

Synergy of Avocado Seed Meal and Expired Commercial Syrup in Enhancing Fermentation Quality of Fattening Sheep Concentrate Silage

Sinergi Tepung Biji Alpukat dan Sirup Komersial Kadaluarsa untuk Meningkatkan Kualitas Fermentasi Silase Konsentrat Domba Penggemukan

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ABSTRACT

The use of additives plays a crucial role in providing energy sources for microorganisms during the ensiling process, enabling optimal physical quality of silage to be formed. Avocado seed meal (ASM) provides gradually released energy to support fermentative activity, while expired commercial syrup (ECS) contains easily degradable sugars that accelerate lactic acid production. The synergy between these two helps the preservation process occur more rapidly, allowing silage to reach stable conditions and exhibit better physical characteristics. This study was designed to evaluate the influence of these two materials in fattening sheep concentrate formulations, with a focus on changes in physical characteristics and acidity levels as benchmarks of fermentation success. The research was conducted using a Completely Randomized Design with five treatments and five replications, where ASM and ECS were administered at levels of 1.50%, 3%, 4.50%, and 6.00% of dry matter, while the base treatment without additives served as the control. The observed variables included silage aroma, texture, and color characteristics, as well as dry matter content, dry matter loss, pH value, and Fleigh Value as indicators of fermentation stability. The obtained data were analyzed using analysis of variance, followed by DMRT test at a 1% significance level. The research findings demonstrated that the combination of ASM and ECS had a highly significant effect ($p < 0.01$) on the aroma, texture, color, pH, and Fleigh Value of fattening sheep concentrate silage, except that dry matter content and dry matter loss were not affected by the two additives. Treatment P5 (addition of ASM and ECS at 6% DM) emerged as the most superior treatment, characterized by strong fermentative aroma (3.32 ± 0.06), smoother texture without clumping (3.49 ± 0.07), more consistent yellowish-brown color (3.47 ± 0.05), lower pH (4.31 ± 0.07), and the highest Fleigh Value (98.9 ± 1.05) as an indication of superior fermentation quality. In conclusion, the combination of avocado seed meal and expired commercial syrup at a dose of 6% of dry matter (3% ASM + 3% ECS) is recommended as an effective local additive to improve the physical quality and fermentation stability of fattening sheep concentrate silage.

Key words: avocado seed meal, concentrate silage, expired commercial syrup, fleigh value, physical quality

ABSTRAK

Penggunaan aditif berperan penting dalam menyediakan sumber energi bagi mikroorganisme selama proses ensilase sehingga mutu fisik silase dapat terbentuk secara optimal. Tepung biji alpukat (TBA) menyediakan energi yang dilepas secara bertahap untuk mendukung aktivitas fermentatif, sedangkan sirup komersial afkir (SKA) mengandung gula mudah terurai yang mempercepat produksi asam laktat. Sinergi keduanya membantu proses pengawetan berlangsung lebih cepat, memungkinkan silase mencapai kondisi stabil serta menunjukkan ciri fisik yang lebih baik. Penelitian ini dirancang untuk mengevaluasi pengaruh kedua bahan tersebut dalam formulasi konsentrat domba pedaging, dengan fokus pada perubahan karakter fisik dan tingkat keasaman sebagai tolok ukur keberhasilan fermentasi. Penelitian dilakukan menggunakan Rancangan Acak Lengkap dengan lima perlakuan dan lima ulangan, di mana TBA dan SKA diberikan pada taraf 1,50%, 3%, 4,50%, dan 6,00% dari bahan kering, sementara perlakuan dasar tanpa aditif dijadikan kontrol. Peubah yang diamati mencakup karakteristik aroma, tekstur, dan warna silase, serta kandungan bahan kering, kehilangan bahan kering, nilai pH, dan Nilai Fleigh sebagai indikator stabilitas fermentasi. Data yang diperoleh dianalisis menggunakan analisis ragam, kemudian dilanjutkan dengan uji DMRT pada taraf signifikansi 1%. Temuan penelitian memperlihatkan bahwa kombinasi TBA dan SKA memberikan pengaruh yang sangat signifikan ($p < 0,01$) terhadap aroma, tekstur, warna, pH, dan Nilai Fleigh silase konsentrat untuk domba pedaging, kecuali kandungan bahan kering dan kehilangan bahan kering tidak dipengaruhi oleh kedua aditif. Perlakuan P5 (penambahan TBA dan SKA sebesar 6% BK) menjadi perlakuan paling unggul, ditandai dengan aroma fermentasi yang kuat ($3,32 \pm 0,06$), tekstur lebih halus tanpa gumpalan ($3,49 \pm 0,07$), warna coklat kekuningan yang lebih konsisten ($3,47 \pm 0,05$), serta pH yang lebih rendah ($4,31 \pm 0,07$) dan Nilai Fleigh tertinggi ($98,9 \pm 1,05$) sebagai indikasi fermentasi yang optimal. Secara keseluruhan, penambahan TBA dan SKA mampu memperbaiki mutu fermentasi silase konsentrat sehingga kualitas silase untuk domba pedaging menjadi lebih baik.

