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Effects of Binder Type and Inclusion Level on the Physical and Nutritional Values of Fruit By-product Pellet Feeds

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Abstract

This study investigated the effects of binder type (molasses and cassava flour) and inclusion level (5% and 10%) on the physical and nutritional characteristics of ruminant pellet feeds formulated with pineapple and passion fruit peels. Four treatments were evaluated: 5% molasses, 10% molasses, 5% cassava flour, and 10% cassava flour, each replicated three times in a completely randomized design. The results showed that pellets with 10% molasses had the greatest durability (95.67%), a high density (475.72 mg mL^{-1}), and elevated sugar (18.44%) and saponin (9.47%) contents, alongside improved concentrations of key amino acids such as lysine (1.29%) and glutamic acid (3.12%). By contrast, the 10% cassava flour treatment produced the lowest pellet durability (92.11%), density (468.06 mg mL^{-1}), and amino acid levels, particularly lysine (0.47%) and aspartic acid (1.01%). Overall, molasses, especially at a 10% inclusion, proved more effective than cassava flour in enhancing both the physical quality and nutritional value of fruit by-product pellets. These results highlight the potential of utilizing fruit processing residues with natural binders to produce sustainable, cost-effective pellet feeds for ruminant production systems.

Keywords

Fruit by-product, natural binder, dose of binder, ruminant pellet feed

Introduction

Vietnam's livestock industry is undergoing rapid growth; however, the sector remains heavily reliant on imported raw materials for animal feed production. It is estimated that approximately 65% of the total national demand for feed ingredients is met through imports (Department of Livestock Production and Health, 2025). This reliance significantly compromises production efficiency due to elevated input costs. Consequently, identifying and utilizing alternative, locally available feed resources has become a strategic

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imperative. Among the viable approaches are the effective exploitation of domestic feed materials, with an emphasis on agricultural by-products, especially those generated from fruit processing industries, as potential alternative feed sources.

Fruit by-products such as peels, pomace, roots, stems, and leaves make up about 40-50% of agricultural residues (Vastolo *et al.*, 2022). These by-products are rich in carbohydrates, protein, fiber, minerals, and bioactive compounds like polyphenols, which can enhance rumen function, digestion, immune responses, and milk production in ruminants (Sharma *et al.*, 2016; Tayengwa *et al.*, 2018; Mahmoud Abdel Gawad *et al.*, 2020; Branciari *et al.*, 2021). The main obstacles in the use of fruit by-products as animal feed are their high moisture content and the variability in nutritional composition, which pose challenges for transportation, storage, and the formulation of diets containing these by-products (Martín García *et al.*, 2016; Yang *et al.*, 2021).

Pelleting green forage or fruit by-products provides several advantages, such as increasing the bulk density to reduce transportation costs, improving animal performance, minimizing feed wastage and selective feeding, facilitating handling, and lowering pathogenic microbial load through thermal processing (Sokhansanj & Turhollow, 2004). However, because the pelleting process involves multiple stages that may cause pellet breakage during production, transport, and storage, the use of binders is essential. Pellet binders are substances incorporated into feed ingredients to enhance cohesion and maintain pellet integrity (Saade & Aslamyah, 2009). Molasses and starch are two common natural binders in pellet feed production. Molasses enhances pellet durability through its viscosity and soluble sugars (Thomas *et al*., 1998; Kaliyan & Morey, 2010), while starch acts via gelatinization, forming gel networks that bind feed particles (Thomas & van der Poel, 1996; Susilawati *et al*., 2012). In this study, molasses and cassava starch were applied as natural binders in pellet feeds formulated with fruit by-products.

