

REIMAGINING FOOD WASTE: THE POTENTIAL OF FRUITS AND VEGETABLES AS ANIMAL FEED – A REVIEW

S.K. Rhamya¹, P. Irene Vethamoni^{2*}, G. Ashokkumar³, M. Anand⁴, G. Amuthaselvi⁴

¹Department of Post Harvest Technology, Horticulture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641003, India

²Horticulture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641003, India

³Department of Vegetable Science, Horticulture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641003, India

⁴Department of Food Process Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641003, India

*Corresponding author: irenevetha17@gmail.com

Abstract

The increasing global demand for food, along with shifting dietary preferences toward plant-based diets, has led to a rise in food production, resulting in significant waste, particularly in the horticultural sector. By-products from the processing of fruits and vegetables, such as apple pomace, citrus pulp, grape pomace, banana peel, pineapple pomace, tomato pomace, and roots and tuber peel, often go to waste or are poorly managed, contributing to environmental pollution and nutrient loss. These residues, rich in vitamins, antioxidants, and fiber, have gained attention for their potential in sustainable practices, particularly in animal nutrition. Utilizing such by-products in animal feed not only reduces waste but also lowers feed costs, enhances feed palatability, and improves livestock performance. This approach aligns with the growing demand for environmentally friendly, cost-effective feed alternatives, helping to mitigate food waste, reduce greenhouse gas emissions, and support food security.

Key words: horticulture waste, ensiling, drying, pomace, ruminants and non-ruminants

In agriculture, food manufacturing is a vital sector whose reach has grown significantly and which could substantially decrease the waste of perishable goods. Meeting the demands of the constantly expanding population and the shifting dietary preferences of consumers who are adopting vegetarian diets are two of the factors driving the increased production (Sagar et al., 2018).

Due to the increased intensity of food production worldwide, a significant amount of food waste and by-products have been produced (Waldron, 2009). According to United Nations Food and Agriculture Organization (FAO) estimation, approximately 14 percent of the world's food is lost corresponding to \$400 billion annual production value basis (Loss and Streams, 2023). Of all food types, horticultural commodities experience the highest losses and waste, up to 60% (Sagar et al., 2018; Doneria et al., 2022; Prusty et al., 2023).

Large amounts of waste and by-products are generated during the processing of fruits and vegetables, primarily consisting of soluble sugars, hydrolyzable components, and fiber. Food waste includes discarded materials such as spoiled produce, peels, and trimmings which, although no longer suitable for human consumption, still retain considerable nutritional value. In addition,

by-products like fruit pulp and vegetable residues are secondary outputs from processing that are not part of the primary product but can be effectively repurposed.

However, there is no proven commercial market for these by-products, nor is there adequate infrastructure to handle such large quantities of biomass. As a result, these leftovers are typically disposed of in municipal waste bins or left to rot, leading to significant environmental pollution. This unsustainable disposal not only contributes to the loss of important nutrients and biomass but also has a substantial impact on the environment (Laufenberg et al., 2003; Babbar and Oberoi, 2014). Fruit and vegetable waste accounts for about 6% of global greenhouse gas emissions, making up roughly 16% of all food waste worldwide (Cassani and Gomez-Zavaglia, 2022), highlighting the urgent need for more sustainable waste management solutions.

As per the ICAR-NIANP's Vision 2050, by 2025, there will be a significant shortage in agricultural resources, with expected deficits of 38.1% in concentrates, 40% in greens, and 21.3% in crop residues. This scarcity has led to feed costs becoming the largest expense in livestock farming, accounting for 70–75% of the total expenses. (Prusty et al., 2024). The potential of different

by-products as resources for animal feed is continuously being explored by researchers (Kaur et al., 2023).

Processing residues from fruits and vegetables have long been utilized as the primary feed element in animal nutrition, and their impact on the performance of animals has been thoroughly investigated (Pfaltzgraff et al., 2013). A significant number of leftovers, including pods, skin, pulp, stones, and seeds, are produced during the processing of vegetables and fruits (Babbar and Oberoi, 2014). These by-products are promising sources of useful molecules including vitamins, antioxidants, antimicrobials, and phytochemicals (such as carotenoids, phenolic compounds, and flavonoids), as well as dietary fats with advantageous nutritional or technical qualities. When incorporated into livestock feed, these compounds can enhance animal health, im-

prove immune response, promote growth performance, and contribute to the production of higher-quality meat, milk, or eggs by enriching them with bioactive nutrients. (Mateus et al., 2024).

Incorporating fruit wastes into animal feed has been shown to lower feed costs while also improving diet palatability, which in turn increases feed consumption (Chaudry et al., 2004). Nowadays, the majority of livestock farmers prefer to employ alternative feedstuff sources that have been shown to be healthy and advantageous for their animals and that have been approved as safe for human consumption (Doyle, 2001). This review article provides a comprehensive overview of the origin of the waste, nutritional composition, feed formulation strategies, and the utilization of feed resources in livestock production systems.

Table 1. Origin of horticulture waste and its by-product

Processing stage	Commodity	Origin of waste	Raw material generated	Percentage (%)	Reference
Harvesting and handling	Apple	Damaged and non-marketed	Rejected apple	30–40	(Bakshi and Wadhwa, 2013)
	Banana	Production process	Failing to meet quality standards – small-sized, damaged bananas, banana peels, leaves, young stalks and pseudostems	30–40	
	Carrot	Glut season	Culled out or surplus carrots	20–40	
	Cabbage	Removal of outer leaves, field trimmings	Outer wrapper leaves	5–25	
	Peas	Shelling and pod removal	Shell	6–79	
Processing	Apple	Juice extraction	Pomace	20–30	(Catana et al., 2018)
			Seeds	2–4	
			Stem	1	
	Mango	Pulp extraction	Peel	15–20	(Mitra et al., 2010; Gurumeenakshi et al., 2019)
			Seed	14–22	
			Inoperable pulp	15–20	
	Citrus	Juice extraction	Peel	60–65	(Crawshaw, 2001)
			Internal tissues	30–35	
			Seed	10	
	Grape	Juice extraction	Stem, skin and seeds	20–25	(Yu and Ahmedna, 2013)
	Papaya	Pulp extraction	Peel waste	8.5	
			Seed	6.5	
			Unusable pulp	32	(Upadhyay et al., 2010; Hemung et al., 2022)
	Pineapple	Peeling and coring for drying and dehydration	Peels	35.5	
			Core	14.7	
			Pomace	6	
			Crown	4.3	
			Bud end	4.3	
	Tomato	Pulping and deseeding for sauce and ketchup production	Skin, core and seeds	20–30	
	Potato	Peeling for chip making	Peel, starch and fiber	15–40	(Kot et al., 2020)
	Carrot	Dehydration and pickling	Peel, top portion, pomace	18–52	

Table 2. Chemical composition of fruit and vegetable waste (% DM basis)

Fruit and vegetable waste	DM	CP	CF	CA	EE	HC	CEL	Reference
Red apple pomace	16.47	2.78	6.27	2.14	0.99	4.3	–	(Neshovska, 2024; NRC, 2001)
Green apple pomace	19.69	4.10	10.46	2.52	1.62	–	–	(Neshovska, 2024)
Green banana peel	11.7	7.0	24.1	8.8	6.0	10.5	18.2	(Hossain et al., 2015; Bakshi and Wadhwa, 2013)
Ripe banana peel	7.7	6.8	16.8	12.1	7.8	–	–	(Hossain et al., 2015)
Banana fruit stalk	–	1.9	15.5	9.1	–	–	–	(Okareh et al., 2015)
Citrus pulp	9.5	10.5	–	4.5	5.8	2.0	12.8	(Bakshi and Wadhwa, 2013)
Grape pomace	35.0	12.2	–	7.9	5.0	3.5	54.0	(Zalikarenab et al., 2007)
Pineapple bran	9.9	4.6	–	3.5	1.5	36.0	–	(NRC, 2001)
Muskmelon peels	12.6	9.5	–	14.9	5.8	23.6	14.8	(Bakshi and Wadhwa, 2013)
Watermelon rind	10.5	7.9	–	7.9	1.8	3.1	26.4	(Bakshi and Wadhwa, 2013)
Mango peel	–	9.12	15.43	3.24	–	–	–	(Jalal et al., 2023)
Pineapple peel	–	8.8	16.3	5.0	–	–	–	(Wimalasiri and Somasiri, 2021)
Papaya peel	–	20.2	16.5	11.6	–	–	–	(Wimalasiri and Somasiri, 2021; Romelle et al., 2016)
Pomegranate peel	–	3.46	17.63	6.07	–	–	–	(Jalal et al., 2023; Romelle et al., 2016)
Potato peel	16.3	13.0	12.5	9.0	0.9	–	–	(Hossain et al., 2015)
Cauliflower leaves	13.0	17.0	–	13.7	4.2	8.1	15.2	(Wadhwa and Bakshi, 2005)
Pea husk	89.2	6.2	48.4	12.6	2.3	12.7	24.0	(Hossain et al., 2015; Bakshi and Wadhwa, 2013)
Tomato pomace	23.5	22.1	–	6.0	11.5	12.0	12.0	(Bakshi et al., 2012)
Pumpkin peel	3.3	16.5	14.8	4.6	1.9	–	–	(Hossain et al., 2015)
Cabbage leaves	10.0	19.9	–	15.8	2.6	11.1	13.7	(Wadhwa and Bakshi, 2005)
Bottle gourd pulp	12.3	24.3	–	9.3	2.4	10.4	10.5	(Wadhwa et al., 2015)
Bottle gourd peel	6.6	7.0	23.0	9.6	2.1	–	–	(Hossain et al., 2015)

DM: dry matter, CP: crude protein, CF: crude fiber, CA: crude ash, EE: ether extract, HC: hemicellulose, CEL: cellulose.

Origin of horticulture waste

The processing of horticultural produce results in a significant volume of by-products at different stages, starting from the initial sorting to the final stages of product development. These by-products typically consist of parts that are non-edible or of low economic value, such as stems, peels, seeds, cores, leaves and pulps which are removed during operations like trimming, juicing, drying, canning and peeling (Table 1). Although often treated as waste these materials have considerable potential for secondary applications particularly as livestock feed, thereby supporting sustainable waste utilization and promoting circular economy strategies.

The initial steps of harvesting and handling play a key role in determining not only the quality of horticultural produce but also the volume and nutritional quality of by-products that can be redirected for animal feeding. A portion of the harvest – such as misshapen, bruised, or undersized produce – is typically sorted out and not marketed for fresh consumption. These culled items, though unsuitable for human diets, are highly valuable as livestock feed. For instance, in banana cultivation, components like damaged fruits, pseudostems, leaves, and immature stalks are often fed to animals ei-

ther directly or after minimal processing. Timely harvesting and careful handling help maintain the nutritive properties of these materials, making them a viable and eco-friendly alternative in animal nutrition (Timmermans et al., 2014).

After harvesting, primary processing operations such as cleaning, grading, slicing, peeling, and juicing generate a substantial amount of organic waste, including peels, seeds, cores, and pulp residues. Despite often being discarded, these residues are nutrient-rich and serve as excellent raw materials for livestock feed. A good example is apple pomace, the fibrous by-product left after juice extraction, which contains high levels of residual sugars and is widely used in animal feed formulations (Ajila et al., 2012). Similarly, mango processing results in cull fruits, peels, and kernel meal, all of which can contribute valuable nutrients to livestock diets when properly managed. The efficient repurposing of these primary processing wastes helps reduce environmental pollution and supports sustainable agricultural practices by transforming waste into useful resources.