Kata kunci: kualitas fisik, nilai fleigh, silase konsentrat, sirup komersial afkir, tepung biji alpukat



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INTRODUCTION

The fulfillment of feed nutritional requirements is a determining factor in the success of fattening sheep enterprises. The main challenge in small ruminant nutrition is maintaining the sustainable availability of quality feed, particularly concentrate that is rich in energy and protein. This condition drives the need for exploration and utilization of alternative feed ingredients, including agro-industrial waste that has not been optimally utilized. Various materials such as corn bran, fish meal, fine rice bran, bran pollard, palm kernel meal, molasses, soybean meal (SBM) 45% Argentina, limestone, salt, comix, dried cassava, corn, various additives, coconut meal, 75-day-old pakchong napier, *Indigofera zollingeriana*, and cassava leaves can be formulated into concentrate with crude protein (CP) content of approximately 14.8% and total digestible nutrients (TDN) of approximately 70.8%. However, most of these agro-industrial wastes have seasonal availability, potentially resulting in production surplus during certain periods. When production increases, preservation becomes important so that these materials can be utilized throughout the year, one of which is through silage making (Borreani et al. 2018).

Silage making requires the availability of water-soluble carbohydrates as substrates for lactic acid bacteria to produce organic acids and rapidly lower pH (Muck et al. 2018). Efforts to accelerate fermentation can be made through the addition of additives in the form of easily fermentable energy sources (Rinne et al. 2020). Avocado seed meal and expired commercial syrup are two materials with potential for use in this process. Both contain carbohydrates that can be utilized by microbes to proliferate, thereby accelerating lactic acid formation and lowering silage pH (Sadarman et al. 2025b). Rapid pH reduction will suppress the activity of spoilage bacteria, resulting in a final product with fresh aroma, compact and soft texture, as well as stable color with high dry matter content that aligns with very low dry matter loss (Ling et al. 2022).

Avocado production in Riau Province and West Sumatra in 2023 reached approximately 19,500 tons per year. Assuming a seed proportion of approximately 15%, the estimated biomass of avocado seeds (wet) reaches 2,925 tons per year. After undergoing drying and grinding processes, the yield of avocado seed meal ranges from 35%-referring to dried seeds. This means that the availability of avocado seed meal as a silage additive has the potential to be developed sustainably at both farmer and feed industry levels, estimated flour availability equivalent to 512 tons/year (Badan Pusat Statistik, 2025; Sadarman et al. 2025). The utilization of this waste not only improves raw material efficiency but also reduces the potential for environmental pollution caused by avocado seed accumulation (Sandoval-Contreras et al. 2023).

Expired commercial syrup is a liquid carbohydrate source that is easily fermentable (Sadarman et al. 2025).

Commercial syrup production in Indonesia in 2023 reached 400,000 tons per year, with an estimated 8,000 tons of expired or discarded syrup. Of this amount, approximately 40 tons per year is estimated to enter Riau Province (Badan Pusat Statistik Provinsi Riau 2025). This volume indicates that expired syrup has considerable potential for utilization as a fermentation additive (Sadarman et al. 2025).

Several recent studies have shown that the addition of expired commercial syrup is capable of improving fermentation quality and lowering silage pH (Sadarman et al. 2024; Sadarman et al. 2025a). Other study results have also reported that the use of avocado seed meal as a silage additive can improve physical characteristics, enhance fermentation stability, and suppress dry matter loss (Sadarman et al. 2025b). In general, successful silage is characterized by fresh sour aroma, soft yet compact texture, stable greenish-brown color, and low pH value indicating dominant lactic acid fermentation, in addition to optimal dry matter content with minimal dry matter loss (McDonald et al. 2022). Thus, the utilization of two local-based additives, namely avocado seed meal and expired commercial syrup, offers great opportunities to improve the quality of concentrate silage for fattening sheep (Rinne et al. 2020).

Based on the aforementioned description, this research was conducted to evaluate the use of avocado seed meal and expired commercial syrup as additives in concentrate silage making. The objective of this research was to assess the influence of the two additives on the physical quality of concentrate silage including aroma, texture, color, dry matter, dry matter loss, pH, and Fleigh Value of silage. The benefit of this research is expected to provide recommendations for the utilization of agro-industrial waste as a cheap, easily obtainable, and sustainable local additive source, as well as to enhance the sustainability of fattening sheep feed production.