Materials and Methods

Sample collection and pellet preparation

Fruit by-products, namely fresh pineapple peels and passion fruit peels, were collected from Dong Giao Foodstuff Export Joint Stock Company (DOVECO). The samples were chopped to pieces about 2-4cm in size and dried directly in sunlight. Dried green tea crumbs were purchased from a local market in Gia Lam, Hanoi. The samples were ground to be 2mm in size, then 10% of water was added and the mixture was thoroughly blended with the other pellet ingredients as listed in **Table 1**. The mixture then was put into a pellet machine and the pellets were dried in a 60^{o}C oven for a day. The pellets were stored in closed plastic boxes for later analysis.

Experimental design

The experiment was arranged in a completely randomized design (CRD) with one factor consisting of four treatments. The treatments were formulated using two binders (molasses and cassava starch), each applied at two supplementation levels (5% and 10%). Thus, the four treatments were: 5% molasses, 10% molasses, 5% cassava starch, and 10% cassava starch. Each treatment was replicated three times. The specific pellet feed formulations are presented in **Table 1**.

Physical analysis

Durability: A 500-gram pellet sample was placed in a rotating device for 10 minutes at 50 rpm. After that, the sample particles were separated through a 3.15mm mesh sieve. The pellets retained in the sieve were weighed. Durability was calculated using the formula: % durability = (A-B) /A x 100 where: A is the pellet weight before being tested and B is the pellet weight after being tested.

Pellet length: The pellet length was determined according to the method of Winowiski (1995) by counting the number of pellets in a pre-weighed feed sample and calculating the number of pellets per gram. A 10-20g sample of screened pellets is usually sufficient.

Table 1. Experiment feed formulation

Ingredients (%)	Pellet feeds			
	5% Molasses	10% Molasses	5% Cassava	10% Cassava
Maize	16.48	10.00	18.23	12.98
Soybean meal	17.79	18.35	17.60	18.13
Cassava residuals	5.00	5.00	5.00	5.00
Urea	1.20	1.20	1.20	1.20
Soybean oil	5.33	6.04	4.58	4.53
DCP	0.83	0.88	0.84	0.89
Premix	0.25	0.25	0.25	0.25
Pineapple peels	33.12	32.30	32.31	32.01
Passion fruit peels	10.00	10.98	10.00	10.00
Green tea crumbs	5.00	5.00	5.00	5.00
Molasses	5.00	10.00	0	0
Cassava flour	0	0	5.00	10.00

Note: DCP: Dicalcium phosphate.

Density: The density of the pellets was determined using the Fahrenholz method (Fahrenholz, 2012). Pellets were added to a measuring cylinder until the volume reached 100 ml, and the weight was recorded. The density was then calculated using the following formula: Density (g mL^{-1}) = mass of the pellets in the measuring cylinder (g)/volume of the measuring cylinder occupied by the pellets (mL).

Chemical analysis

The pellet samples were analyzed for dry matter (DM), crude protein (CP), ash, crude fiber (CF), neutral-detergen fiber (NDF), acid-detergen fiber (ADF), and ether extract (EE) by using the standard methods of Vietnam at the Center Laboratory of the Faculty of Animal Science, Vietnam National University of Agriculture. Dry matter was determined according to TCVN 4326:2001; crude protein according to TCVN 4328-1:2007; ether extract according to TCVN 4331:2001; neutral-detergen fiber according to ANKOM Technology method 6; acid-detergen fiber according to ANKOM Technology method 5; ash according to TCVN 4327: 2007; and sugars and starch were determined by the colorimetric method using the reagent dinitrosalicylic acid (DNS).

To analyze the phytonutrient components, namely total tannins, saponins, and flavonoids, samples were sent to the National Institute for Food Control for analysis where the total saponin content was determined using the NIFC.05.M.182 method. The pelleted feeds were also analyzed for the composition of 17 amino acids. The analyses were performed using a high-performance liquid chromatography (HPLC) system (Waters e2695) at the Laboratory of Feed and Livestock Product Analysis, National Institute of Animal Science.