Secondary processing of horticultural commodities generates additional by-products that can also be

repurposed for animal feeding. For example, pineapple canning produces a variety of residues including skins, crowns, and trimmings along with pomace from juice production. These by-products are versatile feed resources and can be used in fresh, dried, or ensiled forms (Ajila et al., 2012). Likewise, tomato processing yields culled fruits and tomato pomace – a mixture of skin, seeds, and pulp residues that is nutritionally suitable for livestock. By incorporating such residues from secondary processing into animal feed systems, the horticulture sector can significantly lower waste output and enhance environmental sustainability through nutrient recovery and waste valorization.

Nutritional composition of fruits and vegetable wastes

Fruit and vegetable waste (FVW) is a useful but sometimes neglected by-product of food production. This waste is a perfect fit for animal feed because it is packed with a variety of nutrients. The chemical composition of fruit and vegetable waste varies based on the type of produce and the specific plant parts that are discarded (Table 2). Depending on its moisture content, FVW usually has a substantial dry matter percentage varying from 10% to 30% (Lalramhlmi et al., 2022). Additionally, it is high in crude fiber, which promotes better gut health and aids in digestion, and crude protein, which helps animals grow and strengthen their muscles. While the

fibrous components, such as cellulose and hemicellulose, are essential for digestive processes, particularly for herbivores and ruminants, the ether extract (fats) in FVW supplies energy. The cellulose and hemicellulose found in fruit and vegetable waste support the fermentation process in the rumen of ruminant animals. This helps them break down their food more effectively, leading to better nutrient absorption and improved overall digestion.

Despite concerns regarding its high moisture content and perishability, fruit and vegetable waste holds significant potential as a valuable component in animal feed due to its rich content of essential micronutrients. As detailed in Table 3, FVW contains vital minerals such as calcium, phosphorus, sodium, iron, potassium, manganese, and zinc, all of which are crucial for sustaining animal health and metabolic processes. Calcium and phosphorus are necessary for bone development and skeletal integrity, while potassium and sodium support muscle function, nerve transmission, and fluid balance. Manganese contributes to enzymatic activity and antioxidant defense mechanisms, iron is essential for oxygen transport in the blood, and zinc plays a key role in immune function, wound healing, and skin health. Given these nutritional benefits, FVW should not be dismissed as waste but rather embraced as a sustainable, nutrient-rich resource for improving livestock nutrition.

Table 3. Mineral content (%) in fruit and vegetable waste

Commodity	Ca	Mg	P	Na	K	Mn	Zn	Fe	Reference
Red apple pomace	0.20	363	0.14	0.04	0.73	1.8×10^{-2}	2.50	0.01	(NRC, 2001)
Green apple pomace	4.29	4.68	7.24	0.22	47.57	0.1×10^{-2}	0.15	-	(Neshovska, 2024)
Ripe banana peel	0.29	0.30	0.18	0.01	1.11	5.2×10^{-2}	0.11	0.29	(Bakshi and Wadhwa, 2013)
Banana fruit stalk	0.12	0.01	0.18	0.25	0.03	—	—	0.01	(Okareh et al., 2015)
Citrus pulp	0.49	0.11	0.14	0.02	0.66	0.02×10^{-4}	0.04	0.08	(Bakshi and Wadhwa, 2013)
Grape pomace	0.61	0.10	0.06	0.09	0.62	—	2.4×10^{-3}	4.1×10^{-3}	(NRC, 2001)
Pineapple bran	0.23	—	0.13	—	—	—	—	0.05	(NRC, 2001)
Muskmelon peel	0.62	0.43	0.44	0.49	0.44	2.0×10^{-3}	4.0×10^{-3}	0.02	(Bakshi and Wadhwa, 2013)
Watermelon rind	0.47	0.36	0.43	0.21	0.74	1.4×10^{-3}	3.9×10^{-3}	0.01	(Bakshi and Wadhwa, 2013)
Mango peel	0.06	—	—	—	—	0.4×10^{-3}	0.6×10^{-3}	0.01	(Romelle et al., 2016)
Pomegranate peel	0.05	—	—	—	—	0.5×10^{-3}	0.9×10^{-3}	9.2×10^{-3}	(Romelle et al., 2016)
Potato peel	0.08	0.12	0.22	0.01	2.15	7.5×10^{-4}	1.4×10^{-3}	3.9×10^{-3}	(NRC, 2001)
Cauliflower leaves	2.17	0.84	0.34	0.39	0.60	4.0×10^{-3}	4.0×10^{-3}	0.03	(Wadhwa and Bakshi, 2005)
Cabbage leaves	2.38	0.68	0.23	0.43	0.44	5.4×10^{-3}	4.8×10^{-3}	0.08	(Wadhwa and Bakshi, 2005)
Tomato pomace	0.22	0.28	0.47	0.12	0.98	1.1×10^{-3}	5.4×10^{-3}	0.05	(NRC, 2001)
Pea pods	0.85	0.38	0.38	0.03	0.63	2.3×10^{-3}	2.7×10^{-3}	0.02	(Bakshi and Wadhwa, 2013)

Ca: calcium, Mg: magnesium, P: phosphorus, Na: sodium, K: potassium, Mn: manganese, Zn: zinc, Fe: iron.

Table 4. Phytonutrient in horticulture by-products and its potential effect

By-product	Bioactive compounds	Potential effect	Reference
Apple pomace	Catechins, hydroxyl-cinnamates, phloretin glycosides, quercetin glycosides, procyanidins, epicatechin, procyanidin B2 (dimer), trimer, tetramer and oligomer, chlorogenic acid, phloridzin, 3-hydroxy phloridzin	Antioxidant, anti-inflammatory, antimicrobial, improves gut health	(Gupta et al., 2017)
Banana peel	Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), succinic acid, β -sitosterol, palmitic acid, malic acid, 12-hydroxystearic acid, glycosides, d-malic acid	Anti-inflammatory, antibacterial, antioxidant, anticancer; weight gain and increases carcass quality	
Citrus peel	Flavones, flavanones, flavonols, flavones, anthocyanidins, flavanols, limonoids	Anti-inflammatory, antioxidant, antiallergic, immunomodulatory; improve gastrointestinal structure and function; boost mucosal and cellular immunity; alleviate heat stress in livestock	
Grape pomace	Gallic acid, catechin, epicatechin, procatechin, phenolic acids, flavonoids, lignans, stilbenes, anthocyanins, hydroxycinnamic acids, flavanols, flavonol glycosides, procyanidins, resveratrol, quercetin, syringic acid	Antimutagenic, anticarcinogenic, antiallergic, antimicrobial, anti-inflammatory, anti-aging, antitumor, antioxidant, antilipotropic, antithrombotic, cardioprotective, insulinotropic, vasodilatory; promotes gut bacterial proliferation	(Gupta et al., 2017; Spissu et al., 2022)
Mango peel	Syringic acid, quercetin, mangiferin pentoside, ellagic acid	Antioxidant, antimicrobial, anti-inflammatory, antiproliferative	(Ajila et al., 2010)
Pineapple bran	Bromelain, gallic acid, myricetin, salicylic acid, tannic acid, trans-cinnamic acid, p-coumaric acid	Enhances growth performance, provides economic benefits, improves meat quality	(Gupta et al., 2017)
Tomato	Phenols, phenolic acids, coumarins, flavonoids (including flavanones, flavonols, isoflavones, flavanols, anthocyanins), tannins, lignin; carotenoids (lutein, β -cryptoxanthin, zeaxanthin)	Increases antioxidant capacity of animal plasma	(Ban et al., 2022)
Potato	Hydroxycinnamic acids (chlorogenic, caffeic, ferulic, p-coumaric), hydroxybenzoic acids (gallic, vanillic, protocatechuic, p-hydroxybenzoic), flavonoids (flavonols, flavanols, flavones, isoflavones, anthocyanins)	Antioxidant activity via free radical neutralization, metal ion chelation, and enhancement of enzymatic (catalase, superoxide dismutase, glutathione peroxidase) and non-enzymatic (glutathione) antioxidant systems	(Melini et al., 2020)

Fruit and vegetable waste contains a wide range of bioactive compounds – such as polyphenols, carotenoids, alkaloids, glycosides, terpenoids, and vitamins C and E – that can significantly benefit livestock health and productivity (Table 4). These secondary plant metabolites, although not directly involved in plant growth, support plant defense mechanisms and, when incorporated into animal feed, offer a natural alternative to antibiotics and synthetic growth enhancers. Their known antioxidant, antimicrobial, and immune-boosting properties help improve gut health, regulate immune responses, and influence microbial activity in the digestive system. In ruminants, certain compounds like capsaicin can resist breakdown in the rumen, allowing them to act beyond it – enhancing milk production, improving glucose use, and supporting fat metabolism. Moreover, these phytochemicals can cause beneficial changes in rumen fermentation by adjusting microbial balance without harming essential functions. Although laboratory studies show encouraging outcomes, further long-term, *in vivo* research is needed to validate their role in improving animal health, immunity, and performance.

Apart from its nutritional benefits, incorporating FVW into animal feed encourages sustainable agriculture. It helps decrease the waste that might otherwise wind up in landfills and lessens the environmental effect associated with agricultural disposal by recovering food waste into excellent cattle nutrition. FVW provides an alternative to conventional feed ingredients, therefore this strategy can also assist farmers in reducing feed costs.

Process for converting horticulture waste into an animal feed

The process of turning FVW into livestock feed is comprehensive and cautious, requiring a methodical and professional approach that covers collection, pre-processing, and processing. The methodical gathering of FVW from many sources is the first step in the process. Markets and food manufacturing facilities are examples of these sources. Following collection, the waste is divided into two categories: organic and non-organic. While the organic waste moves on to the next phase, the non-organic one, which includes materials for packaging and other contaminants is disposed of appropriately.

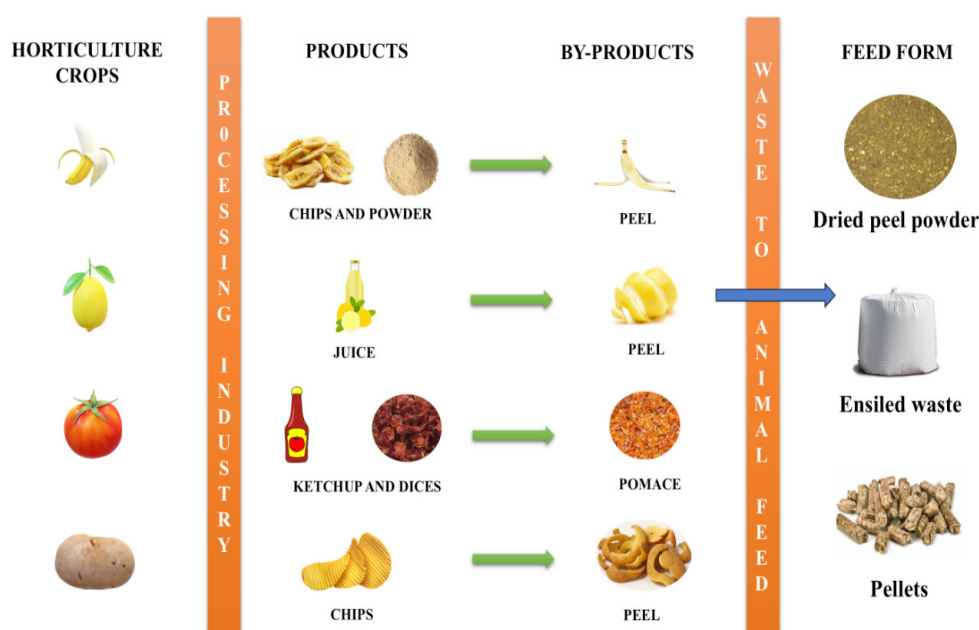


Figure 1. Diagrammatic view for processing of horticulture waste into an animal feed

The pre-processing step begins after the waste is collected and sorted. At this stage, any non-organic materials in the horticultural waste are carefully removed. The waste is then categorized based on its suitability for different types of animal feed. After this, the waste undergoes treatment and is transformed into feed. Depending on the type of waste and the intended use of the feed, this process can involve techniques such as ensiling, pelleting, or drying, as illustrated in Figure 1.