METHODS

Materials and Equipment

The entire series of silage making, harvesting, as well as pH, dry matter (DM), DM loss, and Fleigh value measurements were conducted at the Nutrition and Feed Technology Laboratory, Faculty of Agriculture and Animal Science, Universitas Islam Negeri Sultan Syarif Kasim Riau. The equipment utilized included analytical scales, basins, small knives, cameras, and pH and DM testing devices. The sheep concentrate used as the basal diet (CP 14.8%; TDN 70.8%) was manufactured by PT. Sei Deras Agrofarm. Its composition was categorized based on nutritional sources: (1) energy sources, comprising corn bran, fine rice bran, pollard, dried cassava, corn, molasses, and palm kernel meal; (2) protein sources, consisting of fish meal, SBM 45% Argentina, coconut meal, 75-day-old pakchong napier, *Indigofera*, and cassava leaves; and (3) minerals and

Table 1 Experimental treatments

Code	Treatment	Dose (% DM)
P1	Control (concentrate without additive)	0%
P2	ASM + ECS	0.75% + 0.75% (1.50%)
P3	ASM + ECS	1.50% + 1.50% (3%)
P4	ASM + ECS	2.25% + 2.25% (4.50%)
P5	ASM + ECS	3.00% + 3.00% (6%)

Note: ASM: Avocado Seed Meal, ECS: Expired Commercial Syrup

additives, which were covered by limestone, salt, comix, and other feed additives. Avocado seed meal, expired commercial syrup, distilled water, as well as analytical materials for DM and pH testing were also used as supporting components during the silage making to harvesting process.

Experimental Design

A Completely Randomized Design consisting of five treatments with five replications was used in this study. Treatments were determined based on the level of avocado seed meal and expired commercial syrup addition to the concentrate (Table 1).

Silage Making and Harvesting

Concentrate for each treatment was weighed at 1 kg and then mixed with avocado seed meal and expired commercial syrup according to the dry matter level of the concentrate (35%). The homogeneous mixture was placed into 300 g capacity plastic silos, compacted, sealed tightly, and stored under anaerobic conditions at room temperature for 30 days (Kondo *et al.* 2016), after which each silo was weighed, opened, and left for some time before parameter measurements were taken. The same procedure was applied to all replications.

Observed Parameters

Physical Quality (Organoleptic) (Sadarman *et al.* 2025). Physical evaluation was conducted by 60 untrained panelists who met health and sensory function requirements. Assessment was performed on aroma, texture, and color. Aroma was determined through direct smelling, texture through random sample palpation, and color through visual observation. Each panelist provided individual scores according to the criteria in Table 2, and assessment was conducted in a room with neutral odor and sufficient lighting.

Dry Matter (DM) Content. Silage dry matter testing was conducted using the oven drying method (AOAC 2019). Silage samples of 1000 grams were dried in an oven at 60-70°C for 48-72 hours

Table 2 Silage physical quality scoring system (Hynd 2019)

Criteria	Description	Score
Aroma	Less fresh; fresh; fermentative fragrant	1-3.99
Texture	Smooth-clumping; moderate; smooth-non-clumping	1-3.99
Color	Dark brown; brown; bright brown	1-3.99

until constant weight was achieved. Dry Matter Content (%) = $(Wd/Ww) \times 100\%$, where Ww = Initial wet weight (g) and Wd = Dry weight (g).

Dry Matter Loss (DML). Dry matter loss was calculated based on the difference between the weight of filled silo before fermentation (a) and the weight of filled silo after ensiling for 30 days (b). Dry Matter Loss (%) = $[(a-b)/a] \times 100\%$ (AOAC, 2019). Silage pH. Silage juice preparation was conducted by taking 1 g of silage, adding 9 mL of distilled water (1:9 w/v), and blending. The sample was homogenized, filtered to obtain silage juice (Bernardes *et al.* 2019), placed in a plastic bottle for pH testing using a digital pH meter. Fleigh Value (FV). Fleigh Value was calculated according to Kiliç (1984) as previously reported by Ozturk *et al.* (2006) using the equation: $FV = 220 + [(2 \times \%DM) - 15] - (40 \times pH)$. Silage quality based on FV value: excellent (85-100), good (60-85), moderate (55-60), satisfactory (25-55), and poor/valueless (<25).

Statistical Analysis

Research data were processed using SPSS version 26.0, and results were presented in the form of mean \pm standard deviation. Analysis of variance was applied to assess the effect of treatment on each observed variable. The mathematical model used was $Y_{ij} = \mu + \alpha_i + \epsilon_{ij}$ (Adams *et al.* 2022), where μ represents the overall mean, α_i indicates the effect of treatment i , and ϵ_{ij} is the random error. To explore differences between treatments, Duncan's Multiple Range Test (DMRT) was applied at a 1% significance level ($p < 0.01$).

RESULTS AND DISCUSSION

Silage Physical Quality

Analysis of variance results showed that the addition of avocado seed meal (ASM) and expired commercial syrup (ECS) had a highly significant effect ($P < 0.01$) on the aroma, texture, and color of fattening sheep concentrate silage. Physical Quality Profile of Concentrate Sheep Silage After Ensiling Using ASM and ECS is shown in Figure 1, whereas silage physical quality data are presented in Table 3.

