Research Article

Effect of Pineapple Peel Waste on *In vitro* Digestibility and Fermentability in Goat Rations

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Abstract | Pineapple peel have good nutrients to be used as alternative feed. One of the solutions to reduce costs of ruminant rations is by utilizing pineapple peel waste. Nutrients that break down easily in the rumen can be identified by their high digestibility and fermentability. This study aims to determine the effect of pineapple peel utilization in goat rations on digestibility and fermentability in vitro. This study was designed using a completely randomized design (CRD) with five treatments and six replications. The treatments given were R0 (control ration without pineapple peel waste), R1 (ration with the addition of 10% pineapple peel), R2 (ration with the addition of 20% pineapple peel), R3 (ration with the addition of 30% pineapple peel) and R4 (ration with the addition of 40% pineapple peel). Research data were processed by analysis of variance and Duncan's multiple range test. The results showed that the provision of pineapple peel waste in the ration with ration had significant effect ($P < 0.05$) on the in vitro dry matter digestibility (IVDMD) (50.18% to 72.95%) in vitro organic matter digestibility (IVOMD) (54.07% to 79.99%) and total VFA concentration (97.42 mM to 194.43 mM) but had no significant ($P > 0.05$) on NH_3 concentration. The conclusion of this research is feeding pineapple peel waste-based diets was shown to increase nutrient digestibility and volatile fatty acid (VFA) concentration in goats. These findings suggest that pineapple peels can be utilized as a cheap and sustainable alternative feed ingredient, while supporting efficient use of resources in livestock systems. By enhancing rumen fermentation, this waste has the potential to improve goat production performance, thereby reducing dependence on more expensive conventional feedstuffs. The best level of pineapple peel which produces the best digestibility and fermentability values in goat rations, namely 30%.

Keywords | Pineapple peel waste, *In vitro*, Digestibility, Fermentability

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INTRODUCTION

Feed is one of the factors that determine livestock productivity. Feed is the primary need of the livestock business as well as the largest cost of about 70% of total production (Budiarto *et al*., 2023). Conventional feed such as grass and concentrates are sometimes difficult to obtain by farmers. The dependence of farmers on conventional feed can affect livestock productivity because if feed is difficult to obtain, the fulfillment of livestock nutritional needs is not optimal. One solution to overcome these challenges is to utilize agro-industrial waste, namely pineapple peels. Utilizing agroindustrial waste can be a solution to providing feed at low cost and not competing with human needs (Vastolo *et al*., 2022). Pineapple is classified as a tropical fruit with high production. The global production of pineapple peel waste in 2021 was estimated to be between 8.31 and 11.46 million tons. Pineapple peel waste is rich in bioactive compounds, antioxidants and bromelain. The bioactive content in pineapple peel functions as an antioxidant, anti-inflammatory, and antimicrobial. Pineapple peels contain nutrients in the form of water 3.94%, fat 2.53%, ash 3.98%, protein 4.20%, crude fiber 12.05%, carbohydrates 73.30% (Mala *et al*., 2024). Pineapple peels are rich in fiber and contain good nutrients that can meet the nutrients needed by livestock, making it an alternative solution for goat feed. The largest components in pineapple peels are water (86.7%) and carbohydrates (10.54%). The high water content in pineapple peels makes this waste easily rotten and if not disposed of properly it will cause environmental pollution (Solehah *et al*., 2024). Unutilized pineapple peel waste can pollute the environment because it will produce methane gas during the decomposition process (Mala *et al*., 2024). The solution to overcome this is to use pineapple peels as feed for ruminants. There has been a rise in interest in using agro-industry wastes as feed ingredients in animal rations as a result of the rising cost of conventional feedstuffs. This could resolve environmental concerns as well as lower the cost of feed used in animal production (Kasapsidou *et al*., 2015). Bioactive components in pineapple peel include flavonoids and saponins have a range of biological effects that can impact ruminal microbes, which in turn increases how feed is degraded in the rumen. There is potential to supplement ruminant diets with this peel to enhance rumen fermentation and mitigate methane production (Totakul *et al*., 2024).

