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PINEAPPLE WASTE IN ANIMAL FEED: A REVIEW OF NUTRITIONAL POTENTIAL, IMPACT AND PROSPECTS

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Abstract

Pineapple is a commodity and economic fruit with a high market potential worldwide. Almost 60% of the fresh pineapple, such as peels, pulp, crowns and leaves, are agricultural waste. It is noteworthy that the waste has a high concentration of crude fibre, proteins, ascorbic acid, sugars and moisture content. The pineapple waste utilisation in animal feed has recently drawn the attention of many investigators to enhance growth performance and concomitantly reduce environmental pollution. Its inclusion in animal feed varies according to the livestock, such as feed block, pelleted or directly used as a roughage source for ruminants. The pineapple waste is also fermented to enrich the nutrient content of poultry feed. To date, the inclusion of pineapple waste in animal feed is optimistic not only for livestock but also for farmed fish. Indeed, it is an ideal strategy to improve the feed supply to the farm. This paper aims to overview the source, nutritional composition, and application of pineapple waste in animal feed. The recent findings on its effect on animal growth performance, nutrition and disease control are discussed comprehensively and summarised. The review also covers its benefits, potential impacts on sustainable farming and future perspectives.

Key words: pineapple waste, animal feed, animal nutrition, animal health, environment

Pineapple (*Ananas comosus*) belongs to the genus Bromeliaceae and consists of 2000 species. This fruit is an essential source of sugars, minerals, fibres, organic acids, and vitamins for human consumption (Assumi et al., 2018; Chaudhary et al., 2019). Furthermore, pineapple contains antioxidants such as carotenoids, ascorbic acid, and flavonoids. Nonetheless, the chemical composition of this fruit varies according to varieties worldwide. One fresh pineapple can supply approximately 17% vitamin C and is rich in the B-complex group, such as pyridoxine, folate, riboflavin, and niacin. In addition, pineapple contains bromelain with anti-clotting, anti-cancer, and anti-inflammatory properties (Ajayi et al., 2022; Habotta et al., 2022; Hikal et al., 2021). A 100 g fresh pineapple contains 86.45 g of water, 48 kcal energy, 12.66 g of carbohydrate, 9.35 g total sugar, and 1.4 g fibre. This fruit is also high in minerals, such as potassium (151.5 mg), magnesium (16.5 mg), calcium (13 mg), and phosphorus (11 mg) (Assumi et al., 2018). Meanwhile, pineapple is high in vitamin C (36.5 mg) and vitamin A, B_6, D, E, K, folic acid, thiamine, and riboflavin (Assumi et al., 2018; Das et al., 2021). Most importantly, pineapple is a commercial fruit in tropical regions and some parts of the subtropics. Tropical countries such as Malaysia, Thailand, Indonesia, India, Kenya, the Philippines, and China are among the leading pineapple producers in the world (Lasekan and Hussein, 2018).

In recent years, numerous studies have explored the potential of agricultural waste in minimising environmental pollution (Dawood et al., 2022; Mat et al., 2022). Pineapple waste can be exploited as a raw material for producing valuable compounds, such as fermentable substrates (Roda and Lambri, 2019). To date, pineapple waste has been extensively studied for bromelain, bioactive compounds extraction, citric acid bioethanol and methane production (Gil and Maupoey, 2018). In addition, pineapple waste as an alternative animal feed was explored. For instance, dried pineapple waste was given to pigs (Tuntivisoottikul, 1984), ruminants (Buliah et al., 2019; Costa et al., 2007; Gowda et al., 2015; Kyawt et al., 2020), broilers (Mandey et al., 2018; Shaibu et al., 2020), and fish (Deka et al., 2003; Sukri et al., 2022). Some studies have shown significant results on the growth performance of various livestock without adverse effects on nutrient utilisation. Meanwhile, another study discovered that pineapple waste significantly enhanced the milk production of dairy cattle (Buliah et al., 2019).

The literature has highlighted the potential of pineapple waste as a sustainable alternative feed that could assist farmers in sustaining their farms by reducing the feeding cost. Therefore, this review examined the potential of pineapple waste inclusion in animal feed for ruminants and non-ruminants. First, the source, types, and nutritional composition of pineapple waste are discussed, followed by the benefits of this agriculture by-product in animal nutrition. Moreover, the influence of livestock growth performance, feed utilisation, digestibility and carcass composition were comprehensively discussed. Subsequently, the effect of pineapple waste on animal health, such as intestinal health, blood-related indices, and immune response, were investigated in this review. Finally, the present study reviewed the impact of pineapple waste as animal feed on sustainable farming and the economy, including recommendations for future studies.

Source, forms and types of pineapple waste

Numerous studies have explored the benefits of different pineapple waste (Ali et al., 2020; Gowda et al., 2015; Kyawt et al., 2020), including peel (Roda et al., 2017), core (Azizan et al., 2020) and crown (Azizan et al., 2020; Prado and Spinacé, 2019). For instance, Azizan et al. (2020) reported that the peel and crown of a new pineapple variety, MD2, contain valuable metabolites extracted with 100% ethanol, besides acting as natural sources of α-glucosidase and antioxidants. The total weight of the pineapple is mainly contributed by the fruit peel (29%–42%), which has been utilised in the production of polyhydroxyalkanoate (PHA), a biopolymer sourced through fermentation with various applications in biomedicine, textiles, packaging and household appliances (Vega-Castro et al., 2016).

The pineapple by-product is a good fertilizer in the form of compost. In addition, the pineapple peel can be powdered and fed to the Nile tilapia using a biofloc system (Van Doan et al., 2021). The fish fed with the 10 g kg^{-1} pineapple peel powder (PAPP)-supplemented diet achieved the highest ($P<0.05$) survival rate against *Streptococcus agalactiae*, besides significantly enhancing their growth and feed efficiency ($P<0.05$) (Van Doan et al., 2021). Meanwhile, the silage produced from pineapple fruit residue (PFR) can promote milk production in dairy ruminants (Gowda et al., 2015). The pineapple crop waste silage is a suitable alternative for cattle (Mello et al., 2021) and sheep diets (Cordeiro et al., 2022). Table 1 describes other utilisation of pineapple waste and the study outcomes.

Table 1. Pineapple waste utilisation

Source	Derivatives	Utilisation of pineapple waste	Observation of the study	References
1	2	3	4	5
Peel	Aqueous extract	Physical and enzymatic treatments to produce fruit vinegar	Pineapple vinegar offers significantly higher L-lysine, mullein and gallic acid than the original win.	(Roda et al., 2017)
Peel	Fermented pineapple peel waste (PWS)	Production of PHA for biopolymer application by fermentation from PWS	Extraction of PHA from PWS is possible using *Ralsthonia eutropha* ATCC 17697 strain fermentation	(Vega-Castro et al., 2016)
Peel	Powder	Functional feed additives in aquaculture	Pineapple peel powder showed potential for immunity, related gene expression and growth efficiency in Nile tilapia in the sustainable Biofloc aquaculture system	(Van Doan et al., 2021)
Core	Aqueous extract	Physical and enzymatic treatments to produce fruit vinegar	According to food grade requirements, saccharified pineapple waste indicated clear and no post-filtration deposits	(Roda et al., 2017)
Leaves	Composted leaves	Usage of composted pineapple leaves for sustainable agriculture	Composted leaves are rich in K-fulvate. K-fulvate is a potential fluid fertiliser and a phosphorus fertiliser source in a high soil pH region	(Ahmed et al., 2004)
Crown leaves	Powder	Utilisation of pineapple crown leaf activated carbon (AC) for liquid separation	AC from pineapple crown leaf proved to be an effective absorbent for dye removal from aqueous solution	(Astuti et al., 2019)

Table 1 – contd.