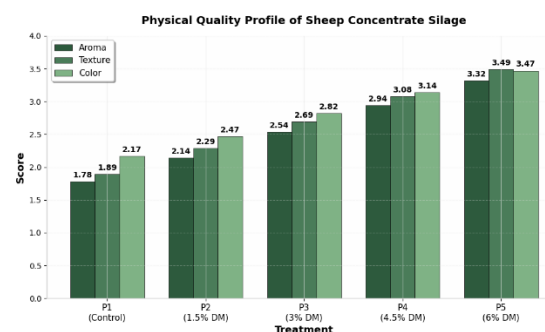
**Figure 1** Physical properties of fattening sheep concentrate silage utilizing ASM and ECS as additive

Table 3 Physical quality of fattening sheep concentrate silage with ASM and ECS addition

Treatment	Aroma	Texture	Color
P1 (Control)	1.78 ^a ± 0.05	1.89 ^a ± 0.07	2.17 ^a ± 0.04
P2 (1.50% DM; ASM: 0.75% + ECS: 0.75%)	2.14 ^b ± 0.06	2.29 ^b ± 0.07	2.47 ^b ± 0.05
P3 (3% DM; ASM: 1.50% + ECS: 1.50%)	2.54 ^c ± 0.06	2.69 ^c ± 0.07	2.82 ^c ± 0.04
P4 (4.50% DM; ASM: 2.25% + ECS: 2.25%)	2.94 ^d ± 0.07	3.08 ^d ± 0.06	3.14 ^d ± 0.06
P5 (6% DM; ASM: 3.00% + ECS: 3.00%)	3.32 ^e ± 0.06	3.49 ^e ± 0.07	3.47 ^e ± 0.05

Note: ASM: Avocado Seed Meal, ECS: Expired Commercial Syrup, different superscripts in the same column indicate that the synergy between ASM and ECS has a highly significant effect on the aroma, texture, and color of concentrate silage for meat sheep (p<0.01)

Effect of Avocado Seed Meal and Expired Commercial Syrup Addition on Silage Aroma

Analysis of variance results showed the addition of the combination of avocado seed meal (ASM) and expired commercial syrup (ECS) had a highly significant effect (P < 0.01; F-calculated = 188 > F-table = 4.43) on the aroma of fattening sheep concentrate silage, with a coefficient of variation of 3.12% indicating high data precision. DMRT test confirmed that all treatments differed highly significantly between dosage levels, where P5 (6% DM) achieved an optimal aroma score of 3.32 ± 0.06 in the "strong fermentative aroma" category (score > 3.00). The increase in aroma score along with additive dosage indicates that carbohydrate substrate availability facilitates optimal lactic acid bacteria (LAB) growth—ECS provides glucose and fructose (60-70% w/v) for the initial fermentation phase, while ASM with complex carbohydrates maintains fermentative activity in the advanced phase (Agarussi et al. 2022), creating a desired volatile metabolite profile through glucose conversion to lactic acid (C₆H₁₂O₆ → 2 CH₃CHOHCOOH).

These findings are consistent with Sadarman et al. (2024) who reported an aroma score of 3.15 ± 0.08 on odot grass silage with 3% DM ECS, comparable to the results of P4 (2.94 ± 0.07) and P5 (3.32 ± 0.06) in this study. Wulandari et al. (2020) and Hansa et al. (2020) confirmed that aroma scores > 3.00 reflect lactic acid dominance and ammonia suppression, indicating superior fermentation quality in P5. In addition to carbohydrate effects, tannin content in ASM (4.50-6.00% DM) plays an important role through the "protein protection effect" mechanism—protein binding by polyphenols forms complexes resistant to proteolytic enzymes (Feng et al., 2023), thereby preventing protein degradation into unpleasant-smelling ammonia and maintaining the distinctive fermentative aroma.

Achieving high-quality aroma requires three main technical strategies: (1) optimal compaction in 300 g plastic silos to create strict anaerobic conditions that suppress aerobic spoilage microbes and facilitate anaerobic LAB growth; (2) balanced carbohydrate:protein ratio regulation, where the 6% DM ASM-ECS combination provides sufficient substrate for dominant fermentation in concentrate with 14.8% CP; and (3) fermentation temperature control of 28-32°C to maintain mesophilic LAB enzyme activity, considering that extreme temperatures can inactivate enzymes or slow fermentation. The integration of these three factors ensures rapid and sustainable lactic acid production,

resulting in a fresh sour aroma that becomes an indicator of prime silage quality.

Effect of Avocado Seed Meal and Expired Commercial Syrup Addition on Silage Texture

Analysis of variance results showed a highly significant effect (p < 0.01; F-calculated = 157 > F-table = 4.43; CV = 2.89%) of the combination of avocado seed meal (ASM) and expired commercial syrup (ECS) on the texture of fattening sheep concentrate silage. DMRT test confirmed that all treatments differed highly significantly between dosage levels, with P5 (6% DM) achieving an optimal score of 3.49 ± 0.07 in the "smooth-non-clumping" category (score > 3.00). The increase in texture score along with additive dosage indicates that more intensive fermentation activity successfully degraded structural components evenly, reflecting optimal compaction and uniform fermentative microbial activity throughout all parts of the silage as stated by Borreani & Tabacco (2017).