Pelleting is a mechanical process that uses heat, pressure, and humidity to compress tiny particles into a constrained volume (Falk, 1985). One popular technique in animal husbandry is pelleting, which tries to decrease the quantity of bulk materials having low density to make storage, transportation, and nutrient addition easier. Pelleting is a method that turns the milled product into compressed pellets by forcing it through numerous holes, either with or without steam. The primary distinction between storing pelleted product and unprocessed raw materials is that the former has a lower humidity content, which inhibits the growth of microorganisms. A consistent and specific ratio of dietary supplements can be added to the pelleted product if it is intended for animal feed (Tumuluru, 2021).

Due to their high moisture content, waste from fruits and vegetables can rot in 3–4 days if they are not properly handled (Hersom, 2006). However, if the moisture content is controlled, these wastes can be used for ensiling because they are high in soluble carbohydrates. Plant waste can be effectively preserved for extended periods of time using ensilage (Kinh et al., 2010). Four steps make up the ensiling process: (1) the aerobic phase, where air trapped in the biomass allows aerobic bacte-

ria and yeasts to dominate; (2) the fermentation phase, during which anaerobic microorganisms turn available substrates into the organic acids; (3) the constant storage phase, where a low pH keeps the silage from spoiling; and (4) the feed-out phase, while the silage gets exposed to air for use (Rooke and Hatfield, 2003; Borreani et al., 2018; Kung Jr et al., 2018).

One effective way to store and extend the shelf life of horticulture waste is to dry it. Additional benefits of drying include reduced greenhouse gas emissions, easier and less expensive transportation and packing of dried horticultural waste, and a decreased storage space requirement compared to other processed horticulture waste (Karam et al., 2016).

Agricultural and waste products are dried using a variety of techniques, such as solar drying, microwave drying, convection drying, spray drying, ultrasound drying, vacuum drying, and fluidized bed drying. Nevertheless, certain techniques are not economical or appropriate for drying waste. Radiative-convective drying is thought to be the best of these for drying waste. Convective dryers must, however, be fueled by inexpensive energy sources, such as solar energy, in order to be commercial and environmentally sustainable because of their high energy requirements.

Utilization of fruit and vegetable waste as an animal feed

Fruit and vegetable by-products, such as apple pomace, mango peel, pineapple pomace, banana peel, citrus pomace, grape pomace, tomato pomace, and tuber and root crop peels, present a promising opportunity for sustainable animal feeding practices. These usually wasted

materials are great complements to conventional animal feed because they are high in vital elements like fiber, vitamins, and antioxidants. We can lessen our impact on the environment, cut feed costs, and encourage circular agriculture – the process of turning waste into a resource for livestock – by repurposing agricultural waste. Recent research, as outlined in Table 4, highlights the potential of these waste materials in animal nutrition, further emphasizing their role in advancing sustainable agricultural practices.

Apple pomace (AP)

Around 95.84 MMT of apples are produced annually, making them a fruit that is grown all over the world. According to Kaushal et al. (2002), most apples have been processed into fruit juice concentrate, while the remaining apples being used to make wine, cider, jams, purees and the dried apple goods. The peel, core, calyx, seeds and stem of apples make up apple pomace, a significant by-product of apple processing. In addition to having a high moisture content (70–85%), the pomace is rich in lignocellulosic materials and contains healthy antioxidants such as procyanidins, phlorizin, quercetin glycosides, and catechins (Costa et al., 2022 a; Zheng and Shetty, 2000).

Apple pomace, with its rich nutritional content and antioxidant properties, offers significant benefits as a feed source for both ruminants and non-ruminants, especially for ruminant animals like dairy cows, sheep, and goats, improving digestion, fermentation, and milk quality, although improper handling can have adverse environmental effects (Gołębiewska et al., 2022). Supplementing Guanzhong dairy goats with 18% apple pomace has been shown to increase milk output, 4 percent fat-corrected milk, and the serum biochemical indicators (Xiong et al., 2021). Apple pomace polyphenols have also been demonstrated to influence fermentation-related ruminal bacteria, increasing the synthesis of omega-3 polyunsaturated fatty acids (PUFAs) and improving the quality of meat and milk (Huang et al., 2022; Yanza et al., 2022).

Dairy goat diets supplemented with 50% apple silage and tomato pomace replacing berseem hay demonstrated enhanced feed efficiency, digestibility, and milk composition in addition to higher milk output. Methane emissions have been found to decrease and fermentation efficiency to increase when fermented apple pomace is added to ruminant diets (Gadulrab et al., 2023). AP tends to become more digestible and has a better nutritional profile after fermentation, which makes it a useful addition to dairy cow diets.

Non-ruminant animals such as hens, pigs, and broilers benefit from apple pomace. It has been demonstrated that including it in their diets would improve growth, strengthen the immune system, and enhance general health. Up to 10% of the maize in broiler feeds can be substituted with dried apple pomace without impairing growth performance. Broilers performed better when

fed apple pomace enriched with commercially available enzymes like hemicellulase, protease, α -amylase and β -glucanase (Matoo et al., 2001; Chamorro-Ramírez et al., 2017).

Fermented apple pomace in broiler diets has improved antibody titers against infectious disease virus (IDV), influenza, and Newcastle disease (Aghili et al., 2019). Additionally, it has been shown that fermented apple pomace improves plasma components like ethanol, lactate, and β -hydroxybutyrate, that improve poultry metabolism and general health (Islam et al., 2018).

Banana peel (BP)

The food sector produces over 3.5 million tons of banana-peel waste annually, which makes up a sizeable amount of the global waste (Sial et al., 2019). However, banana peels remain unexplored and have a lot of potential as a substitute feed source for animals. Around 30% of the banana's weight is made up of the peel, which is also full of important nutrients like cellulose, hemicellulose, pectin, lignin, and vital amino acids like valine, phenylalanine, leucine, and threonine (Ragab et al., 2016). The nutritional value of BP is further increased for both ruminant and non-ruminant animals due to their high concentration of minerals like phosphorus, potassium, calcium, and magnesium (Syukriani et al., 2021).

The beneficial effects of banana peel on ruminant productivity have long been known. Their superior nutritional status is a result of their significant fiber and nutritious content as well as the rumen's efficient digestion of them. According to Dormond et al. (1998), dairy cows that were given ripe banana peels produced more milk, especially when they were given 14–21 kg fresh ripe banana peels every day. Adding BP to ruminant diets has been linked to better feed degradability and the generation of volatile fatty acids (VFAs), which improves digestibility and the overall production efficiency (Ramdani et al., 2019). Furthermore, it has been shown that giving cattle BP increases their weight gain and improves the quality of their carcass (Ibrahim et al., 2000; Siyal et al., 2016).

Banana peel provides energy to nursing goats, preserving their general health and milk production. BP improves the reproductive performance of sheep, including conception, estrus, and lambing %, and it also raises live weight (Kenyon et al., 2004, 2005). It is a good addition to chicken diets, particularly for broilers. Dried banana peels can increase live animal weight gain and feed conversion efficiency by up to 10%, and 15% of them can also keep lactating goats' milk yield stable (Yitbarek, 2019; Agustin et al., 2024). Banana peels higher in starch and oligosaccharide content enhance the quality of poultry's eggs and meat by promoting growth, development, and the reproductive efficiency (Achilonu et al., 2018). However, growth rates may be slowed down if chicken diets contain more than 10% (Yitbarek, 2019).

Adding fermented banana peels aids in the suppression of dangerous intestinal bacteria such as *Escherichia*

coli (Nuriyasa et al., 2020). With no impact on growth performance, the blood biochemical markers, reproductive efficiency, or carcass quality, crossbred grower pigs may withstand up to 20% replacement of BP for corn (Baruah et al., 2024). For instance, banana peels can be used as a source of carbohydrates to replace conventional ingredients like maize, making them a sustainable and efficient feed substitute.

Citrus pomace

Worldwide, citrus fruits are produced in large quantities and offer a rich resource for animal feed, especially when it comes to fruit pulp, a by-product obtained after the juice is extracted. Peel (60–65%), internal tissues (30–35%), and seed (up to 10%) make up the majority of this pulp, which makes about 50–70% of the fruit's weight (Crawshaw, 2001). Citrus fruits, like *Citrus sinensis*, *Citrus clementina*, and *Citrus limon* contain vital minerals like Na, K, Cu, Zn, Mg, Ca, Fe, and Mn. This makes them a great natural source of nutrients for animal feed, especially for goats when replacing maize (Idamokoro and Hosu, 2023).

There was no significant difference in the milk production or 4 percent fat-corrected milk yield when 9% and 18% of the feed were substituted using pelleted dried citrus peel (Santos et al., 2014). In comparison to the control cows on a corn-based ration, Holstein cows under heat stress produced more milk when fed dry orange pulp (Allam et al., 2011). According to Villarreal et al. (2006), high dosages of orange peel supplementation resulted in decreased forage intake but higher digestibility of both dry matter as well as organic matter. When paired with forages high in rumen-degradable protein, such high quantities of orange peel may enhance calorie intake. Rahman et al. (2023) showed that adding 20% of dehydrated citrus pulp to fattening goats ration instead of maize enhanced performance and decreased feeding expenses, indicating that citrus pulp could serve as a useful substitute for maize in diets for ruminants. Citrus pulp is a suitable source of energy for fattening sheep, as revealed by Pérez-Sato et al. (2024), who showed that substituting dried citrus pulp for up to 30% of the maize grain in sheep diets had no negative impact on ruminal microbiological characteristics or productive performance.

It has been demonstrated that adding orange peel and pulp to poultry meals enhances the birds' antioxidant status, lowers oxidative stress, and improves the quality of the meat (Zema et al., 2018). According to Behera et al. (2018), adding 5% citrus waste to broiler starter meals had no detrimental effects on productivity. Broiler chicks fed dried orange leftovers showed improvements in feed consumption, weight gain, the liver and abdominal fat, and levels of blood triglycerides (Abbasi et al., 2015). According to Chaudry et al. (2004), broiler weight and weight gain rose when up to 7.5% citrus waste was added to their diets. Ebrahimi et al. (2013) showed that the legs and wings of broilers gained the most weight when fed 1.5% dried *Citrus sinensis* peels from the first day to 21st

day. IgG, IgM, and red blood cell levels were greater in broiler chicks nourished 1000 mg/L of orange peel extract, indicating an improved immunological response (Pourhossein et al., 2015). Ten percent was the ideal substitution ratio found, supporting nucleotide metabolism and protein synthesis while lowering feed expenses (Xu et al., 2024).

Grape pomace

Approximately 80% of the 74.94 million metric tons of grapes produced globally were utilized to make wine (Mazza, 2018). The residue left behind after the grapes have been processed to make wine, known as grape pomace, makes up roughly 20–25% of the grapes' weight (Meyer et al., 1998). This by-product includes fiber, proteins, lipids, minerals, and a lot of polyphenols, especially in the skins. Essential amino acids are present in grape pomace's 12% dry weight protein composition, with arginine (7.2%), glutamic acid (11.5%), aspartic acid (7.1%) and threonine (21.7%) being the most abundant. Though lysine (4.5%) is the primary limiting amino acid for pig and the second most limiting amino acid for poultry, the amino acid composition is not optimal for all animals (Meyer et al., 1998).