1	2	3	4	5
Crown leaves	Fibre	Cellulose nano-crystal (CNC) from pineapple crown leaves	CNC high hydrophilicity properties enable utilisation in liquid media applications and polymeric nanocomposites	(Prado and Spinacé, 2019)
Stem	Isolated starch (PSS)	Gelatinisation and pasting properties in pineapple stem starch	Pineapple stem starch can be modified and proved to show potential as a tablet binder and disintegrant in pharmaceutical practices	(Rahma et al., 2019)
Crown, peels, and pomace	Silage	Livestock feed from PFR silage	PFR silage resulted in improved growth rate and lactation and did not affect general health in ruminants	(Gowda et al., 2015)
Peel, crown and core	Aqueous extract	Bioactive metabolites for cosmeceutical, functional food and therapeutics application	Crown parts are potential antioxidants, and peel parts of MD2 are α-glucosidase inhibitors.	(Azizan et al., 2020)
Fruit, stem, peel, core and crown		Bromelain obtained from pineapple waste exhibited clinical properties for medicinal application.	Bromelain isolated from fruit, stem, peel, crown and crown reported to have antimicrobial properties that alleviate acne	(Abbas et al., 2021)
Pineapple waste	Silage	Pineapple waste silage (PWS) improved the performance of dairy cattle	PWS as a roughage diet improved energy balance, body weight gain, and nutrient intake in cattle compared to napier grass silage	(Kyawt et al., 2020)
Pineapple crop waste	Silage	Pineapple waste silage improves cattle's feed intake, digestibility and energy content	Pineapple crop waste silage makes an acceptable substitute for cattle diets	(Mello et al., 2021)
		Nutritional evaluation of pineapple crop waste silage on sheep diet.	Pineapple crop waste silage makes an acceptable substitute for sheep diets	(Cordeiro et al., 2022)

Nutritional composition of pineapple waste

Pineapple waste production has been gaining popularity recently due to technological advancements eliminating components unsuitable for human consumption (Hemalatha and Anbuselvi, 2013). The pineapple processing generated 45–65% residues, consisting of pulp, peels, stems and leaves. Consequently, various studies have reported the chemical composition of various pineapple varieties (Correia et al., 2007; Hemalatha and Anbuselvi, 2013; Rani and Nand, 2004), including the nutritional value (De Ancos et al., 2016; Hemalatha and Anbuselvi, 2013), volatile compounds (Dolhaji et al., 2018; Lasekan and Hussein, 2018; Pino, 2013), antioxidants (Ali et al., 2020; Dolhaji et al., 2018) and fibres (Asim et al., 2015). Notably, the substantial nutritional composition in pineapple waste has made the by-product a promising raw material in the animal feed industry.

The pineapple waste contains high moisture (81.2–86.2%) (Hossain et al., 2015), with the major nutrient being total solid (13–19%), consisting of carbohydrates (85%) and fibre (2–3%) (Chaudhary et al., 2019; Rashad et al., 2015). Carbohydrate supplies sugars, organic acids, dietary fibre and essential vitamins and minerals (Hemalatha and Anbuselvi, 2013). Pineapple is a citrus fruit, thus, rich in citric acid (21.5 mg/100 g of ascorbic acid). It was reported that a slight reduction in ascorbic acid was observed in ripening pineapple (Siti Rashima et al., 2019). Meanwhile, vitamin C in pineapple waste can relieve stress and improves health in animal. Furthermore, pineapple waste is rich in bromelain, bioactive and functional compounds which are beneficial as animal feed supplements (Azizan et al., 2020; De Ancos et al., 2016; Pavan et al., 2012).

Hemalatha and Anbuselvi (2013) have reported the low fat and protein content in pineapple waste. Despite the low protein content, the amino acids in pineapple waste could act as growth factors when included in animal feed and enriched via enrichment methods, such as wheat offal utilisation (Makinde et al., 2011). Moreover, pineapple waste has low ash content (0.04%) compared to pineapple pulp (1.8%) (Hemalatha and Anbuselvi, 2013). A study has identified the volatile and non-volatile compounds responsible for the sweet flavour of six pineapple varieties (Moris, Maspine, MD2, N36, Josapine and Sarawak) grown in Malaysia (Dolhaji et al., 2018; Lasekan and Hussein, 2018) Meanwhile, another study (Lasekan and Hussein, 2018) investigated the volatile aromatic compounds in the Shenwan pineapple (Wei et al., 2014).

Numerous studies have attempted to enhance the nutritional composition of pineapple waste, particularly protein, carbohydrate, fibre and moisture content. The fermentation technology is useful in enriching pineapple waste for animal feed production. The improved pineapple waste nutrient could be applied mainly to monogastric animals, aquaculture species (Sukri et al., 2022) and ruminants (Sruamsiri, 2007). For instance, high moisture (Hossain et al., 2015) and carbohydrates (Hemalatha and

Anbuselvi, 2013) in pineapple waste could be alleviated through the microbial fermentation process (Chaudhary et al., 2019; Rashad et al., 2015). Furthermore, fermentation using *Saccharomyces cerevisiae* (Correia et al., 2007), *Aspergillus niger,* and *Trichoderma viride* (Omwango et al., 2013) increased the crude protein and ash content while reducing the crude fibre content (Omwango et al., 2013). In addition, antioxidants could be produced through solid-state fermentation (SSF) (Rashad et al., 2015).

Table 2. Nutritional composition of fermented and non-fermented pineapple waste

Nutrient	NFPW[a]	NFPW[b]	FPW[b] (after 48 h)	FPW[c]
Crude protein (mg/100 g)	10	6.4	16.1	0.91
Crude fibre (g/100 g-fw)	0.60	–	–	–
Ash (%)	0.04	–	–	12.88
Moisture (%)	91.35	–	–	72.49
Total soluble solids (%)	10.2	–	–	27.51
Reducing sugar (%)	8.2	30	3	5
Non-reducing sugar (%)	8.8	–	–	1.7
Total sugar (%)	10.2	–	–	–
Ascorbic acid (mg/100 mg)	26.5	–	–	–

*NFPW: Non-fermented pineapple waste; FPW: fermented pineapple waste (Hemalatha and Anbuselvi, 2013)[a], (Correia et al., 2007)[b], (Rani and Nand, 2004)[c].

Pineapple waste in animal nutrition

Pineapple by-products comprised plant cores, peels, leaves generated on the farm, and waste from juice production. The waste has a similar macronutrient and bioactive compound profile to the lower-quality fruits; hence, an ideal ingredient for animal feed, particularly for livestock that consumes a fibrous and carbohydrate-rich diet. The use of pineapple waste in animal feed has been reported in several countries, mainly pineapple producers such as India, Thailand and Nigeria. The effects of the pineapple waste diet were studied in the broiler (Mandey et al., 2018), cattle (Gowda et al., 2015; Suksathit et al., 2011), goat (Asaolu et al., 2016), rabbit (Adeyemi et al., 2011), and fish (Mandey et al., 2018).

Farmers began utilising pineapple waste in the late 1970s (Müller, 1978) and 1980s (Geoffroy, 1985), where livestock was found to benefit from the cellulose and fibrous ingredients (<80%) (Santos-Silva et al., 2020). Specifically, the pineapple waste diet was associated with improved animal growth performance and cost-effectiveness for farm operations. Recently, cattle fed with pineapple waste exhibited a positive response (Gowda et al., 2015; Suksathit et al., 2011). For instance, (Gowda et al., 2015) fed dairy cattle with silage pineapple waste and reported improved lactation productivity. Furthermore, Suksathit et al. (2011) highlighted the potential use of pineapple silage in Southern Thai native cattle. The pineapple waste silage improved nutrient digestibility in livestock compared to hay silage. Additionally, using pineapple silage maintained normal haematology and biochemistry, thus, a feasible and healthy dietary roughage for cattle. Moreover, pineapple waste was used as an alternative diet to reduce the cost of animal feed. Sheep fed with pineapple waste silage performed similarly to those fed maize silage but at a lower cost (Gowda et al., 2015). In another study, researchers discovered that combining pineapple waste with wheat bran enhanced the palatability of Red Sokoto goat diet (Asaolu et al., 2016). Pineapple waste was also incorporated in the African dwarf goat diet, where the combination of pineapple waste and malted sorghum sprout showed no difference from the control, indicating the safety of pineapple waste as an animal feed ingredient (Asaolu et al., 2016).

Mandey et al. (2018) explored fermented pineapple waste as broiler feed to reduce fibre content and improve other nutritional components. The fermentation process was performed by incubating the pineapple waste with a fungus mixture starter comprised of *A. niger*, *Aspergillus oryzae*, *Candida parapsicosis*, *Candida melinis*, *Hansenula supbeliculosa*, *Hansenula malanga*, and *S. cerevisiae*. This fungal concoction or "ragi" used to ferment the pineapple waste did not negatively impact the growth performance of broilers. Nevertheless, another study reported that 20% fermented pineapple waste improves broiler body indices by reducing intraperitoneal fat accumulation (Mandey et al., 2018). Moreover, raw pineapple waste costs the least in terms of production and income over feed and chick costs (IOFCC). Mandey et al. (2018) recommended 20% fermented pineapple waste be added to broiler feed to improve body condition; raw pineapple waste has no negative effects on the broiler and is more economical.

Pineapple waste is a potential feed ingredient for monogastric animals, despite their low tolerance of herbivores towards high dietary fibre. For instance, incorporating 25% pineapple waste into the rabbit feed lowers the cost significantly, and raw pineapple waste is less expensive than fermented pineapple waste. (Adeyemi et al., 2011). The rabbit's growth performance and feed cost were evaluated when pineapple waste was included in their diet. It was discovered that rabbits could consume raw and fermented pineapple waste without negative health effects (Adeyemi et al., 2011). In addition, the use of pineapple waste could be extended to invertebrates. The agriculture by-product was subjected to nutritional transformation mediated by organic nutrient converters, such as hermetic larvae culture and vermiculture. Furthermore, insect larvae and worms can be utilised directly as waste controllers and nutrient transformers (Saranraj and Stella, 2012).