Pineapple peel waste is an alternative feed ingredient that has been widely studied for its nutritional benefits for ruminants. Most of the previous studies have focused on the use of fermented pineapple peels to improve its nutritional quality and facilitate the digestion process. However, information regarding the utilization of pineapple peels without fermentation is still very limited. This has led to the need to explore the potential of pineapple peels as a direct feed ingredient, given that the fermentation process requires additional time, cost, and technology that may not be available in all farms. Utilization of pineapple peels up to 20% in ruminant rations formulated with 10% ground corn and 70% bran was shown to increase feed intake and digestibility of organic matter. This is due to the sweet taste and the presence of bromelain enzyme that can increase digestibility (Kiatti *et al*., 2023). West African Dwarft sheep fed 30% pineapple waste had a positive impact on performance and dry matter digestibility values (Taiwo *et al*., 2011). Usage of more than 40% in goat rations negatively impact digestibility and fermentability due to its high fiber content and the presence of antinutritional compounds, such as tannins, which can disrupt rumen microbial activity and nutrient utilization.

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Pineapple peel waste before being used as animal feed needs preliminary research, namely *In vitro*. The principle of the *In vitro* method is carried out by mimicking the conditions that exist in the rumen of livestock to determine the quality of feed to be given so that it can be known whether the feed can be utilized by livestock or not. Determination of feed digestibility in-vitro can be used as an assumption of how much nutrients can be absorbed by the body of livestock. This study aims to determine the *In vitro* dry matter digestibility (IVDMD), *In vitro* organic matter digestibility (IVOMD), total volatile fatty acid (VFA) and ammonia (NH_3) production of goat rations given pineapple peel waste as well as answering the challenges in the fulfillment and availability of quality feed in the livestock sector. Specific information on the feeding level of fresh pineapple peel in goat rations is limited. Based on this background, it can be hypothesized that the use of pineapple peel waste in goat rations up to 30% level has a positive effect on digestibility and fermentability.

MATERIALS AND METHODS

Ekperimental Design

In vitro research was conducted at the Laboratory of Ruminant Nutrition and Feed Chemistry, Faculty of Animal Husbandry, Padjadjaran University. Pineapple peel waste and Taiwan elephant grass were cut and then dried under the sun. The dried pineapple peel and Taiwan elephant grass were ground using a grinder with a size of 50-300 mesh, speed 2800 rpm. Concentrate used is a mixture of several types of feed such as ergy sources and protein sources that is rice bran, cassava dregs, palm kernel meal, coconut meal, tofu dregs, soy bean meal. All feed ingredients, pineapple peel waste and taiwan elephant grass were analyzed for moisture, ash, crude fat, crude protein, crude fiber and non-nitrogen-free-extract (NNFE) by the method AOAC (2007). Information on the nutrient content of each feed ingredient used in this study can be seen in Table 1 and concentrate formulations in Table 2. The research was conducted with an experimental method using a completely randomized design (CRD) with a total of 30 experimental units (5 treatments and 6 replicates). This study uses a Completely Randomized Design (CRD) because it is considered the most suitable for testing the effect of treatment on the measured variables, given the homogeneous initial conditions of the samples. This design provides ease of implementation and statistical analysis, especially when the variability between samples is relatively small.

Table 1: Nutrient content.