These findings are consistent with Sadarman et al. (2022) who reported a texture score of 3.2 ± 0.1 on elephant grass silage with 3% DM ECS, comparable to the results of P4 (3.08 ± 0.06) and P5 (3.49 ± 0.07) in this study. Hynd (2019) emphasized that ideal silage texture is smooth, compact, and non-clumping with scores > 3.00, which was achieved by P5. Rahayu et al. (2017) also reported similar increasing texture trends with rice bran and molasses addition. According to Sadarman et al. (2025), the addition of ECS to enhance elephant grass silage quality at a level of 2.50% DM provides an energy contribution comparable to the control, resulting in a similar silage texture. Furthermore, increasing ECS levels up to 10% DM produces a smooth, non-clumpy texture as the sugar content facilitates lactic acid production by beneficial microbes to accelerate the fermentation process. The texture improvement mechanism involves four factors: (1) optimal compaction that expels trapped air and creates anaerobic conditions supporting lactic acid bacteria activity; (2) hemicellulase and pectinase enzyme activity from fermentative microbes that break down hemicellulose and pectin structural bonds; (3) ASM fat content (8-12% DM) functioning as a natural lubricant reducing roughness; and (4) optimal moisture content (65-70%) affecting silage moisture and softness. Achieving high-quality texture requires the integration of four technical strategies: first, manual compaction with consistent pressure for even density and elimination of trapped air; second, uniform particle size regulation enabling optimal compaction and even fermentation;

third, application of 6% DM ASM-ECS additive combination (P5) providing sufficient energy for structural component degradation and smooth texture formation; and fourth, 30-day fermentation period control guaranteeing stable fermentation with optimal structural degradation—too short a period results in coarse texture due to incomplete degradation, while excessive periods cause over-fermentation and overly soft texture. The synergy of these factors results in prime silage texture that contributes to stability and feed palatability.

Effect of Avocado Seed Meal and Expired Commercial Syrup Addition on Silage Color

Analysis of variance results showed a highly significant effect ($p < 0.01$; F -calculated = 142 > F -table = 4.43; $CV = 2.45\%$) of the combination of avocado seed meal (ASM) and expired commercial syrup (ECS) on the color of fattening sheep concentrate silage. DMRT test confirmed that all treatments differed highly significantly between dosage levels, with P5 (6% DM) achieving an optimal score of 3.47 ± 0.05 in the "bright brown" category (score > 3.00). The increase in color score along with additive dosage indicates optimal fermentation that maintains pigment stability (chlorophyll and carotenoids) and prevents oxidation, where consistent yellowish-brown color reflects good anaerobic conditions and rapid pH reduction that suppresses pigment-degrading enzymatic activity as stated by McDonald *et al.* (2022).

These findings are consistent with Hynd (2019) who established color scores > 3.00 as an indicator of quality silage with dominant lactic acid fermentation, and Sadarman *et al.* (2024) who reported scores of 3.2 ± 0.1 comparable to P4 (3.14 ± 0.06) and P5 (3.47 ± 0.05) in this study. Wulandari *et al.* (2020a) also confirmed similar increasing color trends with lactic acid inoculants. The color change mechanism involves four factors (Bhuyan *et al.* 2019): (1) pigment stability where rapid pH reduction and strict anaerobic conditions suppress chlorophyllase enzyme and chlorophyll degradation to yellowish-brown pheophytin; (2) oxidation prevention by polyphenol oxidase and lipoxygenase enzymes through oxygen elimination; (3) antioxidative protection from phenolic compounds and flavonoids in ASM; and (4) controlled Maillard reaction between reducing sugars and amino acids forming brown melanoidins.

Achieving prime color requires the integration of four strategies: first, optimal compaction and tight sealing for strict anaerobic conditions preventing pigment oxidation; second, application of 6% DM ASM-ECS combination (P5) ensuring rapid lactic acid production and drastic pH reduction suppressing pigment-degrading enzymes; third, use of quality concentrate with forage composition (pakchong napier and Indigofera) as sources of chlorophyll and carotenoid pigments; and fourth, 30-day fermentation period control guaranteeing stable fermentation without over-fermentation—optimal periods allow controlled

chlorophyll degradation to pheophytin and pheophorbide that provides the characteristic yellowish-brown color of superior quality silage.

Dry Matter (DM) Content and Dry Matter Loss (DML)

Based on analysis of variance, the addition of additive combinations in the form of avocado seed meal (ASM) and expired commercial syrup (ECS) at various levels (1.50%-6% DM) did not have a significant effect on dry matter content and dry matter loss of sheep-based concentrate silage. DM and DML data are presented in Table 4.