The effects of pineapple waste on animal growth performance

Growth performance is a primary concern in animal husbandry, particularly those farmed for meat. Traditionally, the growth rate is one of the standard parameters in evaluating meat growth for nutritional studies (Moloney and McGee, 2017). The main aim of formulating animal feed using cheap and sustainable ingredients is to increase growth rates and feed conversion efficiencies while maintaining low feed costs. Animal growth is routinely measured as the change in live weight or mass with varying weighing conditions (Owens et al., 1995). Therefore, when a new ingredient is used in formulating animal feed, farmers need to evaluate the animal's ability to utilise the feed ingredients for growth (Glencross et al., 2007). Several studies have assessed the efficacy of pineapple waste as an alternative feed ingredient to enhance the growth of aquatic animals, ruminants, pigs and snails (see Table 3). Each study used a different type of pineapple waste, processing technique and quantity, depending on the farmed animal species. Alternatively, several studies incorporated pineapple waste as an ingredient in pelleted feed, while others combined pineapple waste with other ingredients such as hay to produce silage for livestock such as ruminants.

Table 3. The impacts of pineapple waste as an alternative feed ingredient on farmed animals

Animal	Type of pineapple waste	Amount (in experimental diet)	Experiment duration	Growth performance – SGR/Average daily gain/weight gain		References
				control	best pineapple waste diet	
1	2	3	4	5	6	7
Nile tilapia (*Oreochromis niloticus*) – fingerlings	Pineapple waste, including leaves, crown and peel.	0%, 10%, 20%, 30%	Fed 3 times a day for eight weeks	(0% Pineapple waste) 0.59±0.01%	(30% pineapple waste) 0.69±0.03%	(Sukri et al., 2022)
	Pineapple peel powder	0, 10, 20, 30, 40 g kg^{-1}	Fed twice daily for eight weeks	2.99±0.02%	(10 g kg^{-1} pineapple peel powder) 3.30±0.05%	(Van Doan et al., 2021)
	Peel extract – sprayed on top of pelleted diet and coated with fish oil	0%, 1%, 2%, and 3%	Fed twice daily for eight weeks	1.52±0.05%	(1% peel extract) 1.86±0.02%	(Yuangsoi et al., 2018)
Brahman × Thai steers – 18 months old	Bagasse–vinasse mixture including pineapple peel silage	No specific mention – 70:30 of vinasse and bagasse	90 days	0.38 kg head^{-1} day^{-1}	0.55 kg^{-1} head^{-1} day^{-1}	(Maneerat et al., 2015)
Holstein Friesian × Thai steers – 18 months old	Silage consisting of a mixture of stem residue from bromelain enzyme production and peel residue, 50:50	No specific mention	*Ad libitum* for six months	0.9 kg day^{-1}	1 kg day^{-1}	(Hattakum et al., 2019)
Holstein steers – 18 months old	Pineapple stem by-product	Pineapple stem was used as roughage source along with four levels of restricted concentrate (4, 5, 6 and 7 kg/head/day as fed basis)	Twice per day, 210 days	No differences between treatments		(Pintadis et al., 2020)
Cattle	Unspecified – pineapple waste silage	45% Napier grass silage + 25% pineapple waste silage + 30% concentrate	Twice a day for six weeks	12.67±0.59 kg	15.01±0.48 kg	(Kyawt et al., 2020)

Table 3 – contd.

1	2	3	4	5	6	7
Holstein steers – 18 months old	Pineapple stem by-product	Pineapple stem was used as roughage source along with four levels of restricted concentrate (4, 5, 6 and 7 kg/head/day as fed basis)	Twice per day, 210 days	No differences between treatments		(Pintadis et al., 2020)
Cattle	Unspecified – pineapple waste silage	45% Napier grass silage + 25% pineapple waste silage + 30% concentrate	Twice a day for six weeks	12.67±0.59 kg	15.01±0.48 kg	(Kyawt et al., 2020)
Lambs – 4 months old	Pineapple crown, peels, and pomace	62% pineapple waste (DM basis)	75 days	No differences between treatments		
Dwarf sheep – 6 to 8 months old	Not specified, silage consisting of ensiled cassava root meal + pineapple fruit waste; sun-dried pineapple fruit waste; ensiled cassava peels and pineapple fruit waste	The ratio of 1:4 in each diet (1 cassava: 4 pineapple)	56 days	40.71 g day^{-1}	66.43 g day^{-1}	(Oduguwa et al., 2013)
West African dwarf goats	Unspecified	A mixture of malted sorghum sprout and pineapple waste at 1:2; then four diets were formulated containing 0%, 20%, 40% and 60% of the mixture	12 weeks	14.52 g day^{-1}	(diet 20% mixture) 19.21 g day^{-1}	(Saka et al., 2016)
Saanen female goats – 7 months old	Peel and bagasse	0%, 33%, 66% and 100% dehydrated pineapple by-product	80 days	No differences between treatments		(Costa et al., 2007)
Pigs (Large white × Landrace hybrid)	Unknown	0%, 5%, 10%, and 15% in diets	Unknown	No differences between treatments		(Sanchaisuriya and Thammabut, 1994)
Chicken	Peels fermented with "ragi tape"	0%, 5%, 10%, 15% and 20% in diets	42 days	13.99 g $head^{-1}$ day^{-1}*	19.97 g $head^{-1}$ day^{-1}*	(Mandey et al., 2018)
Snails (*Archachatina marginata*)	Pineapple pulp after juicing	0%, 5%, 10%, and 15% in diets	Unknown	No differences between treatments except the treatment with the highest content of pineapple waste – weight dropped significantly		(Omole et al., 2011)

*It is unknown if statistical analyses were conducted to determine significant differences between the treatments.

Most animals that were fed with pineapple waste diet demonstrated positive outcomes, such as significant growth rate increments compared to the control group. Nonetheless, few studies did not observe significant differences between animals that were provided feed incorporated with pineapple waste and control groups (Costa et al., 2007; Gowda et al., 2015; Pintadis et al., 2020; Sanchaisuriya and Thammabut, 1994). Thus, it can be concluded that pineapple waste is a good alternative feed ingredient due to the comparable animal growth performance to those consuming normal feeds. Notably, excessive inclusion of pineapple waste in animal feed was counterproductive (Saka et al., 2016; Van Doan et al., 2021; Yuangsoi et al., 2018) due to the lack of enhancement in growth performance and significant weight loss in animals (Omole et al., 2011). Therefore, future studies should identify the optimum level of pineapple waste inclusion in the formulated diet to ensure the best growth performance in farmed animals.

The effects of pineapple waste on animals' feed utilisation and digestibility

As pineapple waste contains a substantial amount of fibre, the recommended inclusion level for effective feed utilisation and nutrient digestibility varies between ruminants and non-ruminants. In ruminants, no adverse effects were reported on nutrient utilisation [dry matter (DM), CP, NDF and ADF] when sheep were fed with pineapple waste silage (Cordeiro et al., 2022), while Suksathit et al. (2011) observed improved digestibility (DM, OM, CP, NDF, and ADF) when cattle consumed ensiled pineapple waste diet. The positive outcomes may be contributed by the shorter fibrous particles in pineapple waste that increase the feed passage rate and improve digestibility (Guthrie and Wagner, 1988) compared to the conventional feedstuff, such as hay and Napier grass.

At a lower level of inclusion (5–30%), non-ruminants such as fish (Deka et al., 2003; Sukri et al., 2022), chicken (Mandey et al., 2018; Shaibu et al., 2020), pig (Tuntivisoottikul, 1984) and rabbit (Aboh et al., 2013) can tolerate pineapple waste inclusion in feed without adverse effects on nutrient digestibility and feed utilisation. Furthermore, as an animal feed supplement, pineapple waste has improved feed utilisation and nutrient digestibility in Nile tilapia (Yuangsoi et al., 2018) and broiler chicken (Rahman and Yang, 2018). These observations may be attributed to the presence of protease or proteolytic enzyme in the pineapple waste, which could enhance protein hydrolysis and improve nutrient digestibility (Shi et al., 2016; Tavano, 2013). Table 4 shows the use of pineapple waste as a livestock feed replacement and Table 5 shows the use of pineapple waste as a tilapia and broiler feed supplement.