Statistical analysis

Experimental data were analyzed using one-way analysis of variance (ANOVA) under the general linear model (GLM) of SAS software (2004, SAS 9.4) using the function: $Y_{ij} = \mu + T_i + e_{ij}$, *where*: Y_{ij} is the observation; μ is the overall mean; T_i is the effect of the i^{th} treatment (i = 4; 5% molasses; 10% molasses, 5% cassava, and 10% cassava); and e_{ij} is the random error. When significant differences among treatments were detected, means were separated using Tukey's test at the 5% probability level.

Results and Discussion

The physical properties of the pellet feeds

Table 2 summarizes the effects of the binder type (molasses and cassava flour) and inclusion level (5% and 10%) on pellet durability, length, and density. All studied parameters were significantly affected by the treatments. The highest pellet durability was observed with 10% molasses (95.67%), whereas the lowest was recorded with 10% cassava starch (92.11%). The longest pellets were obtained with 10% cassava starch (88.15 mg $pellet^{-1}$), followed by 10% molasses (83.16 mg $pellet^{-1}$). Pellet density was highest in the 5% molasses treatment (486.57 mg mL^{-1}), followed by 10% molasses (475.72 mg mL^{-1}), compared with 5% cassava starch (470.86 mg mL^{-1}) and 10% cassava starch (468.06 mg mL^{-1}).

The durability denotes the pellet's resilience to mechanical stresses, including impact, abrasion, and compression, that occur during storage and transport (Krisnan & Ginting, 2009; Winowiski, 2019). A higher durability value implies better resistance to these forces, thereby maintaining the structural integrity of the pellet during storage and transit. Pellet density represents the amount of mass that can be contained within a given volume. A higher density means more material can be packed into the same volume (Royani & Herawati, 2020). Length is also an indicator used to assess pellet quality. Longer pellets indicate higher durability and less fines (Winowiski, 2019). The most typical binders applied in pellet production are starch, lignosulphonate, crude glycerin, bentonite, and molasses (Kaliyan & Morey, 2009; Lu *et al.,* 2014). The mechanism of action of binders in pellet feeds varies depending on their chemical nature. Molasses primarily improves pellet quality through its high viscosity and soluble sugar content. During pelleting, these sugars form adhesive films surrounding feed particles, functioning as "solid bridges" that strengthen inter-particle bonding, and upon cooling, sugar crystallization further reinforces the pellet structure (Thomas *et al.*, 1998; Kaliyan & Morey, 2010). Misljenovic *et al.* (2016) indicated that adding molasses leads to reduced energy use, improved pellet durability at lower pelleting temperatures, greater pellet and bulk densities, and reduced moisture levels. In contrast, cassava starch exerts its effect through the process of gelatinization under heat and moisture conditions during pelleting, whereby starch granules swell, lose their crystalline structure, and release amylose to form a gel network that binds feed particles together (Thomas & van der Poel, 1996).

In this study, the molasses at a 10% inclusion level as a binder resulted in the most favorable outcomes across all the evaluated parameters, namely pellet durability, length, and density. Pellet quality is influenced by binders, feed composition, and processing conditions. A high starch content improves pellet durability through gelatinization, whereas fat reduces durability due to its lubricating effect; protein contributes to structural formation, while a high fiber content tends to weaken pellets, and appropriate moisture enhances binding. In this study, the inclusion of molasses and cassava flour at 5% and 10% required proportional adjustments in maize, soybean meal, and soybean oil to maintain comparable nutritional values across the treatments. Although these ingredients may also affect pellet quality through their starch, protein, and fat contents, the adjustments were relatively minor. As shown in **Table 1**, the adjustments reduced the maize content in the 10% molasses diet (the lowest among all the treatments), while the soybean meal and oil levels varied only slightly. Therefore, the observed differences in the physical properties of the pellets in this study

Table 2. Effects of the binders and dose of binders on the physical properties of the pellet feeds

Items	Treatment				SEM	P
	5% Molasses	10% Molasses	5% Cassava	10% Cassava		
Durability (%)	92.34^{c}	95.67^{a}	93.42^{b}	92.11^{c}	0.11	< 0.001
Pellet length (mg $pellet^{-1}$)	72.43^{b}	83.16^{ab}	72.65^{b}	88.15^{a}	2.56	< 0.01
Density (mg mL^{-1})	486.57^{a}	475.72^{ab}	470.86^{b}	468.06^{b}	2.42	< 0.01

Note: Within the same row, values with different superscript letters differ significantly (P <0.05).

were mainly attributed to the type and level of binders used.