Effect of Avocado Seed Meal and Expired Commercial Syrup Addition on Silage Dry Matter (DM)

Analysis of variance results showed that the addition of the combination of avocado seed meal (ASM) and expired commercial syrup (ECS) did not have a significant effect ($P > 0.05$; F -calculated = 0.87 < F -table = 2.87; $CV = 4.52\%$) on the dry matter (DM) content of fattening sheep concentrate silage. DM values ranged from 31.7-33.2% between treatments, which is still within the optimal range for concentrate silage (30-40%) according to McDonald *et al.* (2022). This non-difference is caused by the characteristics of concentrate as a base material that already has high and stable DM composition (~35%), so additive addition in the range of 1.50-6% DM does not drastically alter the water-dry matter balance in the substrate, as confirmed by Borreani & Tabacco (2018) that concentrate with 30-40% DM is resistant to changes due to additives at normal doses.

These findings are consistent with Kustantinah *et al.* (2016) who reported concentrate silage with 32-35% DM providing optimal beef cattle performance, and Rahayu *et al.* (2019a) who found no DM differences in elephant grass silage with various additives such as molasses and fine rice bran. Four technical factors influence DM stability: (1) optimal base material moisture content (65-70%) enabling molecular mobility for enzymatic activity without leachate percolation risk (Demir *et al.* 2026); (2) physical characteristics of additives—ASM with high DM (92-95%) and ECS with higher water content (30-40%) provide balanced contribution (McDonald *et al.* 2022); (3) lactic acid fermentation converting carbohydrates

Table 4 Dry matter content and dry matter loss of silage

Treatment	DM (%)	DML (%)
P1 (Control)	31.7 ± 1.86	3.32 ± 1.86
P2 (1.50% DM; ASM: 0.75% + ECS: 0.75%)	31.8 ± 0.84	3.16 ± 0.84
P3 (3% DM; ASM: 1.50% + ECS: 1.50%)	32.2 ± 0.62	2.76 ± 0.62
P4 (4.50% DM; ASM: 2.25% + ECS: 2.25%)	32.6 ± 1.40	2.44 ± 1.40
P5 (6% DM; ASM: 3.00% + ECS: 3.00%)	33.2 ± 0.71	1.78 ± 0.71

Note: ASM: Avocado Seed Meal, ECS: Expired Commercial Syrup

to lactic acid without significant liquid or gas byproducts (Sadarman et al. 2021); and (4) airtight silo conditions preventing water evaporation during fermentation (de Melo et al. 2023).

Achieving optimal DM requires the integration of five strategies: first, selection of base concentrate with ~35% DM as an ideal ensiling basis; second, additive use considering the DM profile of each component for total balance; third, optimal compaction in silos reducing pore space and preventing liquid loss; fourth, tight sealing for 30 days preventing water evaporation (deMelo et al. 2023); and fifth, 6% DM additive dose application (P5) providing optimal benefits for other quality parameters (aroma, texture, color, pH, and Fleigh Value) without disturbing water-dry matter balance. The synergy of these strategies ensures DM stability while comprehensive fermentation quality improvement (McDonald et al. 2022).

Effect of Avocado Seed Meal and Expired Commercial Syrup Addition on Silage Dry Matter Loss (DML)

Analysis of variance results showed that the addition of the combination of avocado seed meal (ASM) and expired commercial syrup (ECS) did not have a significant effect; $F_{\text{calculated}} = 1.23 < F_{\text{table}} = 2.87$; $CV = 42.8\%$) on dry matter loss (DML) of fattening sheep concentrate silage. This non-difference is caused by high data variability (standard deviation 0.62-1.86) and the characteristics of concentrate that already has high fermentative stability. Numerically, DML decreased from 3.32% (P1) to 1.78% (P5), but all treatments met quality standards well—DML of 1.78-3.32% is well below the maximum threshold of 5% according to McDonald et al. (2022), indicating optimal fermentation efficiency with minimal nutrient degradation by spoilage microbes.

These findings are consistent with Borreani and Tabacco (2017) who reported corn silage DML of 2-4% with *Lactobacillus buchneri* inoculant, and Sadarman et al. (2023) who found DML of 2.50-4.20% on organic market waste (cabbage, spinach, and water spinach) with ECS—both comparable to the results of this study. Four technical factors influence DML minimization (Leontopoulos et al., 2021): (1) fermentation efficiency is determined by pH reduction speed, where the ASM-ECS combination accelerates fermentation with easily fermentable carbohydrate substrates; (2) optimal anaerobic conditions through compaction and tight sealing prevent aerobic spoilage microbe activity; (3) optimal moisture content (65-70%) enables enzymatic activity and lactic acid bacteria growth without leachate percolation; and (4) ASM tannin content (4.50-6.0% DM) protects protein from proteolytic enzyme degradation through the "protein protection effect" mechanism that reduces nitrogen loss.