The effects of pineapple waste on animals' intestinal health

The intestinal morphology is crucial in determining the animals' digestive system health, nutrient absorption and waste material removal (Kari et al., 2021). Generally, the intestinal morphology is an indicator for tested or proposed feed related to animal growth, physiology and health. Morphological changes in the intestine have been reported when plant-based materials are included in animal feed (Batista et al., 2016; Chu et al., 2017; Costa et al., 2007; Gao et al., 2011; Kari et al., 2021, 2020; Molinari et al., 2020; Pimpimol et al., 2020; Ribeiro et al., 2015; Yang et al., 2020). For example, Mitchaothai et al. (2019) reported improved intestinal in Charolais crossbreds when fed with pineapple co-product, without adverse effects on the animal. Furthermore, Huang et al. (2014) revealed that the pineapple by-product improved the hamster's intestinal health due to the water-insoluble fibre-rich fraction. Meanwhile, Wiszniewski et al. (2019) observed that bromelain (20 g/kg) improved the gut tissue in aquatic animals. Bromelain is an enzyme found in pineapple by-products with a broad commercial application (Sharma et al., 2019; Upadhyay et al., 2010). In addition, Tochi et al. (2008) indicated that the bromelain absorption by cells depended on the percentage of inclusion in animal feed.

Table 4. Pineapple waste as a feed replacement

Species	Form	Inclusion level (%)	Results	References
Cattle	Pineapple waste (dried)	75	–	(Snitwong et al., 1985)
Goat	Pineapple waste (dehydrated)	100	OM and cellulose digestibility, Feed efficiency	(Costa et al., 2007)
Labeo rohita	Pineapple waste (dried and powdered)	25	Improved specific growth rate (SGR), feed conversion ratio (FCR), and protein efficiency ratio (PER)	(Deka et al., 2003)
Nile tilapia	Pineapple waste (dried and powdered)	30	Improved SGR	(Deka et al., 2003)
Broiler	Fermented pineapple waste (dried and powdered)	20	Improved FCR	(Mandey et al., 2018)
Broiler	Pineapple peel (dried and powdered)	5	Improved digestibility and no adverse effect on FCR	(Shaibu et al., 2020)
Pig	Pineapple waste (dried)	20	No adverse effect on FCR	(Tuntivisoottikul, 1984)
Rabbit	Pineapple peel (dried)	20	No adverse effect on digestibility and FCR	(Aboh et al., 2013)

Table 5. Pineapple waste as an animal feed supplement

Species	Form	Inclusion level (%)	Results	References
Nile tilapia	Pineapple waste extract	1	Optimum protein digestibility and feed utilisation	(Yuangsoi et al., 2018)
Broiler	Pineapple leaf powder	2 to 3	Improved FCR	(Rahman and Yang, 2018)

Anti-nutritional factors (ANFs) in agricultural waste could also contribute to abnormal intestinal morphology (Feng et al., 2007; Kari et al., 2022; Zulhisyam et al., 2020). Several studies have identified ANFs in pineapple waste incorporated in animal feed. For example, Egwim (2014) showed that fermentation could reduce ANFs in soursop and pineapple peels in animal feed production. In addition, Lima et al. (2012) suggested that 10.39% of pineapple waste can be used on fish feed for Nile tilapia due to the presence of ANFs in the pineapple waste. Similarly, Shiu et al. (2015) observed pathomorphological changes in animal intestines due to the presence of ANFs in the plant-based protein. Therefore, further studies are essential to eliminate ANFs in pineapple waste to ensure optimum animal growth and health. In summary, pineapple waste can be used as a feed additive to improve intestinal and gut health in animals in a dose-dependent manner.

The effects of pineapple waste on blood-related indices

Pineapple wastes are rich in phenolic antioxidants and the proteolytic enzyme bromelain. The action of these components might influence blood-related indices; thus, it is essential to evaluate the blood metabolic profiles to ensure the good nutritional status and health of animals. For example, Gupta et al. (2007) reported that animals fed with pineapple wastes-inclusive diets showed similar or higher values in their blood metabolic profiles than animals that consumed diets without pineapple waste. Furthermore, it was observed that pineapple waste did not lead to adverse effects on the general health of animals (see Table 6). Moreover, feeding pineapple wastes to dairy cattle had no adverse effects on their blood metabolites (Sruamsiri, 2007; Wittayakun et al., 2015).

Similarly, Wittayakun et al. (2019) found that pineapple waste silage with different crude protein: metabolisable energy ratios had no significant effect on blood metabolites in Holstein heifers. In contrast, Choi et al. (2021) investigated the effect of diets with the inclusion of up to 3.0% of dried pineapple cannery by-products (PCB) on the blood metabolic profiles in Hanwoo steers and found significant differences in albumen, blood urea nitrogen (BUN), inorganic phosphorus and magnesium (Mg) concentrations in the treatment groups. Meanwhile, there were no significant differences in other animal blood parameters. Albumen and Mg concentrations in blood increased and BUN concentration decreased with pineapple wastes inclusion (see Table 7). Therefore, different levels of pineapple waste supplementation affect certain nutritional-related blood profile in animals, while other parameters are not affected (Table 8). The health-promoting effects by feeding pineapple wastes to animals may be contributed by the presence of high phenolic antioxidants, bromelain and other bioactive compounds.

Table 6. Performance of livestock fed with pineapple waste dietary treatments

Animal	Treatment	Outcome	References
Cow/ steer	Steers fed a total mixed ration with 0, 1.5 and 3.0% pineapple cannery by-product (PCB)	Albumin and Mg concentration of early finishing steer increased, but BUN concentration tended to decrease with increasing dietary PCB levels Serum triglyceride concentration of late finishing steers increased with increasing dietary PCB level	(Choi et al., 2021)
	Pineapple stem was formulated as a 40% concentrate and fed with forage compared to corn and cassava formulated at the same level.	Pineapple stem did not influence blood lipid profiles	(Khongpradit et al., 2020)
	Cows fed diets with 1.4 and 3.6 kg pineapple residue	Blood triglyceride, nonesterified fatty acids, urea nitrogen, and aspartate transaminase were lower in the high-PR diet Feeding PR did not affect blood malondialdehyde	(Liu et al., 2021)
Buffalo	Concentrate added to pineapple waste silage in differing ratios	Plasma urea nitrogen tended to increase when the proportion of concentrate in the diets increased However, plasma glucose and non-esterified fatty acids were not varied among the animals Plasma insulin increased as the proportion of concentrate in the diets increased	(Jetana et al., 2009)
Goat	Goats fed diets with 0%, 10%, 20% and 30% sundried pineapple waste with or without yeast supplementation	Dietary inclusion of pineapple waste with or without yeast supplementation in a concentrate diet of up to 10% improved the haematological blood parameters	(Adekanbi et al., 2017)
Sheep	Lambs fed either maize or pineapple fruit residue (PFR) silage	Blood biochemical parameters did not differ between the groups of lambs The PFR silage did not have any adverse effect on lambs' health	(Gowda et al., 2015)
Pig	Pigs fed diets with 0%, 5%, 10% and 15% pineapple leaf residue silage (PLRS)	Feeding of PLRS did not show a remarkable difference (P>0.05) in blood biochemical parameters among the treatments	(Han et al., 2015)

Table 7. Effects of pineapple cannery by-product on serum blood parameters of early finishing Hanwoo steers (Source: Choi et al., 2021)

Items	Level of pineapple cannery by-products in diet			SEM	P-value	
	0%	1.5%	3.0%		linear	quadratic
Albumin (g/dL)	3.6 b	3.7 ab	3.7 a	0.05	0.016	0.517
Blood urea nitrogen (mg/dL)	19.3 a	20.1 a	17.4 b	0.66	0.068	0.046
Inorganic phosphorus (mg/dL)	7.3 b	7.9 a	7.3 b	0.16	0.868	0.012
Magnesium (mg/dL)	2.8 b	2.9 b	3.0 a	0.05	0.026	0.292

a, b – means in the same row with different letters differ significantly (P<0.05). SEM, standard error of the mean; BUN, blood urea nitrogen.

Table 8. Performance and biochemical profile in lambs. Source: Gowda et al., 2015

Parameter	Group		Pooled standard error
	maize silage	PFR silage	
Haemoglobin (g %)	13.7	13.8	0.71
Total protein (g %)	6.24	6.51	0.41
Blood urea nitrogen (mg %)	32.9	29.2	2.10
Creatinine (mg %)	1.20	1.30	0.06
SGOT (IU/L)	147	139	12.36
SGPT (IU/L)	24.4	19.5	3.10

SGOT, serum glutamate oxaloacetate transaminase; SGPT, serum glutamate pyruvate transaminase.

The effect of pineapple waste on the immune response

Pineapple waste has been utilised in producing phenolic substances, indicating a high antioxidant content (Van Dyk et al., 2013). Antioxidants, with antibacterial and anti-cancer properties, can inhibit the generation of free radicals induced by the oxidation of biological molecules. Nonetheless, efforts are being undertaken to establish suitable pre-treatment methods to increase the nutritional quality of agricultural waste as a feed, such as a pineapple waste (Rusli et al., 2021).