Feed Ingredients	Food Substances					
	Water	Ash	Ether Extract	Crude Protein	Crude Fiber	NNFE
	Percentage %					
Rice Bran	8.31	11.26	9.09	15.23	10.98	45.14
Cassava Dregs	9.70	3.40	0.45	2.26	13.55	70.66
Palm Kernel Meal	7.29	5.42	9.84	11.88	18.00	47.58
Coconut Meal	8.49	8.25	1.37	24.36	6.37	51.18
Tofu Dregs	5.62	3.31	2.59	20.53	14.38	53.58
Soy Bean Meal	8.18	7.72	1.18	47.08	2.45	33.41
Pineapple Peel	6.88	5.92	1.46	5.16	13.96	66.63
Taiwan Elephant Grass	6.98	17.30	1.57	13.24	27.12	33.80
Concentrate	8.18	6.41	4.38	16.99	11.89	52.15

Source: Proximate analysis results of biotechnology center, bogor agricultural university, 2024; **Note:** NNFE (Non Nitrogen Free Extract).

Table 2: Ingredient composition of concentrate.

Ingredient Concentrate	%
Rice Bran (%)	30.00
Cassava Dregs (%)	10.40
Tofu Dregs	25.00
Palm Kernel Meal	7.83
Coconut Meal	25.00
Soy Bean Meal	1.77

Source: Concentrate composition based on winfeed formulation.

Treatment with a balances of R0 = 60% Grass + 40% Concentrate; R1 = 10% Pineapple Peel Waste + 50% Grass + 40% Concentrate; R2 = 20% Pineapple Peel Waste + 40% Grass + 40% Concentrate; R3 = 30% Pineapple Peel Waste + 30% Grass + 40% Concentrate; R4 = 40% Pineapple Peel Waste + 20% Grass + 40% Concentrate. The level of pineapple peel in the ration was selected to see the livestock response to increasing the proportion of pineapple peel waste in the ration. The variation can determine the optimal limit of pineapple peel use without affecting livestock productivity. Information on the nutrient content of each treatment can be seen in Table 3.

Table 3: Nutrient content of feed formula for each treatment (% DM).

Nutrient Content	R0	R1	R2	R3	R4
Dry Matter (%)	92.53	92.54	92.55	92.56	92.57
Ash (%)	12.44	11.80	10.66	9.53	8.39
Crude Protein (%)	14.74	13.93	13.12	12.31	11.50
Crude Fiber (%)	21.02	19.71	18.39	17.08	15.76
Ether Extract (%)	2.69	2.68	2.67	2.66	2.65
NNFE	41.14	44.42	47.70	50.98	54.27

Source: Nutrient content of feed for each treatment based on winfeed formulation.

Table 4: Results of *in vitro* analysis of the Ruminant Nutrition and Animal Feedd Chemistry Laboratory, 2024.

Parameters	Treatment				
	R0	R1	R2	R3	R4
IVDMD(%)	50.18^{a} ±0.58	56.92^{b}± 5.05	$67,43^{c}$ ± 0,84	$70,54^{d}$ ± 0,84	$72,95^{d}$ ± 0,70
IVOMD (%)	$54,07^{a}$ ± 1,29	$62,52^{b}$± 7,63	$73,65^{c}$ ± 0,79	$76,55^{cd}$ ± 1,62	$79,99^{d}$ ± 2,58
NH_3 (mM)	$9,13^{a}$ ± 1,31	$8,79^{a}$ ± 2,05	$8,57^{a}$ ± 0,98	$7,42^{a}$ ± 2,00	$7,43^{a}$ ± 1,79
VFA (mM)	$97,42^{a}$ ± 18,49	$115,68^{b}$ ±21,38	$131,09^{b}$ ± 11,21	$155,18^{c}$ ±10,06	$194, 43^{d}$ ±12,97

Note: IVDMD: *In vitro* dry matter digestibility; IVOMD: *In vitro* organic matter digestibility; NH3: Ammonia; VFA: Volatile Fatty Acid; mean ± SD.^{a,b,c,d} average followed by different letter row indicate significant differences (P<0,05); R0: 60% grass + 40% concentrate; R1: 10% pineapple peel waste + 50% grass + 40% concentrate; R2: 20% pineapple peel waste + 40% grass + 40% concentrate; R3: 30% pineapple peel waste + 30% grass + 40% concentrate; R4 = 40% pineapple peel waste + 20% grass + 40% concentrate.