Adding 15% grape pomace to dairy cows enhanced blood metabolite profiles as well as milk quality by raising levels of lactose and β -lactoglobulin without having an adverse effect on casein, protein, or milk fat (Chedea et al., 2017). Feeding grape pomace reduced the amount of undesired saturated fatty acids while increasing the quantity of polyunsaturated fatty acids (PUFAs), such as omega-6 and omega-3 fatty acids (Correddu et al., 2016; Manso et al., 2016; Moate et al., 2014). According to Derbali et al. (2024), grape seed tannin extracts improved spermatogenesis and testicular growth in sheep, increasing the weight of both testes and epididymis.

By increasing glutathione levels and improving overall antioxidant activity, Kafantaris et al. (2018) demonstrated that supplementing pigs with grape pomace greatly increased antioxidant capacity. Furthermore, it suppressed dangerous pathogens like *Campylobacter jejuni* and encouraged the growth of the probiotic bacteria, thus enhancing animal health and gastrointestinal health. These studies demonstrate how grape pomace improves animal growth, health, and reproductive efficiency, making it a useful feed element for both pigs and ruminants. According to Costa et al. (2022 b), adding 9% grape pomace to pig diets raised average daily gain. Comparably, da Silveira Almeida et al. (2024) found that giving pigs as much as 10% dried grape pomace did not hinder their ability to grow, but it would cause them to become more adipose, which would lower the quality of their carcass.

Grape pomace added to broiler diets (5–10 g/kg feed) improved meat quality by lowering serum cholesterol and thiobarbituric acid-reactive compounds in breast meat, improving oxidative stability, but it had no apparent impact on growth efficiency, feed intake, and feed conversion ratio (Aditya et al., 2018). Condensed tannins

that bind to proteins and decrease their digestibility are probably the reason why larger concentrations of grape seed by-products (over 6%) had a deleterious impact on feed intake (Sáyago-Ayerdi et al., 2009; Chamorro et al., 2013; Romero et al., 2021).

Pineapple pomace

Due to its high demand and the health benefits of its nutrients, which include vitamins A, C, B₁, B₆, and folic acid; minerals like copper and manganese; and bioactive substances like bromelain, which have anti-inflammatory, antioxidant, and digestive qualities, pineapple production reached about 29.36 million metric tons worldwide in 2022 (Chaudhary et al., 2019; Firatoiu et al., 2021). However, over 65% of the fruit – including the peel, core, bud end, pomace, and crown – is thrown away as trash during processing.

In ruminant diets, silage derived from pineapple by-products can substitute as much as 50% of roughage or maize silage, increasing productivity and lowering feed expenses (Prado et al., 2003; Sruamsiri, 2007). According to research, giving dairy cows and other ruminants pineapple waste silage can increase milk yield (Gowda et al., 2015) and enhance utilization of nutrients (Suksathit et al., 2011). The use of pineapple silage is an acceptable alternative in the diets of cattle and sheep, with no adverse effects on dry matter or fiber digestibility (Mello et al., 2021; Cordeiro et al., 2022). In particular, sheep fed silage made from pineapple waste outperformed animals fed maize silage, albeit at a lesser expense (Gowda et al., 2015). Goat diets have also been proven to be more palatable when pineapple waste and wheat bran are combined (Asaolu et al., 2016). Additionally, pineapple waste has demonstrated encouraging outcomes in boosting the digestibility of organic matter, dry matter, crude protein, and fiber fractions in cattle, as well as improving their digestive function (Suksathit et al., 2011).

Adding up to 20% fermented pineapple waste to broiler diets improves nutrient digestibility, lowers intraperitoneal fat formation, and improves body indices (Mandey et al., 2018; Shaibu et al., 2020). It has been discovered that fermenting pineapple waste with a fungal combination improves nutritional components and lowers fiber content (Mandey et al., 2018). Protease enzymes in pineapple waste can further improve protein hydrolysis and digestion (Rahman and Yang, 2018). Ayandiran et al. (2019) stated that goats' immune systems were enhanced by wheat offal-carried pineapple waste (WCPW), as seen by higher levels of white blood cells, neutrophils, and lymphocytes in comparison to the control groups.

Tomato pomace

With an annual production of almost 180 million tons, tomatoes are one of the most produced vegetables in the world. Of these, a quarter are processed, making them the most processed vegetable (Kaundal et al., 2024). Tomato pomace, which comprises the peel, the pulp, and seeds, is a significant by-product of this operation. Proteins, lipids,

minerals, and bioactive substances like beta-carotenoids, lycopene, tocopherols, and polyphenols are all abundant in tomato pomace. It has drawn interest as a useful feed additive for both ruminant as well as non-ruminant livestock because of its high antioxidant content. Tomato pomace may enhance fatty acid composition, especially omega-3 fatty acids, improve immunological function, and improve meat quality when added to animal diets.

The effects of tomato pomace on ruminant health, meat quality, and milk production have been investigated. According to Mizael et al. (2020), adding tomato pomace to the diet at a rate of 60% decreased the average body weight of nursing goats, but when the amount was restricted to 40%, milk output rose. This suggests that while tomato pomace may have an adverse effect on weight increase, it can also affect milk output. On the other hand, it enhanced milk's vitamin content, digestibility, and dry matter intake while also boosting antioxidant and immunological function.

According to Abdullahzadeh (2012), goats' and sheep's body weight, carcass features, and blood biochemistry were unaffected by varying amounts of tomato pomace (30%). But by adding more protein and crude fat, especially at greater inclusion rates, it did raise the meat's nutritional value. Tomato pomace feeding in goats boosted milk fat content and overall n-6 to n-3 fatty acid ratio while decreasing milk output and protein content (Abbeddou et al., 2015).

The effects of tomato pomace on the reproductive health and growth performance of non-ruminant animals, including laying hens, broilers, and quails, have also been investigated. According to Gungor et al. (2024), adding *Aspergillus niger*-fermented tomato pomace to broiler diets had no discernible impact on their body weight, feed consumption, or feed conversion ratio. According to Mansouri et al. (2008), diets that included 120 g/kg of tomato pulp enhanced yolk color, a crucial characteristic for buyers. When Knoblich et al. (2005) showed that tomato by-products could transfer up to 5.8% of dietary lycopene to the egg yolk, they provided support for this conclusion. Egg yolks may have more nutritional value if they contain lycopene, a useful antioxidant. Furthermore, supplementing with tomato pomace increased high-density lipoprotein (HDL), hatchability, and egg weight while decreasing cholesterol and low-density lipoprotein (LDL) levels.

Roots and tuber peel

Cassava, potatoes, sweet potatoes, and yam are among the plants that store nutrients in their stems, the roots, rhizomes, and tubers, making them important sources of starch. By-products such as peels, which comprise 5–15% of the overall weight (cassava peels, for example), are becoming more well-known for their nutritional worth, which includes minerals and energy content. According to Jiwuba et al. (2018), these peels are being utilized more and more in animal feed, especially for cattle and poultry, because they can lower feed costs while fostering animal growth and productivity.

By-products like cassava and yam peels have shown a great deal of promise in livestock nutrition. According to Uchewa et al. (2014), yam peel can be used to substitute corn in sheep feed at 100% and 66.7% levels, pro-

ducing the greatest weight growth and return on investment. Likewise, Red Sokoto goats were given yam peel in place of all of their maize, with no adverse impacts on digestibility or growth performance.

Table 5. Effect of fruit and vegetable waste on the livestock

By-product	Diet level	Experimental duration	Animal type	Initial weight	Effect	Reference
1	2	3	4	5	6	7
Apple pomace						
Ensiled apple pomace	An 85:15 mixture of apple pomace and wheat straw	8 weeks	Calves	62.22 and 61.15 kg	Wheat straw and AP together could result in increased dry matter intake, weight gain, and feed efficiency ratio.	(Chauhan et al., 2024)
Fermented apple pomace	11%	56 days	Lamb	25.37±2.9 kg	Reduced lipid oxidation during 4°C storage, while maintaining high quality in terms of color, pH, water-holding capacity, drip loss, and tenderness.	(Alarcon-Rojo et al., 2019)
Dried apple pomace	150 g/kg of dry matter	64 days	Dairy cows	630±30 kg	Lowered methane emissions, enhanced food digestibility, and raised the content of ruminal volatile fatty acids by altering the populations of ruminal microorganisms. Higher levels of PUFA and n-3 are reflected in the milk.	(Gadulrab et al., 2023)
Banana peel						
Banana peel	15, 30, 45, and 60%	80 days	F1 Holstein × Zebu cows	500 kg	A lower calorie intake is indicated by the low temperature of the rectum during the morning shift with 60% DM banana peel eating.	(Santos et al., 2022)
Fermented banana peel	2.5–7.5%	12 weeks	Rabbit	Different body weight	The growth of <i>Escherichia coli</i> and Coliform in the hindgut is inhibited by the increased consumption of fermented banana peels. Additionally, the digestibility of proteins, energy, and dry matter has increased.	(Nuriyasa et al., 2020)
Single cell protein peel of banana, potato and pea	2, 4, and 6 g/kg	–	Broilers	–	Stronger immunity and improved gut microbiota contribute to the health and meat of broilers.	(Khan et al., 2024)
Citrus fruit waste						
Dried <i>Citrus sinensis</i> peel (DCSP)	2.50, 5.00, and 7.50%	8 weeks	Broilers	–	At 7.5% it decreased the feed conversion ratio, final weight, and body weight gain. Feeds up to 5.00% have no negative impact on carcass and growth metrics. Progressive decrease in pancreatic weight as dietary DCSP intake increased.	(Aro et al., 2024)
Multi-nutrient concentrate (25% ground corn + 25% citrus by-product)	0, 25, and 50%	90 days	Lambs	15.67±0.30 kg	Creates favorable conditions for the rumen's cellulolysis.	(Saddick and Nayel, 2024)
Dried Nagpur orange peel essential oil powder (limonene)	500 g/ton of antibiotic, 50 g/ton, 100 g/ton, 150 g/ton	6 weeks	Broiler	–	At 100 g/ton there is increased feed consumption, feed conversion ratio, gizzard weight, organic matter, crude protein, dry matter, crude fiber and ether extract. Higher globulin concentration.	(Gore et al., 2024)

Table 5 – contd.