Ruminant

Pineapple waste silage (PWS) is a promising roughage feed for ruminants (Pintadis et al., 2020). Adding pineapple waste to elephant grass ensiling increased rumen degradability indices and silage digestibility (Ferreira et al., 2016). Adekanbi et al. (2017) found that 10% pineapple waste dietary inclusion with or without yeast supplementation enhanced the feed conversion ratio of West African dwarf (WAD) goats without negative impacts on their haematological markers. Furthermore, the neutrophils and lymphocytes count at the end of the trial was within the normal range. These values may indicate that the WAD goats had a well-developed immune system, with enough immune cells to keep them healthy (Daramola et al., 2005). Thus, pineapple waste is beneficial as a grass substitute for goats throughout the dry season.

In another study, the white blood cell, neutrophils, and lymphocyte counts increased significantly when wheat offal-carried pineapple waste (WCPW) was added to the goat diets compared to the control group (Ayandiran et al., 2019). These phagocytes can protect the body by eliminating invading microbes, thus contributing to cellular inflammatory processes and improving immunity (Staub, 1994). In addition, WCPW exhibits immuno-stimulatory properties, which could be related to its high vitamin content, particularly vitamins A and C, as well as bromelain, which are known to have immuno-stimulatory properties (Maurer, 2001). Nevertheless, there is a lack of studies regarding the effect of pineapple waste silage on ruminants' immune response.

Aquaculture

In aquaculture, feed additive supplementation has been used to boost innate and adaptive immune responses (Dawood et al., 2018). A recent study discovered that feeding Nile tilapia pineapple peel powder (PPP) at 10 g kg^{-1} significantly increased their skin mucus lysozyme, peroxidase activity, alternative complement activity, phagocytosis, and respiratory burst activities. Furthermore, a dietary intake of 10 g kg^{-1} PPP increased the interleukin-1 (IL-1), interleukin-8 (IL-8), and LBP gene expressions compared to the control and other supplemented groups. The IL-1 and IL-8 are cytokines produced by the fish's immune system in response to bacterial infections (Acar et al., 2018; Wang et al., 2016). Moreover, another study reported significant improvements in mucosal immunity of common carp, *Cyprinus carpio*, that were fed orange peels-derived pectin, convict cichlid, *Amatitlania nigrofasciata*, fed with polyphenols from agricultural by-products, and rainbow trout, *Oncorhynchus mykiss*, that consume olive, *Olea europea* waste (Hoseinifar et al., 2020).

The antibacterial potential of ethyl acetate extract of pineapple peel was demonstrated by Lubaina et al. (2019) against gram-positive and gram-negative bacterial strains, such as *Staphylococcus aureus* (ATCC 29213), *Escherichia coli* (ATCC 25922), *Pseudomonas aer-*

uginosa (ATCC 27853), *Vibrio cholerae* (MCV09), and *Klebsiella pneumoniae* (ATCC 700603). Based on the findings, pineapple peel has the potential source for antibiotic synthesis, with medical and industrial applications. The antibacterial characteristics of various extracts from pineapple peel have recently attracted a lot of attention due to their potential usage as natural additives (Lubaina et al., 2019) to replace synthetic antimicrobials. Pineapple peel has antioxidant, antibacterial, antidiabetic, and cytotoxic properties (Das et al., 2019).

The presence of polyphenols, flavonoids, saponins, and other secondary metabolites in pineapple extracts could explain their antibacterial activities. Gram-positive bacteria are more resistant to flavonoids and polyphenols. These phenolic compounds have polar characteristics that react with gram-positive bacteria's peptidoglycan layer rather than the non-polar lipid layer. Most plant phenolic compounds are non-toxic to humans and could inhibit the growth of various foodborne and food spoilage microbes. In addition, Van Doan et al. (2021) reported that bromelain supplementation improved villus length and mucosal folds, gut tissue and intestinal absorptive cells, and increased lipase and pepsin enzymatic activities, thus, enhancing Nile tilapia nutrient absorption and digestion. Therefore, pineapple waste is a promising functional feed supplement in aquaculture.

Impact of pineapple waste on sustainable farming

Pineapple is a popular tropical plant cultivated for sweet and sour fruit and juice. The increasing demands in the culinary industry have led to increased pineapple fruit production and agricultural waste. The pineapple planting and processing by-products (crown, stem, leaves, skin and pulp) accounted for 40–50% (w/w) of the plant and decomposed naturally or were eliminated by open burning on site (Buliah et al., 2019). Exploiting the pineapple wastes which contain vitamins, organic acids, sugars, protein, and fibre, is an environmentally friendly solution in sustainable farming by converting waste to valuable products such as animal feed pellets and blocks (Baidhe et al., 2021). In Ghana, using pineapple waste as microbial protein in animal feed served as cheap protein supplements for cattle, poultry, swine and fish breeding (Kyawt et al., 2020; Mensah and Twumasi, 2017). Furthermore, Hattakum et al. (2019) evaluated the effect of pineapple stem silage as a feed source for cattle and reported a significant reduction in the feeding cost. In addition, pineapple waste can be converted into value-added animal feed, thus reducing the storage of low-quality and rejected fruits and decreasing the need for landfills and waste transportation costs (Roda and Lambri, 2019).

Apart from minimising post-harvest agricultural waste disposal, this waste management can create job opportunities for youth and improve community earnings in countries like Uganda, Ghana and in Africa (Hattakum et al., 2019; Kumar, 2021). Moreover, the potential of pineapple waste as animal feed has captured the interest of stakeholders due to its cost-effectiveness, leading to economic growth and empowerment (Chu et al., 2021). Additionally, the agricultural by-products could be compressed and moulded into dense blocks using the feed block technology, serving as feed supplements for farmed animals. Furthermore, the process requires minimal electricity consumption while reducing transportation and waste management costs (Assumi et al., 2018). A previous study by Assumi et al. (2018) reported a waste volume reduction of up to 91% through compaction when 30% of pineapple waste was compressed into a feed block at a pressure of 27.58 MPa. Therefore, pineapple waste disposal could be reduced while utilising the waste as animal feed pellets or feed blocks. Most importantly, this concept could stimulate economic growth for related industries such as pineapple planting and the animal feed industry, thus increasing stakeholder revenues (Gómez-García et al., 2021).

Conclusions and perspectives

The conversion of pineapple waste into animal feed has aided farmers in minimising the farm operating cost. The constant availability of pineapple waste contributes to the lower price, besides acting as a nutritious and safe raw material for animal feed. Most pineapple waste feeding trials focused on ruminant livestock, namely cattle, buffalo, goats, and sheep. Further investigations should be conducted on non-ruminants, such as horses, rabbits and farmed fish. Based on the review, pineapple waste inclusion in animal feed significantly influenced the growth performance of several farmed animals or exhibited no adverse effects on their health. Notably, the significant findings varied depending on the types of pineapple waste and supplementation level in the prepared feed. Some studies also performed the fermentation process before incorporating pineapple by-products in feeding trials to improve the nutritional value of feed. In addition, pineapple waste is rich in bioactive compounds, antioxidants, and bromelain, which are beneficial for farmed animals. Bromelain and phenolic antioxidants in pineapple waste improved the animals' intestinal health and did not cause adverse effects on blood metabolites. Nevertheless, pineapple waste contains ANFs that could affect intestinal health, but these factors could be treated via fermentation or incorporated at lower levels in the feed. Contrary to the aquaculture industry, the study on the effects of pineapple waste on the ruminant immune response remains scarce. Based on the potential outlined in this review, it is pertinent to conduct more studies and evaluate the efficacy of pineapple waste in animal diets for sustainable farming.

Conflicts of Interest

The authors declare no conflict of interest.

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References

Abbas S., Shanbhag T., Kothare A. (2021). Applications of bromelain from pineapple waste towards acne. Saudi J. Biol. Sci., 28: 1001−1009.

Aboh A., Zoffoun G., Djenontin A., Babatounde S., Mensah G. (2013). Effect of graded levels of dry pineapple peel on digestibility and growth performance of rabbit. J. Appl. Biosci., 67: 52711−5276.

Acar Ü., Karabayır A., Kesbiç O., Yılmaz S., Zemheri F. (2018). Effects on some immunological parameters and gene expression levels of lupin meal (*Lupinus albus*) replaced with fish meal in rainbow trout (*Oncorhynchus mykiss*). COMUJAF, 6: 811−89.

Adekanbi A., Onwuka C., Oni A., Ojo V., Ajayi F., Popoola M. (2017). Performance evaluation and haematological biochemical parameters of West African dwarf goats fed pineapple waste (*Ananas comosus*) with or without yeast (*Saccharomyces cerevisiae*) supplementation. Nigerian J. Anim. Prod., 44: 3421−353.