Preparation of Rumen Fluid and McDougall's Solution

Goat rumen fluid was taken from three goats at Cisaranten and Cileunyi Slaughterhouse, Bandung City. Goats are only given grass without concentrate. This should have been written. Goats are only given grass feed without concentrate. The slaughterhouse where the rumen fluid was collected has obtained a business license and halal certificate from the Indonesian Ulema Council. The rumen fluid taken was stored in a thermos that had previously been filled with hot water (40°C). Before the rumen fluid was taken, the hot water in the thermos was discarded, then the thermos was filled with goat rumen fluid until it was full. The rumen fluid was taken by squeezing the contents of the rumen using a muslin cloth. Preparation of artificial saliva or McDougall's solution was made with reference to McDougall's instructions 1948. The ingredients used to make artificial saliva were $NaHCO_3$ (9.80 g), $Na_2HPO_4.12H_2O$ (9.30 g), NaCl (0.47 g), KCl (0.57 g), $CaCl_2.{}_2H_2O$ (0.04 g) and $MgSO_4.{}_7H_2O$ (0.06 g). The chemicals were put into a beaker glass and 1000 mL of distilled water was added and then homogenized using a magnetic strirrer. The mixture of rumen fluid and artificial saliva was continuously supplied with CO_2 gas before 50 ml of rumen fluid and artificial saliva were put 100 ml into fermenter tube that had been filled with feed samples from each treatment. Afterward, the fermentor tube were incubated in a waterbath for 48 hours at 39°C and shaking every 3 hours.

Measurement Procedures for IVDMD and IVOMD

Digestibility shows the quality of feed and the ability of livestock to utilize a type of feed. High digestibility indicates the high amount of nutrients that can be digested by rumen microbes. The higher the digestibility value, the better the quality of the feed ingredients. Dry matter digestibility and organic matter digestibility were measured using the procedure Theodorou *et al*. (1994).

NH_3 Concentration Analysis

Ammonia concentration in the rumen is an important element to control because it determines the optimization of rumen microbial growth. The higher the ammonia concentration, the higher the protein in the feed is fermented in the rumen. Ammonia products in the rumen are utilized by rumen microbes for the synthesis of their bodies. NH_3 measurement was measured using the Conway method (Conway, 1950).

Total VFA Concentration Analysis

The fermentation of organic matter that produces carbohydrates is called volatile fatty acid (VFA). VFA is the main source of energy for ruminants as well as a source of carbon skeleton for the formation of microbial protein. Total VFA measurement was measured using the General Laboratory Procedures (1966).

Statistical Analysis

The study used a completely randomized design (CRD). The mathematical model used is as follows:

$$Yij = \mu + \alpha_i + \mathcal{E}_{ij}$$

Where;
Yij: observed response due to *i*-th treatment and *j*-th replication.
μ: general mean.
τi : effect of *i*-th treatment.
εij: effect of error from *i*-th treatment and *j*-th replication.

All data were analyzed using one-way ANOVA using SPSS (v.25) with pineapple peel ratio as the independent variable and IVDMD, IVOMD, total VFA and NH3 concentration as the dependent variable. The treatment was said to have a significant effect if $p<0.05$. Duncan's Multiple Range Test was used to determine the real difference between treatments. Statistical significance between treatments ments were said to be significantly different if $p<0.05$.

RESULTS AND DISCUSSION

The results showed that after the incubation process for 48 hours for treatments the IVDMD ranged from 50.18% - 72.95%, IVOMD ranged from 54.07% - 79.99%, NH_3 concentration ranged from 9.13 mM- 7.43 mM and total VFA concentration ranged from 97.42 mM – 194.43 mM. Based on the results of statistical tests and Duncan's multiple range test provision of pineapple peel waste to goat rations had a significant effect ($P < 0.05$) on the value of IVDMD, IVOMD, and total VFA but not significant ($P > 0.05$) on NH_3 concentration.