1	2	3	4	5	6	7
Grape pomace						
Red grape pomace (RGP) treated with ozone (O ₃) gas	0, 20, and 40%	7 days post-partum to 45 days in milk.	Dairy ewes	51±2 kg	The dry matter's and the neutral detergent fiber's digestibility coefficients rose. The number of ruminal protozoa increased linearly. The concentration of albumin and plasma glucose increased, as did the production of milk and its fat, protein, and lactose contents.	(Asadnezhad et al., 2024)
Ensiled grape pomace	0, 10, 20, and 40%	35 days	Lamb	21.5±3.0 kg	Increasing daily consumption of ether extract	(Massaro Junior et al., 2021)
Wine grape pomace	10% dietary WGP	74 days	Lamb	25.0±0.2 kg	Total antioxidative capacity (TAOC), glutathione peroxidase 4 (GPx4), superoxide dismutase (SOD) activity, body weight, average daily gain, feed to gain ratio, Warner-Bratzler shear force, and collagen content all were increased.	(Zhao et al., 2018)
Pineapple pomace						
Fermented pineapple pomace	0, 25, and 50%	30 days	Simmental bull	546±44 kg	The average daily weight gain were increased. At 50% the muscle's levels of proline, cysteine, and crude fat had increased. At 25%, the relative abundance of <i>Lachnospiraceae bacterium</i> RM44 was much lower, whereas tyrosine, proline, and phenylalanine were significantly elevated.	(Deng et al., 2022)
Fermented pineapple peel residue	0, 25, and 50%	35 days	Chuanzhong black goats	10.23±1.42 kg	Enhanced the quantity of probiotics, including <i>Ruminococcus albus</i> , <i>Butyrivibrio fibrisolvens</i> , and <i>Blautia</i> .	(Yang et al., 2022)
Pineapple waste silage	25%	6 weeks	Myanmar local cattle	255.00±6.19 and 275.46±31.42 kg	Greater intakes of dry matter, non-fiber carbohydrates, crude protein, neutral detergent fiber and energy, and energy balance.	(Kyawt et al., 2020)
Tomato pomace						
Dried tomato pomace	Feel free to provide	36 days	Comisana goat	14.53±2.16 kg	L*, b*, C*, and H* increased (where H* stands for hue, L* for lightness, C* for chroma, and b* for yellowness). Lipid oxidation and growth performance are unaffected. Reduced reactive compounds of 2-thiobarbituric acid, or TBARS.	(Valenti et al., 2018)
Ensiled tomato pomace	10%	—	Holstein cow	710.9±15.5 kg	No impact on the content and output of milk. Increased digestibility, DM intake, and milk's vitamin content. Elevated levels of IgA, IgG, and IgM, serum aspartate aminotransferase, antioxidants, total cholesterol, and high-density lipoprotein cholesterol.	(Tuoxunjiang et al., 2020)
Dried tomato pomace	3, 6, 9, and 12%	8 weeks	Japanese quail	—	Enhances digestive enzymes, antioxidant qualities, and immunological function. Reduces LDL (low density lipoprotein), or cholesterol. Lycopene deposition benefited from increased HDL (high density lipoprotein), hatchability, and egg weight, the biggest of which was 6%.	(Reda et al., 2022)

Table 5 – contd.

1	2	3	4	5	6	7
Roots and tuber peel						
Yam tuber waste meal	0, 12, 22, and 32%	8 weeks	Broiler	–	There was an increase in live weight, dress weight, and dress percentage. Feed conversion ratio, the average weight gain, feed utilization efficiency, and eight gained were all noticeably improved.	(Anigbogu et al., 2023)
Sweet potato tuber waste (by-products)	0, 10, 20, 30, and 40%	21 days	Goat	23.4±1.91 kg	Enhanced daily weight growth, feed conversion, and feed and nutritional consumption.	(Truong and Tuan, 2024)
Cassava peels biodegraded by white rot fungi (<i>Pleurotus tuber-regium</i>)	0, 25, 50, 75, and 100%	84 days	West African Dwarf (WAD) goats	6.17±0.96 kg	Crude protein was higher (above 17%) than recommendation of the diet. Additional CP content may compensate for poor digestion and an imbalance in the amino acid composition created during protein breakdown.	(Barde et al., 2015)

According to a study conducted by Olugbemi et al. (2010), broiler diets enriched with cassava chips and *Moringa oleifera* leaf meals at 5% and 10% could substitute maize by up to 55.56% and 83.33%, respectively, without having an adverse effect on hematological parameters or productivity. Furthermore, potato peel has demonstrated potential as a feed additive, providing a source of the polyphenol that can be used in the manufacturing of animal feed (Kasapidou et al., 2015).

It has also been demonstrated that potato peel extract exhibits bacteriostatic and bactericidal properties, however only at high doses (Kasapidou et al., 2015). It was shown by Karimi et al. (2014) that quail may be fed potato powder instead of maize, or without the glucanase enzymes, and their performance would not be impacted. Additionally, adding 25 ml/kg of a purple sweet potato extracts to broiler feed increased feed intake, growth rate, and feed conversion ratio while lowering blood cholesterol and LDL levels (Nasoetion et al., 2019).

Powdered potato peel and potato peel extract added to quail diets at doses of 15 and 30 g/kg or 15 and 30 ml/l, respectively, improved carcass characteristics and production (Mutter and Abbas, 2023). While low density increased the production index, high density was linked to decreased belly fat. Furthermore, broiler diets supplemented with sun-dried potato peel up to 15% of the time instead of maize offered enough nutrients to support growth without compromising production (Kpanja et al., 2019).

Limiting factors of fruit and vegetable waste utilization in animal feed

The two limiting factors that inhibit the use of horticulture waste as an animal feed are anti-nutrient and the heavy metal composition. Anti-nutritional factors (ANFs) constitute naturally occurring compounds present in many plant-based livestock feeds and meals that can prevent vital nutrients from being absorbed and

utilized properly. These compounds either limit food bio-availability or cause metabolic disturbances, resulting in a variety of health concerns in both animals and humans. Hydrogen cyanide, oxalates, phytic acid, and tannins are among the most frequent ANFs. Understanding the mechanisms by which these substances influence the absorption of nutrients and metabolism is critical for enhancing livestock nutrition and food safety.

Since ancient times, metals like copper, lead, and antimony have been known to cause heavy metal poisoning, which is a serious concern to animal health (Gallo and Doull, 1996). The extensive use of heavy metals in agriculture, industry, and technology has raised the risk (Tchounwou et al., 2012). Agricultural fields are contaminated by sewage runoff and industrial waste, which introduces metals like copper, zinc, and cadmium into plants that then enter into the food chains (Khan et al., 2008). The degree of exposure, the type of metal, and animal characteristics like sex, age, and nutritional state all affect toxicity; metals build up in organs like the kidneys and liver. Reproductive abnormalities, immunotoxicity, cardiotoxicity, oxidative stress, and endocrine disruption are examples of common harmful consequences (Swarup and Dwivedi, 2002).

Developing and putting into practice efficient treatment techniques to lessen or get rid of these dangerous materials is crucial to maximizing the potential of horticulture waste as an animal feed resource. In order to make the waste more appropriate and safe for cattle consumption, this involves methods to detoxify ANFs and eliminate heavy metals. To better understand the relationship between heavy metals, anti-nutrients, and animal physiology, as well as to investigate safe and affordable treatment solutions, more research is necessary. In order to ensure the health and safety of livestock and to maximize the use of horticulture waste in sustainable animal agriculture, such research will be essential.

Future prospects

To increase the quality of animal feed, research is required to standardize the use of feed-grade fungi, yeast, bacteria, and enzymes for digesting low-value feedstocks, such as fruit and vegetable waste. Although bioprocessing improves fiber consumption, breaks down lignin, and improves protein quality, additional research is needed to optimize these processes for reliable outcomes. Research is also required to decrease anti-nutritional elements such as mycotoxins and increase the digestibility of phosphorus. A more sustainable and effective food supply system would result from standardizing these practices, which would also boost feed value, decrease waste, and lower the carbon, nitrogen, and phosphorus footprint of animal feed.

Conclusion

Agri-food industrial by-products and waste materials offer a sustainable alternative to conventional feed ingredients for both ruminant and non-ruminant livestock. These by-products often contain valuable bioactive compounds with antioxidant, antimicrobial, and immunomodulatory properties that can enhance animal health and productivity. Their utilization contributes to waste valorization and supports environmentally sustainable livestock systems. However, several challenges hinder their broader adoption. Nutritional variability, reduced digestibility – particularly in non-ruminants – and concerns related to the presence of anti-nutritional factors, mycotoxins, heavy metals, pesticide residues, and microbial contaminants pose significant risks. Additionally, regulatory restrictions, high processing and transportation costs, and the need for proper preservation and storage further complicate their use. Ensuring safety and nutritional adequacy requires standardized processing techniques, robust quality control measures, and comprehensive risk assessments. Moreover, economic feasibility and scalability must be critically evaluated to integrate these by-products effectively into feed formulations without compromising animal health or production efficiency.

References

- Abbasi H., Seidavi A., Liu W., Asadpour L. (2015). Investigation on the effect of different levels of dried sweet orange (*Citrus sinensis*) pulp on performance, carcass characteristics and physiological and biochemical parameters in broiler chicken. *Saudi J. Biol. Sci.*, 22: 139–146.
- Abbeddou S., Rischkowsky B., Hilali M.E.-D., Haylani M., Hess H.D., Kreuzer M. (2015). Supplementing diets of Awassi ewes with olive cake and tomato pomace: On-farm recovery of effects on yield, composition and fatty acid profile of the milk. *Trop. Anim. Health Prod.*, 47: 145–152.
- Abdullahzadeh F. (2012). The effect of tomato pomace on carcass traits, blood metabolites and fleece characteristic of growing Markhoz goat. *J. Am. Sci.*, 8: 848–852.
- Achilonu M., Nwafor I., Umesiobi D., Sedibe M. (2018). Biochemical proximates of pumpkin (*Cucurbitaceae* spp.) and their beneficial effects on the general well-being of poultry species. *J. Anim. Physiol. Anim. Nutr.*, 102: 5–16.
- Aditya S., Ohh S.-J., Ahammed M., Lohakare J. (2018). Supplementation of grape pomace (*Vitis vinifera*) in broiler diets and its effect on growth performance, apparent total tract digestibility of nutrients, blood profile, and meat quality. *Anim. Nutr.*, 4: 210–214.
- Aghili A.H., Toghyani M., Tabeidian S.A. (2019). Effect of incremental levels of apple pomace and multi enzyme on performance, immune response, gut development and blood biochemical parameters of broiler chickens. *Int. J. Recycl. Org. Waste Agricult.*, 8: 321–334.
- Agustin F., Jamarun N., Pazla R., Desrayeni C. (2024). Feed intake, fiber fraction digestibility and milk yield of lactating goats fed banana peel in the diet. 3rd International Conference on Animal Production for Food Sustainability 2023, Bali, Indonesia, 07–08.09.2023.
- Ajila C., Aalami M., Leelavathi K., Rao U.P. (2010). Mango peel powder: A potential source of antioxidant and dietary fiber in macaroni preparations. *Innov. Food. Sci. Emerg. Technol.*, 11: 219–224.
- Ajila C., Brar S.K., Verma M., Prasada Rao U. (2012). Sustainable solutions for agro processing waste management: An overview. *Environmental protection strategies for sustainable development*, 65–109.
- Alarcon-Rojas A., Lucero V., Carrillo-Lopez L., Janacua H. (2019). Use of apple pomace in animal feed as an antioxidant of meat. *S. Afr. J. Anim. Sci.*, 49: 131–139.
- Allam S.M., Abou-Ward G., Tawila M., Ali M., Al-Hosseiny H.M., Sayed S., El-Naggar S.I. (2011). Nutritional and economical impact of using dried orange pulp as energy source in growing lambs rations. *Egyptian J. Nutr. Feeds*, 14: 337–347.
- Anigbogu N.M., Ononuju A.N., Agida C.A. (2023). Yam (*Dioscorea rotundata*) tuber waste as feed for poultry production: An alternative kitchen garbage waste management. *Aceh J. Anim. Sci.*, 8: 16–23.
- Aro S.O., Oboh G., Oboh T., Olateju I., Ojo O.R., Ademosun A.O. (2024). Growth performance and carcass traits of broiler chickens fed dietary *Citrus sinensis* peel-based diet. *Slovak J. Anim. Sci.*, 57: 3–11.
- Asadnezhad B., Pirmohammadi R., Alijoo Y., Khalilvandi-Behroozyar H., Abdi-Benmar H., Tirado-González D.N., Ruiz P.E.H., Ordóñez V.V., Lackner M., Salem A.Z. (2024). The effects of dietary supplementation with red grape pomace treated with ozone gas on ruminal fermentation activities, nutrient digestibility, lactational performance, and blood metabolites in dairy ewes. *J. Agric. Food Res.*, 18: 101452.
- Asaolu V.O., Binuomote R.T., Oyelami O.S. (2016). Assessment of feeding value of vegetable-carried pineapple fruit wastes to Red Sokoto goats in Ogbomoso, Oyo State of Nigeria. *Afr. J. Biotechnol.*, 15: 1648–1660.
- Ayandiran S.K., Odeyinka S., Oyebanji B. (2019). Hematological and biochemical parameters of West African Dwarf (WAD) goats fed wheat offal-carried pineapple waste (WCPW). *Int. J. Anim. Sci.*, 3: 1046s.
- Babbar N., Oberoi H.S. (2014). *Enzymes in value-addition of agricultural and agro-industrial residues*. Nova Science Publishers, Inc.
- Bakshi M., Kaur J., Wadhwa M. (2012). Nutritional evaluation of sun dried tomato pomace as livestock feed. *Indian J. Anim. Nutr.*, 29: 6–19.
- Bakshi M., Wadhwa M. (2013). Nutritional evaluation of cannery and fruit wastes as livestock feed. *Indian J. Anim. Sci.*, 83: 1198–1202.
- Ban C., Paengkoum S., Yang S., Tian X., Thongpea S., Purba R.A.P., Paengkoum P. (2022). Feeding meat goats mangosteen (*Garcinia mangostana* L.) peel rich in condensed tannins, flavonoids, and cinnamic acid improves growth performance and plasma antioxidant activity under tropical conditions. *J. Appl. Anim. Res.*, 50: 307–315.
- Barde R., Attah S., Wuanor A., Okpanachi U. (2015). Weight gain and cost benefit of West African Dwarf goats fed *Pleurotus tuber-regium* biodegraded cassava (*Manihot esculenta*) peels based diets. *Am. J. Exp. Agric.*, 9: 1–8.
- Baruah K., Khargharia G., Deori S., Kadirvel G., Doley S., Baruah A., Abedin S. (2024). Effect of feeding sun dried banana pseudostem as a partial replacement of dietary maize on performance and pro-