Adeyemi O., Ajado A., Okubanjo A., Eniolorunda O. (2011). Response of growing rabbits to graded levels of fermented and unfermented pineapple peel. Nigeria J. Anim. Prod., 38: 861−898.

Ahmed O.H., Husni M., Anuar A., Hanafi M. (2004). Towards sustainable use of potassium in pineapple waste. Sci. World J., 4: 10071−1013.

Ajayi A.M., Coker A.I., Oyebanjo O.T., Adebanjo I.M., Ademowo O.G. (2022). *Ananas comosus* (L) Merrill (pineapple) fruit peel extract demonstrates antimalarial, anti-nociceptive and anti-inflammatory activities in experimental models. J. Ethnopharmac., 282: 114576.

Ali M.M., Hashim N., Abd Aziz S., Lasekan O. (2020). Pineapple (*Ananas comosus*): A comprehensive review of nutritional values, volatile compounds, health benefits, and potential food products. Food Res. Int., 137: 109675.

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.

Asim M., Abdan K., Jawaid M., Nasir M., Dashtizadeh Z., Ishak M., Hoque M.E. (2015). A review on pineapple leaves fibre and its composites. Int. J. Polym. Sci., 950567.

Assumi S., Jha S., Kaur C. (2018). Valorization of pineapple waste for development of animal feed block. Int. J. Curr. Microbiol. Appl. Sci., 7: 3787−3795.

Astuti W., Sulistyaningsih T., Kusumastuti E., Thomas G.Y.R.S., Kusnadi R.Y. (2019). Thermal conversion of pineapple crown leaf waste to magnetized activated carbon for dye removal. Bioresour. Technol., 287: 121426.

Ayandiran S.K., Odeyinka S.M., Oyebanji B.O. (2019). Hematological and biochemical parameters of West African Dwarf (WAD) goats fed wheat offal-carried pineapple waste (WCPW). Int. J. Animal Sci., 3: 1046s.

Azizan A., Lee A.X., Abdul Hamid N.A., Maulidiani M., Mediani A., Abdul Ghafar S.Z., Zolkeflee N.K.Z., Abas F. (2020). Potentially bioactive metabolites from pineapple waste extracts and their antioxidant and α-glucosidase inhibitory activities by 1H NMR. Foods., 9: 173.

Baidh E., Kigozi J., Mukisa I., Muyanja C., Namubiru L., Kitarikawe B. (2021). Unearthing the potential of solid waste generated along the pineapple drying process line in Uganda: a review. Environ. Challenges, 2: 100012.

Batista S., Medina A., Pires M., Moriñigo M., Sansuwan K., Fernandes J., Valente L., Ozório R. (2016). Innate immune response, intestinal morphology and microbiota changes in Senegalese sole fed plant protein diets with probiotics or autolysed yeast. Appl. Microbiol. Biotechnol., 100: 7223−7238.

Buliah N., Jamek S., Ajit A., Abu R. (2019). Production of dairy cow pellets from pineapple leaf waste. AIP Conference Proceedings, 2124: 020048.

Chaudhary V., Kumar V., Vaishali S., Sing K., Kumar R., Kumar V. (2019). Pineapple (*Ananas comosus*) product processing: A review. J. Pharmacog. Phytochem., 8: 4642−4652.

Choi Y., Lee S., Na Y. (2021). Effects of a pineapple (*Ananas comosus* L.) cannery by-product on growth performance and carcass characteristics in finishing Hanwoo steers. Anim. Biosci., 34: 233.

Chu P.H., Jenol M.A., Phang L.Y., Ibrahim M.F., Prasongsuk S., Bankeeree W., Punnapayak H., Lotrakul P., Abd-Aziz S. (2021). Starch extracted from pineapple (*Ananas comosus*) plant stem as a source for amino acids production. Chem. Biol. Technol. Agric., 8: 1−15.

Chu Y.T., Lo C.T., Chang S.C., Lee T.T. (2017). Effects of *Trichoderma* fermented wheat bran on growth performance, intestinal morphology and histological findings in broiler chickens. Ital. J. Anim. Sci., 16: 82−92.

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. de. Zootec., 51.

Correia R., Magalhaes M., Macêdo G. (2007). Protein enrichment of pineapple waste with *Saccharomyces cerevisiae* by solid state bioprocessing. J. Sci. Ind. Res., 66: 259−262.

Costa R., Correia M., Da Silva J., De Medeiros A., De Carvalho F. (2007). Effect of different levels of dehydrated pineapple by-products on intake, digestibility and performance of growing goats. Small Rumin. Res., 71: 138−143.

Daramola J., Adeloye A., Fatoba T., Soladoye A. (2005). Haematological and biochemical parameters of West African Dwarf goats. Livest. Res. Rural. Dev., 17: 95.

Das G., Patra J.K., Debnath T., Ansari A., Shin H.S. (2019). Investigation of antioxidant, antibacterial, antidiabetic, and cytotoxicity potential of silver nanoparticles synthesized using the outer peel extract of *Ananas comosus* (L.). PLoS One., 14: e0220950.

Das U., Bhattacharyya R., Sen D., Bhattacharjee P., Choudhury P. (2021). Organic pineapple production technology in Tripura − The lone AEZ for fruits in North East India. Int. J. Agric. Environ. Biotechnol., 14: 149−158.

Dawood M.A.O., Habotta O.A.E., Elsabagh M., Azra M.N., Van Doan H., Kari Z.A., Sewilam H. (2022). Fruit processing by-products in the aquafeed industry: A feasible strategy for aquaculture sustainability. Rev. Aquac., 14: 1945−1965.

De Ancos B., Sánchez-Moreno C., González-Aguilar G.A. (2016). Pineapple composition and nutrition. Handbook of Pineapple Technology: Production, Postharvest Science, Processing and Nutrition, Lobo M.G., Paull R.E. (eds). pp. 221−239.

Deka A., Sahu N., Jain K. (2003). Utilization of fruit processing wastes in the diet of *Labeo rohita* fingerling. Asian Australas J. Anim. Sci., 16: 1661−1665.

Dolhaji N.H., Muhamad I.I., Ya'akub H., Abd Aziz A. (2018). Evaluation of chilling injury and internal browning condition on quality attributes, phenolic content, and antioxidant capacity during suboptimal cold storage of Malaysian cultivar pineapples. Malays. J. Fund. Appl. Sci., 14: 456−461.

Egwim E.C. (2014). Production of animal feed concentrates from sour sop and pineapple peels using solid state fermentation. J. Biol. Agri. Healthcare., 4: 22−29.

Feng J., Liu X., Xu Z., Liu Y., Lu Y. (2007). Effects of *Aspergillus oryzae* 3.042 fermented soybean meal on growth performance and plasma biochemical parameters in broilers. Anim. Feed Sci. Technol., 134: 23−242.

Ferreira A.C.H., Rodriguez N.M., Neiva J.N.M., Pimentel P.G., Gomes S.P., Campos W.E., Lopes F.C.F., Mizubuti I.Y., Moreira G.R. (2016). In situ degradability of elephant grass ensiled with increasing levels of pineapple agro-industrial byproduct. Semina: Ciências Agrárias., 37: 2807−2818.

Gao Y., Storebakken T., Shearer K.D., Penn M., Øverland M. (2011). Supplementation of fishmeal and plant protein-based diets for rainbow trout with a mixture of sodium formate and butyrate. Aquaculture, 311: 233−240.

Geoffroy F. (1985). Fruits and fruit by-products as cereal substitutes in animal feeding. Proc. FAO Expert Consultation on the Substitution of Imported Concentrate Feeds in Animal Production Systems in Developing Countries.

Gil L.S., Maupoey P.F. (2018). An integrated approach for pineapple waste valorisation. Bioethanol production and bromelain extraction from pineapple residues. J. Clean. Prod., 172: 1224−1231.

Glencross B.D., Booth M., Allan G.L. (2007). A feed is only as good as its ingredients – a review of ingredient evaluation strategies for aquaculture feeds. Aquac. Nutr., 13: 17−34.

Gómez-García R., Campos D.A., Aguilar C.N., Madureira A.R., Pintado M. (2021). Valorisation of food agro-industrial by-products: From the past to the present and perspectives. J. Environ. Manage., 299: 113571.

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.

Gupta A., Patra R., Saini M., Swarup D. (2007). Haematology and serum biochemistry of chital (*Axis axis*) and barking deer (*Muntiacus muntjak*) reared in semi-captivity. Vet. Res. Commun., 31: 801−808.

Guthrie M., Wagner D. (1988). Influence of protein or grain supplementation and increasing levels of soybean meal on intake, utilization and passage rate of prairie hay in beef steers and heifers. J. Anim. Sci., 66: 1529−1537.

Habotta O.A., Dawood M.A., Kari Z.A., Tapingkae W., Van Doan H. (2022). Antioxidative and immunostimulant potential of fruit derived biomolecules in aquaculture. Fish Shellfish Immunol., 130: 317−322.