In vitro Dry Matter Digestibility

In vitro Dry Matter Digestibility (IVDMD) is the part of the dry matter in the feed that is digested by the animal at a certain level of feed consumption. Feed digestibility is closely related to the amount of microbial activity in the rumen and the capacity of the rumen (Aprianto *et al*., 2016). The digestibility value is a measure of the quality of feed consumed by livestock, with higher values indicating better quality. A high digestibility value indicates that the nutrients in the feed can be utilized by livestock while low digestibility indicates that the feed given cannot meet the nutrient needs of livestock. The average value of IVDMD for treatments R0, R1, R2, R3 and R4 were 50.18%, 56.92%, 67.43%, 70.54% and 72.95%, respectively. As the level of pineapple peel waste increased, the IVDMD value increased. The provision of pineapple peel waste (R4) in the ration resulted in the highest IVDMD value of 72.95%.

In vitro Dry Matter Digestibility (IVDMD) value increases with the addition of pineapple peel usage level in goat rations. The R4 treatment produced the highest IVDMD value of 72.95%. This is because pineapple peel contains soluble carbohydrates as a source of energy for rumen microbes. From the results of the ration formulation, the content of non-nitrogen-free-extract (NNFE) increased along with the increasing level of pineapple peel use in the ration. Non-nitrogen-free-extract (NNFE) content of R4 treatment amounted to 54.27% (Table 3). Non- nitrogen-free-extract (NNFE) is a soluble carbohydrate as an energy source for microbial growth (Faisal *et al*., 2021). Non-nitrogen-free-extract (NNFE) are soluble carbohydrates including monosaccharides, disaccharides and polysaccharides that are easily soluble so that they have high digestibility (Aling *et al*., 2020). The rate of rumen microbial synthesis is positively correlated with the availability of digestible carbohydrates, the more digestible carbohydrates in the ration consumed, the higher the rate of rumen synthesis (Tuturoong, 2014). This causes IVDMD to increase.

Pineapple peel contains bioactive saponins and flavonoids. Flavonoids can increase digestibility in feed because they can increase the population of bacteria in the rumen and can modify rumen fermentation (Seradj *et al*., 2014). Flavonoids in pineapple peel act as antioxidants so that activities in the digestive process run well and can cause increased feed consumption (Zalzabila *et al*., 2024). The flavonoid content in pineapple peel is 3.47% flavonoids (Rivera *et al*., 2023). Flavonoids can make the rumen fermentation process effective and can increase dry matter digestibility (Zhao *et al*., 2023). Flavonoids function as antibacterials so that they can inhibit the growth of pathogenic bacteria in the digestive tract. This can increase the digestibility and utilization of food substances in the body (Yunanda, 2017). This is in accordance with the opinion of Sukri *et al* (2023) that phenolic compounds (flavonoids) can improve animal intestinal health. Saponins contained in pineapple peel can also increase digestibility. Saponins play a role in the process of cell wall absorption in the intestine and increase the absorption of feed nutrients (Irwani and Candra, 2020).

Another study using dragon fruit peel waste as ruminant feed mentioned that saponins and flavonoids against rumen fermentation. Based on the findings of Natsir and Syahrir (2023), revealed that the addition of dragon fruit peel powder at a level of 10 % could be used as a feed component suitable for ruminants, particularly goats. The conclusion was reached based on estimations of dry matter and organic matter intake. According to the findings of Jami *et al*. (2012) there was a significant improvement in the digestibility of dry matter, crude protein, and neutral detergent fiber in addition to milk and energy-corrected milk outputs in cows that were provided with a supplement of 4 % pomegranate peel extract. This is because of the saponin content contained in pomegranate peel has the potential to enhance ruminal fermentation, milk production, and nutrient utilization in lactating goats.