- duction economics of crossbred grower pigs. *Indian J. Anim. Res.*, 58.
- Behera D.P., Sethi A., Pathak D., Singh U., Wadhwa M. (2018). Effect of different levels of citrus waste (*Kinnow* sp.) on duodenal morphology of broiler birds without and with cocktail of enzymes. *J. Anim. Res.*, 8: 775–782.
- Borreani G., Tabacco E., Schmidt R., Holmes B., Muck R.A. (2018). Silage review: Factors affecting dry matter and quality losses in silages. *J. Dairy. Sci.*, 101: 3952–3979.
- Cassani L., Gomez-Zavaglia A. (2022). Sustainable food systems in fruits and vegetables food supply chains. *Front. Nutr.*, 9: 829061.
- Catana M., Catana L., Iorga E., Lazar M.-A., Lazar A.-G., Teodorescu R.I., Asanica A.C., Nastasia B. (2018). Achieving of functional ingredient from apple wastes resulting from the apple juice industry. *AgroLife Sci. J.*, 7.
- Chamorro S., Viveros A., Centeno C., Romero C., Arija I., Brenes A. (2013). Effects of dietary grape seed extract on growth performance, amino acid digestibility and plasma lipids and mineral content in broiler chicks. *Animal*, 7: 555–561.
- Chamorro-Ramírez F. H., Durán-Meléndez L.A., García-Macias J.A., Peña-González E.M., González-Sánchez J.F. (2017). Productivity of pigs fed with solid-state fermented apple pomace and an enzymatic complex. *Ecosis. Recur. Agropec.*, 4: 453–463.
- Chaudhary V., Kumar V., Singh K., Kumar R., Kumar V. (2019). Pineapple (*Ananas comosus*) product processing: A review. *J. Pharmacogn. Phytochem.*, 8: 4642–4652.
- Chaudry M., Badshah A., Bibi N., Zeb A., Ahmed T., Ali S., Meulen U.T. (2004). Citrus waste utilization in poultry rations. *Eur. Poult. Sci.*, 68: 206–210.
- Chauhan S., Wadhwa D., Sharma A., Katoh S., Upadhyay S. (2024). Effect of ensiled mixture of apple pomace and wheat straw based complete feed on growth performance of calves. doi: 10.21203/rs.3.rs-3867502/v1
- Chedea V.S., Pelmus R.S., Lazar C., Pistol G.C., Calin L.G., Toma S.M., Dragomir C., Taranu I. (2017). Effects of a diet containing dried grape pomace on blood metabolites and milk composition of dairy cows. *J. Sci. Food Agric.*, 97: 2516–2523.
- Cordeiro C.D.C., Fernandes A.M., Oliveira T.S.D., Camilo M.G., Baffa D.F., Glória L.S., Bernardo S.E.E. (2022). Intake, total apparent digestibility, and microbial efficiency of sheep fed pineapple waste silage in different planes of nutrition. *Rev. Bras. Zootec.*, 51.
- Correddu F., Gaspa G., Pulina G., Nudda A. (2016). Grape seed and linseed, alone and in combination, enhance unsaturated fatty acids in the milk of Sarda dairy sheep. *J. Dairy Sci.*, 99: 1725–1735.
- Costa J.M., Ampese L.C., Ziero H.D.D., Sganzerla W.G., Forster-Carneiro T. (2022 a). Apple pomace biorefinery: Integrated approaches for the production of bioenergy, biochemicals, and value-added products – An updated review. *J. Environ. Chem. Eng.*, 10: 108358.
- Costa M.M., Alfaia C.M., Lopes P.A., Pestana J.M., Prates J.A. (2022 b). Grape by-products as feedstuff for pig and poultry production. *Animals*, 12: 2239.
- Crawshaw R. (2001). Co-product feeds: animal feeds from the food and drinks industries. In *J. Sci. Food. Agric.* Nottingham University Press, 285 pp.
- da Silveira Almeida B.C., Ludke M.D.C.M.M., Bertol T.M., Ludke J.V., Bernardi D.M., Cunha Jr A., Coldebella A. (2024). Growth performance, meat quality, and lipid oxidation in pigs' fed diets containing grape pomace. *Appl. Biosci.*, 3: 378–391.
- Deng M., Xiao Z., Liu G., Sun B., Guo Y., Zou X., Liu D., Yang Z., Li Y. (2022). The effects of fermented pineapple residue on growth performance, meat quality, and rumen microbiota of fattening Simmental bull. *Front. Microbiol.*, 13: 942208.
- Derbali H., Ben Saïd S., Abid K., Aroua M., Jabri J., Dhaouafi J., Tissaoui M., Malek A., Bouzid K., Mahouachi M. (2024). Valorization of dehydrated grape pomace waste as a low-cost feed additive to improve reproduction and growth performance of male rabbits. *Waste Biomass Valorization*, 15: 3987–3996.
- Doneria R., Dubey M., Gendley M., Chourasia D., Pathak R., Ramteke R., Prusty S., Parmar M. (2022). Impact of dietary supplementation of cinnamon oil on the oxidative stress indices, immune response and intestinal morphology in broiler chickens. *Indian J. Anim. Sci.*, 92: 991–994.
- Dormond H., Boschini C., Rojas Bourrillon A. (1998). Effect of two levels of ripe banana peel on milk production by dairy cattle. *Agron. Costarricense*, 22: 43–49.
- Doyle M. E. (2001). Alternatives to antibiotic use for growth promotion in animal husbandry. Food Research Institute, Department Food Microbiology and Toxicology.
- Ebrahimi A., Qotbi A.A.A., Seidavi A. (2013). The effects of different levels of dried *Citrus sinensis* peel on broiler carcass quality. *Acta Sci. Vet.*, 41: 1–8.
- Falk D. (1985). Pelleting cost center. In: *Feed Manufacturing Technology III*. American Feed Manufacturers Association, Arlington, pp. 167–190.
- Firatoiu A.-R., Chiurciu I.-A., Marcu L., Chereji A.-I., Soare E., Voicu V., Marcu A. (2021). Study on the Production and Marketing of Pineapples Worldwide. *Proc. 37th International Business Information Management Association (IBIMA)*, Cordoba, Spain, pp. 1–2.
- Gadulrab K., Sidoruk P., Kozłowska M., Szumacher-Strabel M., Lechniak D., Kołodziejski P., Pytlewski J., Strzałkowska N., Horbańczuk J.O., Józwick A. (2023). Effect of feeding dried apple pomace on ruminal fermentation, methane emission, and biohydrogenation of unsaturated fatty acids in dairy cows. *Agriculture*, 13: 2032.
- Gallo M.A., Doull J. (1996). History and scope of toxicology. In: *Cassarett and Doull's Toxicology. The Basic Science of Poisons*, Klassen C.D. (ed.). 5th ed. New York: McGraw-Hill, pp. 3–11.
- Golebiewska E., Kalinowska M., Yildiz G. (2022). Sustainable use of apple pomace (AP) in different industrial sectors. *Materials*, 15: 1788.
- Gore S.M., Deshpande K.Y., Mandavgane S.A., Shinde P.N., Patil M.R., Chakravarty I., Zadaonkar L.A., Borkar A.M., Vedpathak A., Kamdi B.P. (2024). Waste 'Nagpur orange' peel essential oil for improved performance, gut health and immune response in broiler chicken: in vivo studies. *Waste Biomass Valorization*, 15: 3395–3411.
- Gowda N.K.S., Vallesha N.C., Awachat V.B., Anandan S., Pal D.T., Prasad C.S. (2015). Study on evaluation of silage from pineapple (*Ananas comosus*) fruit residue as livestock feed. *Trop. Anim. Health Prod.*, 47: 557–561.
- Gungor E., Altop A., Erener G. (2024). Effect of fermented tomato pomace on the growth performance, antioxidant capacity, and intestinal microflora in broiler chickens. *Anim. Sci. J.*, 95: e13885.
- Gupta C., Prakash D., Nazareno M.A. (2017). Nutraceutical potential of agri-horticultural wastes. *Obes. Control Therapies*, 44: 1–8.
- Gurumeenakshi G., Varadharaju N., Rajeswari R. (2019). Quality analysis of mango fruit waste for utilization in food products. *Int. J. Curr. Microbiol. Appl. Sci.*, 8: 20–27.
- Hemung B.-O., Sompholkhang M., Wongchai A., Chanshotikul N., Ueasin N. (2022). A study of the potential of by-products from pineapple processing in Thailand. *Int. J. Health Sci.*, 6: 12605–12615.
- Hersom M.J. (2006). By-product feed utilization for forage diets. *Florida Beef Cattle Short Course*, 10.
- Hossain M.E., Sultana S.A., Karim M.H., Ahmed M.I. (2015). Vegetable peels: a promising feed resource for livestock. *Online J. Anim. Feed Res.*, 5: 33–39.
- Huang H., Lechniak D., Szumacher-Strabel M., Patra A.K., Kozłowska M., Kołodziejski P., Gao M., Ślusarczyk S., Petrič D., Cieslak A. (2022). The effect of ensiled paulownia leaves in a high-forage diet on ruminal fermentation, methane production, fatty acid composition, and milk production performance of dairy cows. *J. Anim. Sci. Biotechnol.*, 13: 104.
- Ibrahim M., Holmann F., Hernández M., Camero A. (2000). Contribution of *Erythrina* protein banks and rejected bananas for improving cattle production in the humid tropics. *Agrofor. Syst.*, 49: 245–254.
- Idamokoro E., Hosu Y. (2023). Relative analysis of two citrus species versus maize for potential nutritive traits as livestock feed. *Online J. Anim. Feed Res.*, 13: 357–366.
- Islam S., Islam M., Matsuzaki M. (2018). Effect of apple pomace si-