Han J., Du J., Zhang J., Lian W., Li M. (2015). How the pineapple leaf residue silage influence the finishing pigs' growing performance and biochemical parameters of the blood. Proc. 6th International Conference on Manufacturing Science and Engineering. Atlantis Press, pp. 1929−1934.

Hattakum C., Kanjanapruthipong J., Nakthong S., Wongchawalit J., Piamya P., Sawanon S. (2019). Pineapple stem by-product as a feed source for growth performance, ruminal fermentation, carcass and meat quality of Holstein steers. S. Afr. J. Anim. Sci., 49: 147−155.

Hemalatha R., Anbuselvi S. (2013). Physicohemical constituents of pineapple pulp and waste. J. Chem. Pharm. Res., 5: 240−242.

Hikal W.M., Mahmoud A.A., Said-Al Ahl H.A., Bratovcic A., Tkachenko K.G., Kačániová M., Rodriguez R.M. (2021). Pineapple (*Ananas comosus* L. Merr.), waste streams, characterisation and valorisation: An overview. Open J. Ecol., 11: 610−634.

Hoseinifar S.H., Jahazi M.A., Nikdehghan N., Van Doan H., Volpe M.G., Paolucci M. (2020). Effects of dietary polyphenols from agricultural by-products on mucosal and humoral immune and antioxidant responses of convict cichlid (*Amatitlania nigrofasciata*). Aquaculture, 517: 734790.

Hossain M.F., Akhtar S., Anwar M. (2015). Nutritional value and medicinal benefits of pineapple. Int. J. Nutr. Food Sci., 4: 84−88.

Huang Y.-L., Tsai Y.-H., Chow C.-J. (2014). Water-insoluble fiber-rich fraction from pineapple peel improves intestinal function in hamsters: evidence from cecal and fecal indicators. Nutr. Res., 34: 346−354.

Jetana T., Suthikrai W., Usawang S., Vongpipatana C., Sophon S., Liang J. (2009). The effects of concentrate added to pineapple (*Ananas comosus* Linn. Mer.) waste silage in differing ratios to form complete diets, on digestion, excretion of urinary purine derivatives and blood metabolites in growing, male, Thai swamp buffaloes. Trop. Anim. Health Prod., 41: 449−459.

Kari Z.A., Kabir M.A., Razab M.K.A.A., Munir M.B., Lim P.T., Wei L.S. (2020). A replacement of plant protein sources as an alternative of fish meal ingredient for African catfish, *Clarias gariepinus*: A review. J. Trop. Resour. Sustain. Sci., 8: 47−59.

Kari Z.A., Kabir M.A., Mat K., Rusli N.D., Razab M.K.A.A., Ariff N.S.N.A., Edinur H.A., Rahim M.Z.A., Pati S., Dawood M.A. (2021). The possibility of replacing fish meal with fermented soy pulp on the growth performance, blood biochemistry, liver, and intestinal morphology of African catfish (*Clarias gariepinus*). Aquac. Rep., 21: 100815.

Kari Z.A., Kabir M.A., Dawood M.A., Razab M.K.A.A., Ariff N.S.N.A., Sarkar T., Pati S., Edinur H.A., Mat K., Ismail T.A. (2022). Effect of fish meal substitution with fermented soy pulp on growth performance, digestive enzyme, amino acid profile, and immune-related gene expression of African catfish (*Clarias gariepinus*). Aquaculture, 546: 737418.

Khongpradit A., Boonsaen P., Homwong N., Suzuki Y., Koike S., Sawanon S., Kobayashi Y. (2020). Effect of pineapple stem starch feeding on rumen microbial fermentation, blood lipid profile, and growth performance of fattening cattle. Anim. Sci. J., 91: e13459.

Kumar A. (2021). Utilization of bioactive components present in pineapple waste: A review. J. Pharma Innov., 10: 954−961.

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.

Lasekan O., Hussein F.K. (2018). Classification of different pineapple varieties grown in Malaysia based on volatile fingerprinting and sensory analysis. Chem. Cent. J., 12: 1−12.

Lima M.R.D., Ludke M.D.C.M.M., Holanda M.C.R.D., Pinto B.W.C., Ludke J.V., Santos E.L. (2012). Performance and digestibility of Nile tilapia fed with pineapple residue bran. Acta Scient. Anim. Sci. J., 34: 41−47.

Liu C., Asano S., Ogata H., Ito S., Nakase T., Takeda S., Miyoshi K., Numata Y., Takahashi K., Kajikawa H. (2021). Digestive, fermentative, and physical properties of pineapple residue as a feed for cattle. Anim. Sci. J., 92: e13535.

Lubaina A., Renjith P., Kumar P. (2019). Antibacterial potential of different extracts of pineapple peel against gram-positive and gram-negative bacterial strains. Asian J. Pharm. Pharmacol., 5: 66−70.

Makinde O., Odeyinka S., Ayandiran S. (2011). Simple and quick method for recycling pineapple waste into animal feed. Livest. Res. Rural Dev., 23: 188.

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, 102: 012042.

Maneerat W., Prasanpanich S., Tumwasorn S., Laudadio V., Tufarelli V. (2015). Evaluating agro-industrial by-products as dietary roughage source on growth performance of fattening steers. Saudi J. Biol. Sci., 22: 580−584.

Mat K., Abdul Kari Z., Rusli N.D., Che Harun H., Wei L.S., Rahman M.M., Mohd Khalid H.N., Mohd Ali Hanafiah M.H., Mohamad Sukri S.A., Raja Khalif R.I.A. (2022). Coconut palm: Food, feed, and nutraceutical properties. Animals, 12: 2107.

Maurer H. (2001). Bromelain: biochemistry, pharmacology and medical use. Cell. Mol. Life Sci., 58: 1234−1245.

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.

Mensah J.K., Twumasi P. (2017). Use of pineapple waste for single cell protein (SCP) production and the effect of substrate concentration on the yield. J. Food Process Eng., 40: e12478.

Mitchaothai J., Lukkananukool A., Polyorach S., Chaosap C., Sitthigripong R. (2019). Villous morphology of small intestine of Charolais crossbred beef cattle raised by pineapple co-product diet. Khon Kaen Agric. J., 47: 1041−1046.

Molinari G.S., McCracken V.J., Wojno M., Rimoldi S., Terova G., Kwasek K. (2020). Can intestinal absorption of dietary protein be improved through early exposure to plant-based diet? PLoS One, 15: e0228758.

Moloney A.P., McGee M. (2017). Factors influencing the growth of meat animals. In: Lawrie's Meat Science. Elsevier, pp. 19−47.

Müller Z. (1978). Feeding potential of pineapple waste for (beef) cattle. World Anim. Rev., 25: 25−29.

Oduguwa B., Sanusi G., Fasae O., Oni O. (2013). Nutritive value, growth performance and haematological parameters of West African dwarf sheep fed preserved pineapple fruit waste and cassava by-products. Niger. J. Anim. Prod., 40: 123−132.

Omole A., Ajasin F., Adejuyigbe A., Soetan A. (2011). Effects of feeding snails with pineapple waste on feed consumption, growth and cost benefits. Arch. Zootec., 60: 53−56.

Omwango E.O., Njagi E.N.M., Orinda G.O., Wanjau R.N. (2013). Nutrient enrichment of pineapple waste using *Aspergillus nige*r and

Trichoderma viride by solid state fermentation. Afr. J. Biotechnol., 12: 6193−6196.

Owens F.N., Gill D.R., Secrist D.S., Coleman S. (1995). Review of some aspects of growth and development of feedlot cattle. J. Anim. Sci., 73: 3152−3172.

Pavan R., Jain S., Kumar A. (2012). Properties and therapeutic application of bromelain: a review. Biotechnol. Res. Int., 2012.

Pimpimol T., Thiammueang D., Karnchanamayoon K., Kanjanamayoon K., Tongsiri S. (2020). Effect of pineapple juice and dried papaya peel in the diet on growth performances of channel catfish (*Ictalurus punctatus*). Maejo Int. J. Energ. Environ. Comm., 2: 29−34.

Pino J.A. (2013). Odour-active compounds in pineapple (*Ananas comosus* [L.] Merril cv. Red Spanish). Int. J. Food Sci. Technol., 48: 564−570.

Pintadis S., Boonsaen P., Hattakum C., Homwong N., Sawanon S. (2020). Effects of concentrate levels and pineapple stem on growth performance, carcass and meat quality of dairy steers. Trop. Anim. Health Prod., 52: 1911−1917.

Prado K.S., Spinacé M.A. (2019). Isolation and characterization of cellulose nanocrystals from pineapple crown waste and their potential uses. Int. J. Biol. Macromol., 122: 410−416.