Chemical compositions of the pellet feeds

The effects of the two binders (molasses and cassava flour) at their inclusion levels (5% and 10%) on the chemical compositions of the pellet feeds are presented in **Table 3**. The dry matter, crude protein, ether extract, ash, ADF, ADL, and tannin contents were not significantly affected ($P > 0.05$), indicating that these components remained relatively stable across the treatments. In contrast, significant differences were observed for the NDF, sugar, starch, and saponin contents. NDF was the highest in 10% cassava (28.19%), compared with the other treatments (24.39-24.90%; $P < 0.01$). The sugar concentration increased markedly with higher molasses inclusion, peaking at 18.44% in 10% molasses ($P < 0.001$), while cassava flour at 5-10% and molasses at 5% resulted in higher starch levels (> 27%). This aligns with the carbohydrate profiles of each binder. The saponin levels also varied significantly ($P < 0.001$), with molasses at 10% showing the highest concentration (9.47%), potentially enhancing functional properties.

In formulating the experimental diets, the inclusion of molasses and cassava flour at 5% and 10% required proportional adjustments of the maize, soybean meal, and soybean oil to maintain comparable nutritional profiles across the treatments. Although, these ingredients may have also influenced the results of the physical properties (pellet durability, density, and length) through their starch, protein, and fat contents.

In this study, the inclusion of fruit by-products with natural binders (molasses or cassava flour) produced pellet feeds with nutritional profiles well-suited for ruminants. All the treatments had high dry matter (95.81-96.33%) and adequate crude protein (19.45-20.01%) for rumen microbial activity. The saponin content, especially in the molasses-based pellets (up to 9.47%), may have offered functional benefits like reduced methane and improved nitrogen use. The findings of this study align with previous research demonstrating the nutritional potential of fruit by-product-based pellets for ruminant feeding. Matra *et al.* (2021) reported that supplementing ruminants with dragon fruit peel-based pellets at 400 g/hd/day improved rumen fermentation and reduced methane production. Similarly, Prommachart *et al.* (2024) found that fruit peel mixtures (mangosteen, rambutan, and banana) combined with tung oil enhanced in vitro fermentation, emphasizing the role of bioactive components in modulating ruminal ecology. Phesatcha *et al.*

Table 3. Effects of the binder type and their level on the chemical compositions of the pellet feeds

Items	Treatment				SEM	*P*
	5% Molasses	10% Molasses	5% Cassava	10% Cassava		
DM	96.14	96.04	96.33	95.81	0.38	0.80
CP	19.45	20.01	19.41	19.37	0.58	0.84
EE	6.76	7.39	6.33	6.14	0.34	0.12
Ash	6.91	7.04	6.30	6.78	0.49	0.74
NDF	24.90^{b}	24.39^{b}	24.80^{b}	28.19^{a}	0.50	< 0.01
ADF	13.41	13.65	13.65	14.47	0.36	0.26
ADL	2.04	2.07	2.50	2.09	0.29	0.67
Sugar	7.87^{c}	18.44^{a}	13.10^{b}	10.10^{c}	0.57	< 0.001
Starch	30.35^{a}	16.38^{c}	27.41^{b}	28.01^{ab}	0.59	< 0.001
Tannin	1.25	1.32	1.14	1.04	0.11	0.39
Saponin	8.36^{b}	9.47^{a}	8.18^{bc}	7.94^{c}	0.08	< 0.001
Flavonoids	-	-	-	-	-	-

Note: Within the same row, values with different superscript letters differ significantly ($P < 0.05$). -: non detectable (< LOQ 0.15 mg g^{-1}).

