Zikria V, Y Annisa, D Hayati, N Nasrullah and M Furqan. 2025. Prioritizing sustainable alternatives for managing agricultural harvest waste in Aceh Besar. *IOP Conference Series Earth and Environmental Science* **1510(1)**:012049. **DOI**: https://doi.org/10.1088/1755-1315/1510/1/012049

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