Achieving minimal DML requires the integration of five strategies (Skenderidis et al. 2021): first, optimal compaction expels trapped air and creates anaerobic conditions as quickly as possible, reducing the initial aerobic phase that potentially causes oxidation; second,

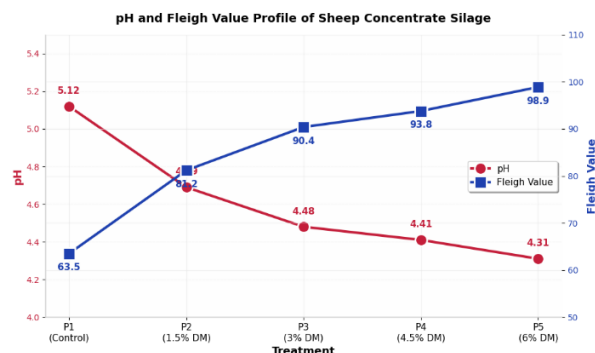


Figure 2 pH profile and fleigh value of concentrate sheep silage after ensiling using ASM and ECS

6% DM ASM-ECS combination application (P5) provides sufficient substrate for optimal lactic acid bacteria growth and rapid pH reduction; third, tight silo sealing for 30 days prevents oxygen entry; fourth, use of materials with 65-70% moisture prevents leachate percolation that carries dissolved nutrients; and fifth, 28-32°C fermentation temperature control ensures maximum lactic acid bacteria activity without overheating risk. Implementation of these strategies produces silage with minimal nutrient loss and maintained economic value.

pH and Fleigh Value

The additive combination of avocado seed meal (ASM) and expired commercial syrup (ECS) had a highly significant effect ($p < 0.01$) on pH value reduction and Fleigh Value increase of sheep-based concentrate silage. pH and Fleigh Value data are presented in Table 5, The pH profile and Fleigh value of silage made from fattening sheep concentrate enriched with ASM and ECS are shown in Figure 2.

Effect of Avocado Seed Meal and Expired Commercial Syrup Addition on Silage pH

Analysis of variance results showed a highly significant effect ($p < 0.01$; $F_{\text{calculated}} = 89.67 > F_{\text{table}} = 4.43$; $CV = 2.18\%$) of the combination of avocado seed meal (ASM) and expired commercial syrup (ECS) on silage pH of fattening sheep concentrate.

Table 5 pH and fleigh value of fattening sheep concentrate silage

Treatment	pH	Fleigh value
P1 (Control)	5.12 ^d ± 0.15	63.5 ^a ± 2.10
P2 (1.50% DM; ASM: 0.75% + ECS: 0.75%)	4.69 ^c ± 0.08	81.2 ^b ± 1.45
P3 (3% DM; ASM: 1.50% + ECS: 1.50%)	4.48 ^b ± 0.06	90.4 ^c ± 1.20
P4 (4.50% DM; ASM: 2.25% + ECS: 2.25%)	4.41 ^{ab} ± 0.09	93.8 ^{ad} ± 1.85
P5 (6% DM; ASM: 3.00% + ECS: 3.00%)	4.31 ^a ± 0.07	98.9 ^d ± 1.05

Note: ASM: Avocado Seed Meal, ECS: Expired Commercial Syrup, different superscripts in the same column indicate that the synergy between ASM and ECS has a high significant effect on pH and Fleigh Value of concentrate silage for fattening sheep ($p < 0.01$)

DMRT test confirmed that all treatments differed highly significantly from the control (P1: 5.12 ± 0.15), with sequential reduction P2 (4.69 ± 0.08), P3 (4.48 ± 0.06), P4 (4.41 ± 0.09), and P5 (4.31 ± 0.07). The optimal treatment P5 achieved pH 4.31 ± 0.07 approaching the optimal range for concentrate silage (3.8-4.2), indicating dominant lactic acid fermentation and suppression of spoilage microbe activity. The response pattern shows substrate saturation principle—increasing dosage from 3% to 4.50% and 6% no longer provided significant pH reduction, indicating lactic acid bacteria (LAB) capacity approaching maximum point at 4.50-6% DM dosage, so 4.50% DM dosage can be considered as the optimal economic efficiency point.

These findings are consistent with Sadarman *et al.* (2024) who reported pH reduction from 5.20 to 4.30 with 3% DM ECS, and Yulistiani *et al.* (2018) who found pH 4.20-4.40 with molasses at 3-5% of the dry matter of corn plant waste—both comparable to P5 (4.31) results in this study. McDonald *et al.* (2022) emphasized optimal concentrate silage pH of 3.8-4.2 which was nearly achieved by P5. The pH reduction mechanism involves four factors: (1) substrate availability—ECS with glucose and fructose (60-70% w/v) as ideal LAB substrates metabolized to lactic acid ($C_6H_{12}O_6 \rightarrow 2 CH_3CHOHCOOH$); (2) LAB population and activity supported by sustainable energy, where ECS provides fast sugars for the initial phase and ASM provides complex carbohydrates for the middle and final phases; (3) optimal anaerobic conditions through compaction and sealing that facilitate anaerobic LAB growth; and (4) 65-70% moisture enabling molecular mobility for enzymatic activity and LAB growth.