In vitro Organic Matter Digestibility

In vitro organic matter digestibility (IVOMD) includes the digestibility of feed substances in the form of organic matter components such as carbohydrates, proteins, fats and vitamins. Factors that affect the IVOMD are the crude fiber and mineral content of feedstuffs. The *In vitro* organic matter digestibility (IVOMD) is closely related to the digestibility of dry matter because some dry matter consists of organic and inorganic matter. The average value of IVOMD for treatments R0, R1, R2, R3 and R4 were 54.07%, 62.52%, 73.65%, 76.55% and 79.99%, respectively. Giving pineapple peel waste (R4) in the ration resulted in the highest IVOMD value of 79.99%.

The high *In vitro* Organic Matter Digestibility (IVOMD) value in the R4 treatment is related to the *In vitro* Dry Matter Digestibility (IVDMD). This is because some dry matter consists of organic and inorganic materials (Aprianto *et al*., 2016). According to Suardin and Aka (2014), a decrease in IVDMD results in decreased IVOMD and vice versa. The digestibility value of organic matter is higher than the digestibility value of dry matter because the digestibility of dry matter still contains ash and the digestibility of organic matter does not contain ash. Ash in dry matter has an impact on the slow digestibility of feed dry matter so that organic matter without ash content is more easily digested by rumen microbes (Putra *et al*., 2019). The high IVOMD is due to the high cellulose content in pineapple peel. Pineapple peel has a cellulose content of 23.4% (Chaokaur *et al*., 2014) while from the results of the analysis conducted pineapple peel contains 30.19% cellulose. Cellulose is one of the energy sources for rumen microorganisms. Cellulose when completely degraded by rumen microbes can increase the IVODM (Munasik, 2007).

Pineapple peel also contains tannins. The tannin content in pineapple peel is relatively low at 1.38 mg/100 g (Bakri *et al*., 2020) while in another study it was mentioned that pineapple peel contains 5.02 mg/100g tannin (Ukanwoko and Nwachukwu, 2017). Tannins can increase the IVODM. The results of research by Jayanegara *et al*. (2009) forage supplementation of *R. thypina* and *S. alba* containing tannin compounds in low quality forage feed (hay and straw) can increase IVODM. Tannins can change the microbial pattern in the rumen. Tannins become a defaunation agent for the growth of protozoa in the rumen so that bacterial growth becomes better. Optimal rumen bacterial growth will be able to increase feed utilization so that digestibility will increase (Wahyuni *et al*., 2014). Other research on the utilization of rambutan peel waste as ruminant feed states that the tannin content does not have a negative effect on feed intake and total tract digestibility of nutrients in dairy cows (Ampapon and Wanapat, 2021).

Concentration of NH_3

The main nitrogen (N) source of bacteria is obtained from ammonia, bacteria are able to utilize ammonia by 82% as a source of N used in the process of microbial protein synthesis (Trisnadewi *et al*., 2014). The average ammonia production (NH_3) of goat rations treated with R0, R1, R2, R3 and R4 were 9.13 mM, 8.79 mM, 8.57 mM, 7.42 mM and 7.43 mM.

Ammonia production in the rumen is influenced by the level of feed protein contained in the ration. Based on Table 3, the protein content of the ration decreased along with the additional level of pineapple peel use. Low crude protein content in the ration will result in low NH_3 concentration (Irmawati *et al*., 2023). The concentration of ammonia (NH_3) in the rumen indicates the amount of crude protein content that is broken down by rumen microbes.

Crude protein content in the ration decreasing along with the increase in the level of pineapple peel use. Replacement of forage feed such as elephant grass and calliandra with pineapple waste can reduce ammonia concentrations as the percentage of replacement increases. This occurs because pineapple waste has a low protein content compared to forage. Ammonia concentration in the rumen is influenced by the amount of protein in the ration consumed by livestock (Adi *et al*., 2024).