- lage on blood parameters in Suffolk ewe: apple pomace silage in ewes. *Bangladesh J. Anim. Sci.*, 47: 51–60.
- Jalal H., Giammarco M., Lanzoni L., Akram M. Z., Mammi L. M., Vignola G., Chincari M., Formigoni A., Fusaro I. (2023). Potential of fruits and vegetable by-products as an alternative feed source for sustainable ruminant nutrition and production: a review. *Agriculture*, 13: 286.
- Jiwuba P., Ogbuewu I., Nwachukwuguru K. (2018). Performance and economy of production of broilers fed Siam weed (*Chromolaena odorata*) leaf meal (SWLM). *Trop. Anim. Health Prod.*, 50: 1305–1311.
- Kafantaris I., Kotsampasi B., Christodoulou V., Makri S., Stagos D., Gerasopoulos K., Petrotos K., Goulas P., Kouretas D. (2018). Effects of dietary grape pomace supplementation on performance, carcass traits and meat quality of lambs. *In Vivo*, 32: 807–812.
- Karam M.C., Petit J., Zimmer D., Djantou E.B., Scher J. (2016). Effects of drying and grinding in production of fruit and vegetable powders: A review. *J. Food Eng.*, 188: 32–49.
- Karimi M., Kheiri F., Faghani M. (2014). The effect of dried potato powder with enzyme supplementation on performance of Japanese quail (*Coturnix japonica*). *Cibtech J. Zool.*, 3: 124–130.
- Kasapidou E., Sossidou E., Mitlianga P. (2015). Fruit and vegetable co-products as functional feed ingredients in farm animal nutrition for improved product quality. *Agriculture*, 5: 1020–1034.
- Kaundal M., Sharma K., Anand H. (2024). Processing, value addition and post-harvest technology of tomato: A scoping review on global and Indian perspective. *J. Adv. Biol. Biotechnol.*, 27: 339–347.
- Kaur M., Singh A.K., Singh A. (2023). Bioconversion of food industry waste to value added products: Current technological trends and prospects. *Food Biosci.*, 102935.
- Kaushal N., Joshi V., Sharma R. (2002). Effect of stage of apple pomace collection and the treatment on the physico-chemical and sensory qualities of pomace papad (fruit cloth). *J. Food Sci. Technol.*, 39: 388–393.
- Kenyon P., Pinchbeck G., Perkins N., Morris S., West D. (2004). Identifying factors which maximise the lambing performance of hoggets: a cross sectional study. *N Z Vet. J.*, 52: 371–377.
- Kenyon P., Morel P., Morris S., West D. (2005). The effect of individual liveweight and use of teaser rams prior to mating on the reproductive performance of ewe hoggets. *N Z Vet. J.*, 53: 340–343.
- Khan A.R., Ahmad B., Khan M., Khan M.A., Sultan S., Sultana K., Hassan S. (2024). Production of single cell protein (SCP) from the peel waste of pea, potato, and banana by *Aspergillus Flavus* NRRL 21882 as an efficient organic poultry supplement. *ACS Omega*, 9: 37763–37770.
- Khan S., Cao Q., Zheng Y., Huang Y., Zhu Y. (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environ. Pollut.*, 152: 686–692.
- Kinh L., Trung V., Ninh P., Sy P., Phu N., Chau L. (2010). Rice bran as ingredient for ensiling fresh cashew apple in laboratory. Available from: http://www.iasvn.org/uploads/files/rice_bran_0521144646.pdf
- Knoblich M., Anderson B., Latshaw D. (2005). Analyses of tomato peel and seed byproducts and their use as a source of carotenoids. *J. Sci. Food Agric.*, 85: 1166–1170.
- Kot A.M., Pobiega K., Piwowarek K., Kieliszek M., Błażej S., Gniewosz M., Lipińska E. (2020). Biotechnological methods of management and utilization of potato industry waste – a review. *Potato Res.*, 63: 431–447.
- Kpanja E., Duru S., Omege J., Sekoni A., Gonjoh P. (2019). Proximate composition, anti-nutritional factors and the effect of Irish potato (*Solanum tuberosum* L.) peels on the performance and carcass characteristics of broiler chickens. *Niger. J. Anim. Sci.*, 21: 214–222.
- Kung Jr L., Shaver R., Grant R., Schmidt R. (2018). Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. *J. Dairy Sci.*, 101: 4020–4033.
- Kyawt Y.Y., San Win K., San Mu K., Aung A., Aung M. (2020). Feeding pineapple waste silage as roughage source improved the nutrient intakes, energy status and growth performances of growing Myanmar local cattle. *J. Adv. Vet. Anim. Res.*, 7: 436.
- Lalramhlumi B., Mukherjee D., Chakraborty I., Ghosh N., Chattopadhyay A., Dey R.C. (2022). Fruit and vegetable wastes as livestock feeds. In: *Fruits and Vegetable Wastes: Valorization to Bioproducts and Platform Chemicals*, Springer, pp. 139–168.
- Laufenberg G., Kunz B., Nystroem M. (2003). Transformation of vegetable waste into value added products: (A) the upgrading concept; (B) practical implementations. *Bioresour. Technol.*, 87: 167–198.
- Loss R.F., Streams V.F.P.S. (2023). *Food Science and Technology Solutions to Improve Food and Nutrition Security: Reducing Food Loss and Valorizing Food Processing Side Streams*. Institute of Food Technologists.
- Mandey J., Tulung B., Leke J., Sondakh B. (2018). Performance and carcass quality of broiler chickens fed diet containing pineapple waste meal fermented by “ragi tape”. *IOP Conference Series: Earth and Environmental Science*, 27–27.09.2017, Semarang, Indonesia.
- Manso T., Gallardo B., Salvá A., Guerra-Rivas C., Mantecón A., Lavín P., De la Fuente M. (2016). Influence of dietary grape pomace combined with linseed oil on fatty acid profile and milk composition. *J. Dairy Sci.*, 99: 1111–1120.
- Mansouri B., Modir S.M., Kiaei M. (2008). Influence of dried tomato pomace as an alternative to wheat bran in maize or wheat based diets, on the performance of laying hens and traits of produced eggs. *Iran J. Vet. Res.*, 9: 25.
- Massaro Junior F.L., Bumbieris Junior V.H., Pereira E.S., Zanin E., Horst E.H., Calixto O.P. P., Peixoto E.L.T., Galbeiro S., Mizubuti I.Y. (2021). Grape pomace silage on growth performance, carcass, and meat quality attributes of lambs. *Sci. Agric.*, 79: e20200343.
- Mateus A.R.S., Pena A., Sanches-Silva A. (2024). Unveiling the potential of bioactive compounds in vegetable and fruit by-products: exploring phytochemical properties, health benefits, and industrial opportunities. *Curr. Opin. Green Sustain. Chem.*, 48: 100938.
- Matoo F., Beat G., Banday M., Ganaie T. (2001). Performance of broilers fed on apple pomace diets supplemented with enzyme (S). *Indian J. Anim. Nutr.*, 18: 349–352.
- Mazza G. (2018). *Anthocyanins in fruits, vegetables, and grains*. CRC press.
- Melini V., Melini F., Acquistucci R. (2020). Phenolic compounds and bioaccessibility thereof in functional pasta. *Antioxidants*, 9: 343.
- Mello B.L., Fernandes A.M., de Oliveira T.S., Leonel F.P., Glória L.S., Silva R.S. (2021). Feed intake, digestibility, and energy contents in growing bull fed pineapple crop waste silage in different planes of nutrition. *Trop. Anim. Health Prod.*, 53: 1–10.
- Meyer A.S., Jepsen S.M., Sørensen N.S. (1998). Enzymatic release of antioxidants for human low-density lipoprotein from grape pomace. *J. Agric. Food Chem.*, 46: 2439–2446.
- Mitra S., Pathak P., Lembisana Devi H., Chakraborty I. (2010). Utilization of seed and peel of mango. *Proc. IX International Mango Symposium*, 992.
- Mizael W.C., Costa R.G., Rodrigo Beltrão Cruz G., Ramos de Carvalho F.F., Ribeiro N.L., Lima A., Domínguez R., Lorenzo J.M. (2020). Effect of the use of tomato pomace on feeding and performance of lactating goats. *Animals*, 10: 1574.
- Moate P., Williams S., Torok V., Hannah M., Ribaux B., Tavendale M., Eckard R., Jacobs J., Auldist M., Wales W. (2014). Grape marc reduces methane emissions when fed to dairy cows. *J. Dairy Sci.*, 97: 5073–5087.
- Mutter Z.A., Abbas R.J. (2023). Effect of stocking density and supplementation of potato peel (*Solanum tuberosum* L.) powder and extract on productive performance and some carcass characteristics of Japanese quail. *J. Surv. Fish. Sci.*, 10: 2693–2703.
- Nasoetion M.H., Atmomarsono U., Sunarti D., Suthama N. (2019). Growth performance and lipid profile of broilers fed different levels of purple sweet potato extract and raised under different stocking densities. *Livest. Res. Rural Dev.*, 31: 97.
- National Research Council, Committee on Animal Nutrition, and Subcommittee on Dairy Cattle Nutrition (2001). *Nutrient requirements of dairy cattle: 2001 Seventh Revised Edition*. National Academies Press.
- Neshovska H. (2024). Determination of the chemical and mineral