(2022) demonstrated that pellet supplementation with *Mitragyna speciosa* leaves at 10-30 g/hd/d improved nutrient digestibility and microbial protein synthesis, and these effects were partially attributed to elevated levels of saponins and other phytochemicals. Overall, the consistency of our results with existing literature further validates the use of fruit by-products and natural binders as sustainable and nutritionally appropriate components in ruminant pellet feed formulations.

The effects of binder type (molasses and cassava flour) and inclusion level (5% and 10%) on the amino acid compositions of the pellet feeds are presented in **Table 4**. Significant differences were observed for aspartic acid, glutamic acid, threonine, alanine, arginine, leucine, lysine, and proline (P <0.05), while the others remained unaffected. The aspartic acid and glutamic acid concentrations were significantly elevated in the 10% molasses group (1.99 and 3.12%, respectively) compared with 10% cassava (1.01 and 1.64%), while intermediate values were recorded in 5% molasses and 5% cassava (P <0.001). Similar patterns were observed for threonine, alanine, leucine, lysine, and proline, all of which increased with molasses inclusion, particularly at 10%, whereas 10% cassava consistently produced the lowest concentrations. Notably, lysine peaked in 10% molasses (1.29%) but declined to 0.47% in 10% cassava (P <0.01), and proline followed the same trend (0.90% vs. 0.53%; P <0.01).

Conclusions

This study demonstrated that the binder type and its inclusion level significantly affected the physical and nutritional properties of fruit by-product pellet feeds. Molasses, particularly at a 10% inclusion level, was more effective than cassava flour in enhancing pellet durability, density, NDF, saponin, and the content of several essential amino acids. The results highlight 10% molasses as the most effective binder, providing dual benefits of improved feed handling and enhanced nutritional value. This approach not only supports the valorization of agricultural

Table 4. Effects of the binder type and their level on the amino acid profile of the pellet feeds

Items	Treatment				SEM	P
	5% Molasses	10% Molasses	5% Cassava	10% Cassava		
Aspartic acid	1.76^{ab}	1.99^{a}	1.55^{b}	1.01^{c}	0.09	< 0.001
Glutamic acid	2.82^{ab}	3.12^{a}	2.54^{b}	1.64^{c}	0.08	< 0.001
Serine	0.87	0.95	0.81	0.52	0.1	0.08
Histidine	0.44	0.46	0.43	0.26	0.1	0.53
Glycine	0.76	0.81	0.72	0.48	0.09	0.14
Threonine	0.55^{ab}	0.78^{a}	0.53^{ab}	0.38^{b}	0.07	0.04
Alanine	0.88^{a}	0.96^{a}	0.81^{ab}	0.53^{b}	0.06	0.01
Arginine	1.04^{ab}	1.14^{a}	1.00^{ab}	0.62^{b}	0.08	0.67
Tyrosine	0.51	0.51	0.49	0.34	0.09	0.02
Valine	0.83	0.90	0.76	0.45	0.11	0.07
Methionine	0.39	0.40	0.37	0.25	0.1	0.72
Phenylalanine	0.82	0.86	0.80	0.55	0.1	0.21
Isoleucine	0.70	0.77	0.66	0.44	0.09	0.11
Leucine	1.28^{a}	1.37^{a}	1.21^{a}	0.78^{b}	0.09	< 0.01
Lysine	1.19^{a}	1.29^{a}	0.85^{ab}	0.47^{b}	0.1	< 0.01
Proline	0.86^{a}	0.90^{a}	0.81^{a}	0.53^{b}	0.06	< 0.01
Cystine	0.25	0.23	0.22	0.13	0.06	0.49

Note: Within the same row, values with different superscript letters differ significantly (P <0.05).

waste but also contributes to more sustainable and cost-effective feeding strategies for ruminant livestock systems in developing countries.

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