Pineapple peel contains quite high fiber and low protein content, making it difficult to degrade in the rumen due to the strong lignocellulose bonds in pineapple peel, resulting in low microbial protein (Syapura *et al*., 2013). This is the reason why the use of pineapple peels in goat rations does not have a significant effect. Pineapple peel contains 14-38% cellulose, 20-42% hemicellulose, and 1-13% lignin (Kurniati *et al*., 2021). Flavonoids contained in pineapple peel can reduce NH_3 production. Flavonoids have antimicrobial properties that can inhibit the activity of proteolytic bacteria in the rumen. These bacteria play a role in breaking down feed protein into peptides, amino acids and then into NH_3. In addition, tannins found in pineapple peel can cause a decrease in ammonia concentration. The bond between protein and tannin in the rumen can make it difficult for bacteria to digest protein into NH_3 so that it can reduce protein absorption in the rumen (Ifani *et al*., 2022).

The observation that NH_3 concentration was not significantly affected by varying levels of pineapple peel in the diet has important implications for protein metabolism in goats. Ammonia (NH_3) in the rumen serves as a key intermediate in the microbial degradation of dietary protein and is essential for the synthesis of microbial protein, which contributes substantially to the host animal's protein requirements. The stability of NH_3 concentration across treatments suggests that the inclusion of pineapple peel did not impair microbial activity or protein utilization in the rumen. Furthermore, it implies that the dietary protein supplied alongside pineapple peel was adequate to meet the nitrogen requirements of rumen microbes without exceeding the threshold where NH_3 would accumulate excessively, potentially leading to nitrogen wastage.

Ammonia production that can meet the needs will not be detrimental to rumen microbial synthesis, otherwise if NH_3 production is low, it will affect the production of rumen microbial synthesis. From the results of the study, the ammonia concentration was 9.13 mM - 7.43 mM. These results are still in the optimal range for rumen microbial needs of 6-21 mM (McDonald *et al*., 2002).

Concentration of Total Volatile Fatty Acid

Volatile fatty acid is one of the end products of the fermentation process of feed digestion. The formation of total VFA starts with the breakdown of complex carbohydrates into monosaccharides through hydrolysis, then continued with glycolysis to produce pyruvic acid. Pyruvic acid will be converted into VFA such as acetate, propionate and butyrate. The average VFA production in the ration of goats treated with R0, R1, R2, R3 and R4 was 97.42 mM, 115 mM, 131.09 mM, 155.18 mM and 194.43 mM, respectively. The value of total VFA with the highest mean VFA in treatment R4.

The increase in total VFA content is due to the fact that pineapple peel contains easily digestible carbohydrates. Pineapple peel contains carbohydrates of 39.29% (Adi *et al*., 2024) while according to Mala *et al*. (2024) the carbohydrate content of pineapple peel is 73.30%. The resulting total VFA production can be seen from the amount of organic matter in the feed material that can be degraded by rumen microbes. One of the organic materials is non-nitrogen- free-extract (NNFE).

From the results of the ration formulation (Table 3), the content of non-nitrogen-free-extract (NNFE) increased in line with the level of pineapple peel use. Non-nitrogen-free-extract (NNFE) is a class of non-structural carbohydrates that are easily digested (Dewi *et al*., 2020). Non-nitrogen-free-extract (NNFE) consists of sugar, starch, and other constituents. non-structural carbohydrates can be found in plant cells and have higher digestibility compared to structural carbohydrates (Mukharomah *et al*., 2023). High and low. The amount of VFA produced indicates the ability of feed degraded by rumen microbes (Christiyanto *et al*., 2021). The less VFA production produced, the less protein and soluble carbohydrates (Jena *et al*., 2020). The higher the VFA concentration indicates the more effective fermentation (Rahayu *et al*., 2018). The higher the VFA concentration, the easier the carbohydrates in the ration undergo the fermentation process (Abani *et al*., 2018). Pineapple peel waste containing easily fermentable carbohydrates tends to produce high propionic acid (Hilali *et al*., 2018). Propionic acid is formed from the decomposition of starch by the enzyme amylase. This is in accordance with Wanapat *et al*. (2024) the use of tropical fruit peels can produce 109.0% propionic acid. This means that the higher the level of pineapple peel use in the ration, the higher the available energy. Saponins and flavonoids contained in pineapple peel contribute to increasing total VFA concentration. Saponins can increase VFA production and increase microbial activity in the rumen (Ramandhani *et al*., 2018). Flavonoids have a function as antioxidants that can increase fermentation in the rumen (Mardalena, 2015).