- composition of apple pomace in relation to its utilisation as an innovative feed raw material. *Tradit. Mod. Vet. Med.*, 9.
- Nuriyasa I., Sukada I., Puspani E., Ariana N. (2020). Microbial composition of hind gut, digestability and growth rate of local rabbit with feed fermented banana peels (*Acuminata balbisiana*) supplementation. *Plant Arch.*, 20: 6334–6338.
- Okareh O., Adeolu A., Adepoju O. (2015). Proximate and mineral composition of plantain (*Musa paradisiaca*) wastes flour; a potential nutrients source in the formulation of animal feeds. *Afr. J. Food Sci. Technol.*, 6: 53–57.
- Olugbemi T., Mutayoba S., Lekule F. (2010). Effect of moringa (*Moringa oleifera*) inclusion in cassava based diets fed to broiler chickens. *Int. J. Poult. Sci.*, 9: 363–367.
- Ovando-Martínez M., López-Teros M., Tortoledo-Ortiz O., Astiazarán-García H., Ayala-Zavala J., Villegas-Ochoa M., González-Aguilar G. (2018). Effect of ripening on physico-chemical properties and bioactive compounds in papaya pulp, skin and seeds. *Indian J. Nat. Prod. Res.*, 9: 47–59.
- Pérez-Sato M., Pérez-Hernández H., García-García U., Soni-Guillermo E., Flores-Espinosa B.B., Domínguez-Perales L. A. (2024). Productive and ruminal microbiological behavior of sheep fed with two levels of dehydrated orange residue. *Agro Productividad*, 17.
- Pfaltzgraff L.A., Cooper E.C., Budarin V., Clark J.H. (2013). Food waste biomass: a resource for high-value chemicals. *Green Chem.*, 15: 307–314.
- Pourhossein Z., Qotbi A.A.A., Seidavi A., Laudadio V., Centoducati G., Tufarelli V. (2015). Effect of different levels of dietary sweet orange (*Citrus sinensis*) peel extract on humoral immune system responses in broiler chickens. *Anim. Sci. J.*, 86: 105–110.
- Prado I.N.D., Lallo F.H., Zeoula L.M., Caldas Neto S.F., Nascimento W.G.D., Marques J.D.A. (2003). Bulls performance in feedlot with levels of substituting corn silage by pineapple by-products silage. *Rev. Bras. Zootec.*, 32: 737–744.
- Prusty S., Prasad Tiwari S., Dubey M., Parveen K., Doneria R., Gade N. (2023). Effect of replacement of concentrate feed with Moringa leaves on dietary nutrient utilization of non-descript Chhattisgarh goats. *Ind. J. Dairy Sci.*, 76.
- Prusty S., Gendley M., Singh A., Dubey M., Patil P., Sharma V. (2024). Jackfruit waste and peels: Potential as livestock feed. *Indian J. Anim. Sci.*, 94: 395–400.
- Ragab M., Osman M., Khalil M., Gouda M. (2016). Banana (*Musa* sp.) peels as a source of pectin and some food nutrients. *J. Agric. Res. Kafr El-Sheikh Univ.*, 42: 88–102.
- Rahman A., Kalsoom H., Khanum S., Sajid M., Zahid M.Z., Hayat Z., Asif A.R., Mahmood M., Ahmed I., Nawaz S. (2023). Evaluation of dried citrus pulp addition to total mixed ration in replacement to corn on mutton goat performance and health indices. *Sustainability*, 15: 6584.
- Rahman M.M., Yang D.K. (2018). Effects of *Ananas comosus* leaf powder on broiler performance, haematology, biochemistry, and gut microbial population. *Rev. Bras. Zootec.*, 47: e20170064.
- Raj D., Senapati A., Patel N. (2016). Waste management in horticulture processing industry. *Commercial Horticulture*, pp. 391–401.
- Ramdani D., Hernaman I., Nurmeidiansyah A., Heryadi D., Nurachma S. (2019). Potential use of banana peels waste at different ripening stages for sheep feeding on chemical, tannin, and *in vitro* assessments. *IOP Conf. Ser.: Earth Environ. Sci.*, 29–30.08.2018, Bandung, Indonesia.
- Reda F.M., Madkour M., Abd El-Azeem N., Aboelazab O., Ahmed S.Y., Alagawany M. (2022). Tomato pomace as a nontraditional feedstuff: Productive and reproductive performance, digestive enzymes, blood metabolites, and the deposition of carotenoids into egg yolk in quail breeders. *Poult. Sci.*, 101: 101730.
- Romelle F.D., Rani A., Manohar R.S. (2016). Chemical composition of some selected fruit peels. *Eur. J. Food Sci. Technol.*, 4: 12–21.
- Romero C., Nardoia M., Arija I., Viveros A., Rey A. I., Prodanov M., Chamorro S. (2021). Feeding broiler chickens with grape seed and skin meals to enhance α - and γ -tocopherol content and meat oxidative stability. *Antioxidants*, 10: 699.
- Rooke J.A., Hatfield R.D. (2003). Biochemistry of ensiling. *Silage Sci. Technol.*, 42: 95–139.
- Saddick E., Nayel U. (2024). Effect of replacing corn grains with citrus by-product in concentrate feed blocks form on the performance and feed utilization of lambs. *J. Anim. Poult. Prod.*, 15: 1–8.
- Sagar N.A., Pareek S., Sharma S., Yahia E.M., Lobo M.G. (2018). Fruit and vegetable waste: Bioactive compounds, their extraction, and possible utilization. *Compr. Rev. Food Sci. Food Saf.*, 17: 512–531.
- Santos G., Lima L., Schogor A., Romero J., De Marchi F., Grande P., Santos N., Santos F., Kazama R. (2014). Citrus pulp as a dietary source of antioxidants for lactating Holstein cows fed highly polyunsaturated fatty acid diets. *Asian Australas. J. Anim. Sci.*, 27: 1104.
- Santos H.P., Santos B.V.B., Cunha B.F.C., Ferreira M., Alves I.C.D.S., Aiura A.L.D.O., Aiura F.S., Rocha Junior V.R., Rodriguez M.A.P. (2022). Physiological parameters of F1 Holstein $\times$ Zebu cows fed with banana peel. *Cienc. Rural*, 52: e20210463.
- Sáyago-Ayerdi S., Brenes A., Viveros A., Goñi I. (2009). Antioxidative effect of dietary grape pomace concentrate on lipid oxidation of chilled and long-term frozen stored chicken patties. *Meat Sci.*, 83: 528–533.
- Shaibu M., Aremu A., Alabi O.J. (2020). Performance of broiler chicken fed sun-dried pineapple (*Ananas comosus*) and orange (*Citrus sinensis*) peels waste based diets under single phase feeding. *Niger. J. Anim. Prod.*, 1377–1381.
- Sial T.A., Khan M.N., Lan Z., Kumbhar F., Ying Z., Zhang J., Sun D., Li X. (2019). Contrasting effects of banana peels waste and its biochar on greenhouse gas emissions and soil biochemical properties. *Process Saf. Environ. Prot.*, 122: 366–377.
- Siyal F.A., Wagan R., Bhutto Z.A., Tareen M.H., Arain M.A., Saeed M., Brohi S.A., Soomro R.N. (2016). Effect of orange and banana peels on the growth performance of broilers. *Adv. Anim. Vet. Sci.*, 4: 376–380.
- Spissu Y., Gil K.A., Dore A., Sanna G., Palmieri G., Sanna A., Cossu M., Belhadj F., Gharbi B., Pinna M.B. (2022). Anti-and pro-oxidant activity of polyphenols extracts of Syrah and Chardonnay grapevine pomaces on melanoma cancer cells. *Antioxidants*, 12: 80.
- Sruamsiri S. (2007). Agricultural wastes as dairy feed in Chiang Mai. *Anim. Sci. J.*, 78: 335–341.
- Suksathit S., Wachirapakorn C., Opatpatanakit Y. (2011). Effects of levels of ensiled pineapple waste and pangola hay fed as roughage sources on feed intake, nutrient digestibility and ruminal fermentation of Southern Thai native cattle. *Songklanakarin J. Sci. Technol.*, 33.
- Swarup D., Dwivedi S. (2002). Environmental pollution and effects of lead and fluoride on animal health. *Indian Council of Agricultural Research*.
- Syukriani L., Febjislami S., Lubis D., Hidayati R., Asben A., Suliansyah I., Jamsari J. (2021). Physicochemical characterization of peel, flesh and banana fruit cv. raja [*Musa paradisiaca*]. *IOP Conference Series: Earth and Environmental Science*.
- Tchounwou P.B., Yedjou C.G., Patlolla A.K., Sutton D.J. (2012). Heavy metal toxicity and the environment. *Mol. Clin. Environ. Toxicol.*, 101: 133–164.
- Timmermans A., Ambuko J., Belik W., Huang J. (2014). Food losses and waste in the context of sustainable food systems. *CFS Committee on World Food Security HLPE*.
- Truong N.B., Tuan T.T. (2024). Effect of sweet potato tuber by-product provision on feed intake, nutrient digestibility and nitrogen retention of Boer crossbred goats. *Development*, 36: 4.
- Tumuluru J.S. (2021). Biomass Densification: Systems, Particle Binding, Process Conditions, Quality Attributes, Conversion Performance, and International Standards. *Springer Nature*.
- Tuoxunjiang H., Yimamu A., Li X., Maimaiti R., Wang Y. (2020). Effect of ensiled tomato pomace on performance and antioxidant status in the peripartum dairy cow. *J. Anim. Feed Sci.*, 29.
- Uchewa E., Orogwu C., Nwakpu P. (2014). Effect of yam peel meal (YPM) replacement for maize on the growth performance and carcass traits of weaner rabbits. *Int. J. Agric. Innov. Res.*, 2: 536–541.
- Upadhyay A., Lama J.P., Tawata S. (2010). Utilization of pineapple waste: a review. *J. food sci. technol. Nepal*, 6: 10–18.
- Valenti B., Luciano G., Pauselli M., Mattioli S., Biondi L., Priolo

- A., Natalello A., Morbidini L., Lanza M. (2018). Dried tomato pomace supplementation to reduce lamb concentrate intake: Effects on growth performance and meat quality. *Meat Sci.*, 145: 63–70.
- Villarreal M., Cochran R., Rojas-Bourrillón A., Murillo O., Muñoz H., Poore M. (2006). Effect of supplementation with pelleted citrus pulp on digestibility and intake in beef cattle fed a tropical grass-based diet (*Cynodon nlemfuensis*). *Anim. Feed Sci. Technol.*, 125: 163–173.
- Wadhwa M., Bakshi M. (2005). Vegetable wastes – a potential source of nutrients for ruminants. *Indian J. Anim. Nutr.*, 22: 70–76.
- Wadhwa M., Saini J., Bakshi M. (2015). Potential of bottle gourd pomace as feed for goat bucks. *Small Rumin. Res.*, (in print).
- Waldron K.W. (2009). *Handbook of waste management and co-product recovery in food processing*. Elsevier.
- Wimalasiri S., Somasiri S. (2025). Ensiled fruit peels of pineapple (*Ananas comosus*) and papaya (*Carica papaya*) as an animal feed. *Proc. International Conference on Agriculture, Food Security and Safety (AgroFood)*.
- Xiong M.-L., Wu X.-J., Zhu X.-F., Zhang W.-J. (2021). Effects of different apple pomace levels on lactation performance, nutrient apparent digestibility, serum biochemical indices and the rumen pH of Guanzhong dairy goats. *Acta Prataculturae Sin.*, 30: 81–88.
- Xu C., Xiong P., Song W., Song Q., Hu Y., Song T., Ji H., Chen X., Zou Z. (2024). Effects of fermented navel orange pulp on growth performance, carcass characteristics, meat quality, meat nutritional value, and serum biochemical indicators of finishing Tibetan pigs. *Foods*, 13: 1910.
- Yang C., Zhao W., Tian H., Wang M., Gao C., Guo Y., Sun B. (2022). A preliminary study on the possibility of fermented pineapple peel residue partially replacing whole corn silage in feeding Chuanzhong black goats. *Front. Microbiol.*, 13: 959857.
- Yanza Y.R., Szumacher-Strabel M., Lechniak D., Ślusarczyk S., Kolodziejski P., Patra A.K., Váradyová Z., Lisiak D., Vazirigohar M., Cieslak A. (2022). Dietary *Coleus amboinicus* Lour. decreases ruminal methanogenesis and biohydrogenation, and improves meat quality and fatty acid composition in *longissimus thoracis* muscle of lambs. *J. Anim. Sci. Biotechnol.*, 13: 1–19.
- Yitbarek M. (2019). Some selected vegetable and fruit wastes for poultry feed. *J. Vet. Anim. Res.*, 2: 102.
- Yu J., Ahmedna M. (2013). Functional components of grape pomace: Their composition, biological properties and potential applications. *Int. J. Food Sci. Technol.*, 48: 221–237.
- Zalikarenab L., Pirmohammadi R., Teimuriyansari A. (2007). Chemical composition and digestibility of dried white and red grape pomace for ruminants. *J. Anim. Vet. Adv.*, 6: 1107–1111.
- Zema D.A., Fòlino A., Zappia G., Calabrò P.S., Tamburino V., Zimbone S.M. (2018). Anaerobic digestion of orange peel in a semi-continuous pilot plant: An environmentally sound way of citrus waste management in agro-ecosystems. *Sci. Total Environ.*, 630: 401–408.
- Zhao J., Li Q., Zhang R., Liu W., Ren Y., Zhang C., Zhang J. (2018). Effect of dietary grape pomace on growth performance, meat quality and antioxidant activity in ram lambs. *Anim. Feed Sci. Technol.*, 236: 76–85.
- Zheng Z., Shetty K. (2000). Solid-state bioconversion of phenolics from cranberry pomace and role of *Lentinus edodes* β -glucosidase. *J. Agric. Food Chem.*, 48: 895–900.

Received: 5 I 2025

Accepted: 12 VI 2025