Rahma A., Adriani M., Rahayu P., Tjandrawinata R.R., Rachmawati H. (2019). Green isolation and physical modification of pineapple stem waste starch as pharmaceutical excipient. Drug Dev. Ind. Pharm., 45: 1029−1037.

Rahman M., Yang D.K. (2018). Effects of *Ananas comosus* leaf powder on broiler performance, haematology, biochemistry, and gut microbial population. R. Bras. Zootec., 47: e20170064.

Rani D.S., Nand K. (2004). Ensilage of pineapple processing waste for methane generation. J. Waste Manag., 24: 523−528.

Rashad M.M., Mahmoud AE., Ali M.M., Nooman M.U., Al-Kashef A.S. (2015). Antioxidant and anticancer agents produced from pineapple waste by solid state fermentation. Int. J. Toxicol. Pharmacol. Res., 7: 287−296.

Ribeiro L., Moura J., Santos M., Colen R., Rodrigues V., Bandarra N., Soares F., Ramalho P., Barata M., Moura P. (2015). Effect of vegetable based diets on growth, intestinal morphology, activity of intestinal enzymes and haematological stress indicators in meagre (*Argyrosomus regius*). Aquaculture, 447: 116−128.

Roda A., Lambri M. (2019). Food uses of pineapple waste and by-products: a review. Int. J. Food Sci. Technol., 54: 1009−1017.

Roda A., Lucini L., Torchio F., Dordoni R., De Faveri D.M., Lambri M. (2017). Metabolite profiling and volatiles of pineapple wine and vinegar obtained from pineapple waste. Food Chem., 229: 734−742.

Rusli N., Ghani A., Mat K., Yusof M., Zamri-Saad M., Hassim H. (2021). The potential of pretreated oil palm frond in enhancing rumen degradability and growth performance: a review. Adv. Anim. Vet. Sci., 9: 811−822.

Saka A., Adekunjo R., Ogunleke F., Ogunfolabo L., Adetola O., Awodele O., Lawrence-Azua O., Okuneye O. (2016). Performance characteristics and blood profile of West African dwarf goats fed diet containing graded level of malted sorghum sprout mixed with pineapple waste based diet. Niger. J. Anim. Sci., 18: 145−153.

Sanchaisuriya P., Thammabut B. (1994). Effect of pineapple waste in growing-finishing pig diets. Kaen Kaset, 22:193−197.

Santos-Silva J., Alves S.P., Francisco A., Portugal A.P., Almeida J., Fialho L., Jerónimo E., Bessa R.J. (2020). Effects of a high-fibre and low-starch diet in growth performance, carcass and meat quality of young Alentejana breed bulls. Meat Sci., 168: 108191.

Saranraj P., Stella D. (2012). Vermicomposting and its importance in improvement of soil nutrients and agricultural crops. Novus Nat. Sci. Res., 1: 14−23.

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. Soc. Anim. Prod., 45: 1377−1381.

Sharma S.A., Krishnakumar V., Arulraj J. (2019). Impact of *Ananas comosus* extract supplementation on the growth and biochemical profile of *Cyprinus carpio* fingerlings. Trends Fish Res., 8: 69−77.

Shi Z., Li X.-Q., Chowdhury M.K., Chen J.-N., Leng X.-J. (2016). Effects of protease supplementation in low fish meal pelleted and extruded diets on growth, nutrient retention and digestibility of gibel carp, *Carassius auratus gibelio*. Aquaculture, 460: 37−44.

Shiu Y.L., Wong S.L., Guei W.C., Shin Y.C., Liu C.H. (2015). Increase in the plant protein ratio in the diet of white shrimp, *Litopenaeus vannamei* (Boone), using *Bacillus subtilis* E20-fermented soybean meal as a replacement. Aquac. Res., 46: 382−394.

Siti Rashima R., Maizura M., Wan Nur Hafzan W., Hazzeman H. (2019). Physicochemical properties and sensory acceptability of pineapples of different varieties and stages of maturity. Food Res., 5: 491−500.

Snitwong C., Suwangumjai T., Intharachote U. (1985). Utilization of pineapple waste in complete ration for weaning cattle. Sattawaphaet San., 36: 357−366.

Sruamsiri S. (2007). Agricultural wastes as dairy feed in Chiang Mai. Anim. Sci. J., 78: 335−341.

Staub N.C. (1994). Pulmonary intravascular macrophages. Annu. Rev. Physiol., 56: 47−67.

Sukri S.A.M., Andu Y., Harith Z.T., Sarijan S., Pauzi M.N.F., Wei L.S., Dawood M.A., Kari Z.A. (2022). Effect of feeding pineapple waste on growth performance, texture quality and flesh colour of nile tilapia (*Oreochromis niloticus*) fingerlings. Saudi J. Biol. Sci., 29: 2514−2519.

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: 281−289.

Tavano O.L. (2013). Protein hydrolysis using proteases: An important tool for food biotechnology. J. Mol. Catal. B Enzym., 90: 1−11.

Tochi B.N., Wang Z., Xu S.-Y., Zhang W. (2008). Therapeutic application of pineapple protease (bromelain): a review. Pak. J. Nutr., 7: 513−520.

Tuntivisoottikul K. (1984). Utilization of pineapple waste and coontail aquatic weed (*Ceratophyllum demersum* L.) in growing-finishing pigs diets. FAO.

Upadhyay A., Lama J.P., Tawata S. (2010). Utilization of pineapple waste: a review. J. Food Sci. Technol. Nepal., 6: 10−18.

Van Doan H., Hoseinifar S.H., Harikrishnan R., Khamlor T., Punyatong M., Tapingkae W., Yousefi M., Palma J., El-Haroun E. (2021). Impacts of pineapple peel powder on growth performance, innate immunity, disease resistance, and relative immune gene expression of Nile tilapia, *Oreochromis niloticus*. Fish Shellfish Immunol., 114: 311−319.

Van Dyk J., Gama R., Morrison D., Swart S., Pletschke B. (2013). Food processing waste: Problems, current management and prospects for utilisation of the lignocellulose component through enzyme synergistic degradation. Renew. Sust. Energ. Rev., 26: 521−531.

Vega-Castro O., Contreras-Calderon J., León E., Segura A., Arias M., Pérez L., Sobral P.J. (2016). Characterization of a polyhydroxyalkanoate obtained from pineapple peel waste using *Ralsthonia eutropha*. J. Biotechnol., 231: 232−238.

Wang E., Wang J., Long B., Wang K., He Y., Yang Q., Chen D., Geng Y., Huang X., Ouyang P. (2016). Molecular cloning, expression and the adjuvant effects of interleukin-8 of channel catfish (*Ictalurus punctatus*) against *Streptococcus iniae*. Sci. Rep., 6: 1−12.

Wei C.B., Ding X.D., Liu Y.G., Zhao W.F., Sun G.M. (2014). Application of solid-phase microextraction for the analysis of aroma compounds from pineapple fruit. Adv. Mater. Res., 988: 397−406.

Wiszniewski G., Jarmołowicz S., Hassaan M.S., Mohammady E.Y., Soaudy M.R., Łuczyńska J., Tońska E., Terech-Majewska E., Ostaszewska T., Kamaszewski M. (2019). The use of bromelain as a feed additive in fish diets: Growth performance, intestinal morphology, digestive enzyme and immune response of juvenile sterlet (*Acipenser ruthenus*). Aquac. Nutr., 25: 1289−1299.

Wittayakun S., Innaree S., Innaree W., Chainetr W. (2015). Supplement of sodium bicarbonate, calcium carbonate and rice straw in lactating dairy cows fed pineapple peel as main roughage. Slovak J. Anim. Sci., 48: 71−78.

Wittayakun S., Innsree W., Inaree S., Chainetr W., Kongngoen N. (2019). Effect of protein to metabolizable energy ratio in pineapple waste silage-based diets on performance of holstein heifers. J. Anim. Health Prod., 7: 158−165.

Yang X., He Y., Chi S., Tan B., Lin S., Dong X., Yang Q., Liu H., Zhang S. (2020). Supplementation with *Saccharomyces cerevisiae* hydrolysate in a complex plant protein, low-fishmeal diet improves intestinal morphology, immune function and *Vibrio harveyi* disease resistance in *Epinephelus coioides*. Aquaculture, 529: 735655.

Yuangsoi B., Klahan R., Charoenwattanasak S., Lin S.M. (2018). Effects of supplementation of pineapple waste extract in diet of Nile tilapia (*Oreochromis niloticus*) on growth, feed utilization, and nitrogen excretion. J. Appl. Aquac., 30: 227−237.

Zulhisyam A.K., Kabir M.A., Munir M.B., Wei L.S. (2020). Using of fermented soy pulp as an edible coating material on fish feed pellet in African catfish (*Clarias gariepinus*) production. AACL Bioflux, 13: 296−308.

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