According to Raguati *et al*. (2024), an increase in total VFA concentration occurred along with an increase in pineapple peel in goat feed. An increase in total VFA concentration can increase goat productivity such as milk production and growth. The observed increase in total VFA concentration with higher levels of pineapple peel inclusion has significant practical implications for goat nutrition and energy metabolism. Total VFA primarily acetate, propionate, and butyrate, are the major end products of carbohydrate fermentation in the rumen and represent a critical energy source for ruminants. The positive relationship between pineapple peel levels and VFA production suggests that this by-product may serve as an effective fermentable energy source in goat diets. Other studies have shown that the addition of mangosteen peel in ruminant rations affects the production of total VFA, particulary propionate because mangosteen peel contains bioactive flavonoids and saponins. Supplementation of mangosteen peel powder resulted in a significant reduction in rumen protozoa production, accompanied by an increase in the population of major cellulolytic bacteria thereby increasing fermentability in the rumen (Wanapat *et al*., 2024).

The optimum total VFA concentration is 70-150 mM. VFA concentrations more than 200 mM cause acidosis (Tanuwiria *et al*., 2023; Zahera *et al*., 2020). Ruminal acidosis or increased accumulation of organic acids in the rumen reflects imbalance between microbial production, microbial utilization, and ruminal absorption of organic acids. The severity of acidosis, generally related to the amount, frequency, and duration of grain feeding, varies from acute acidosis due to lactic acid accumulation, to subacute acidosis due to accumulation of volatile fatty acids in the rumen. Ruminal microbial changes associated with acidosis are reflective of increased availability of fermentable substrates and subsequent accumulation of organic acids (Nagaraja and Titgemeyert, 2007). The results of the study obtained a total VFA of 97.42 mM - 194.43 mM. In this study, the total VFA concentration was higher than the optimum VFA production range. The high concentration of total VFA indicates that the organic matter in the ration is easily degraded by rumen microbes. This indicates that pineapple peel provides an abundant substrate for rumen microbes and this causes the production of total VFA concentration to be higher than the optimum condition.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion the use of pineapple peel level up to 30% in the ration for goats judging from the digestibility values of dry matter, organic matter, NH_3 and total VFA. However, excessive inclusion beyond 40% may negatively impact nutrient utilization due to its high fiber content and the presence of antinutritional factors. For practical application, pineapple peel should be properly processed such as by drying to improve its nutritional value and stability in commercial feed formulations. Feed producers can incorporate pineapple peel as an economical substitute for conventional ingredients, helping to lower feed costs while sustaining animal performance.

Recommendations for future research are in vivo studies are needed to determine the optimal level of pineapple peel waste in goat rations. This can be done by testing various levels of substitution in feed and evaluating performance parameters such as body weight gain, feed efficiency and milk production.

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NOVELTY STATEMENT

The novelty of this study lies in its focus on the utilization of pineapple peel waste in goat rations if given directly without fermentation process. Unlike previous research that focus on the fermentation process of pineapple peel waste before being given to livestock, this study focuses more on giving pineapple peel waste directly in goat feed and focuses on the optimal balance in giving pineapple peel waste in goat rations if given directly without the fermentation process.

AUTHOR'S CONTRIBUTIONS

Alya Nur Ismayanti: play a role in carrying out research in the field, writing research reports in the form of journals and data processing.
Iin Susilawati and Ujang Hidayat Tanuwiria: Research conceptualization, Methodology and carrying out research in the field.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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