Achieving optimal pH requires the integration of five strategies: first, 6% DM ASM-ECS combination application (P5) provides sufficient substrate for optimal lactic acid production and rapid pH reduction; second, optimal compaction and tight sealing create strict anaerobic conditions that facilitate anaerobic LAB growth while suppressing spoilage microbes; third, use of materials with 65-70% moisture ensures maximum enzymatic activity and LAB growth; fourth, 28-32°C fermentation temperature control maintains optimal mesophilic LAB activity; and fifth, 30-day fermentation period guarantees fermentation reaches stable stage with maximum pH reduction. Implementation of these strategies produces silage with near-optimal pH, superior fermentation stability, and resistance to spoilage microbe contamination.

Effect of Avocado Seed Meal and Expired Commercial Syrup Addition on Silage Fleigh Value

Analysis of variance results showed a highly significant effect ($p < 0.01$; F -calculated = 98.3 > F -table = 4.43; CV = 1.87%) of the combination of avocado seed meal (ASM) and expired commercial syrup (ECS) on the Fleigh Value of fattening sheep concentrate silage. Fleigh Value—as a comprehensive indicator of fermentation success, silage stability, and nutritional quality—is highly responsive to

the combination of dry matter (DM) content and pH influenced by additives. DMRT test confirmed that all treatments differed highly significantly from the control (P1: 63.5 ± 2.10 , "fairly good" category), with sequential increase P2 (81.2 ± 1.45), P3 (90.4 ± 1.20), P4 (93.8 ± 1.85), and P5 (98.9 ± 1.05 , "excellent" category 85-100). The significant increase from 63.5 to 98.9 was driven by stable DM (31.7-33.2%) and drastic pH reduction (5.12 to 4.31), with response patterns showing additive effectiveness saturation point at 4.50% DM dosage (P4 and P5 not significantly different).

These findings outperform Kurniawan *et al.* (2019) who reported Fleigh Values of 72-85 ("good" category) on local forage silage—this difference is explained by higher concentrate nutritional content (CP 14.8%; TDN 70.8%) and ASM-ECS combination effectiveness. Sadarman *et al.* (2025a) evaluated a discarded commercial syrup as a stimulant additive to improve the quality of elephant grass silage; the results showed a Fleigh value of 88-92, which is comparable to the results of this study for P3 and P4, while Ozturk *et al.* (2006) established >85 threshold as "excellent" category which was exceeded by P5 (98.9) with significant margin. Four technical factors influence Fleigh Value based on the formula $FV = 220 + [(2 \times \%DM) - 15] - (40 \times pH)$: (1) stable DM (31.7-33.2%) provides positive contribution indicating maintained nutrition; (2) pH reduction contributes 32.4 points (40×0.81) to Fleigh Value increase; (3) lactic acid bacteria dominance and spoilage microbe suppression reflect optimal fermentation quality; and (4) storage stability is influenced by anaerobic conditions and rapid pH reduction.

Achieving optimal Fleigh Value requires the integration of five strategies: first, maintaining 30-40% DM through quality base materials (concentrate DM ~35%) and leachate percolation prevention; second, rapid pH reduction with 6% DM ASM-ECS combination (P5) ensures optimal lactic acid production; third, strict anaerobic conditions through compaction and tight sealing facilitate lactic acid bacteria growth while suppressing spoilage microbes (Canbolat 2021); fourth, 28-32°C temperature control maintains maximum lactic acid bacteria activity; and fifth, 30-day fermentation period guarantees stable fermentation with optimal quality (McDonald *et al.* 2022). Implementation of these strategies produces silage with Fleigh Value approaching 100, reflecting comprehensive fermentation success and prime feed quality (Du *et al.* 2023).

CONCLUSION

The combination of avocado seed meal and expired commercial syrup had a highly significant effect ($p < 0.01$) on the physical quality (aroma, texture, color), pH, and Fleigh Value of fattening sheep concentrate silage, but did not have a significant effect on dry matter and dry matter loss.

The optimal treatment was achieved at the addition of ASM and ECS respectively at 3% of dry matter (total 6% DM), producing strong fermentative aroma (3.32±0.06), smooth non-clumping texture (3.49±0.07), consistent yellowish-brown color (3.47±0.05), pH 4.31±0.07, and Fleigh Value 98.9±1.05 (excellent category).

The utilization of agro-industrial waste in the form of avocado seed meal and expired commercial syrup is effective as an economical and sustainable alternative silage additive for fattening sheep concentrate preservation.

SUGGESTIONS

Further research is needed regarding the effect of feeding concentrate silage with ASM and ECS additives on in vivo fattening sheep performance to confirm nutritional benefits and palatability. It is recommended to optimize silo compaction and sealing techniques to minimize dry matter loss which still shows high variability.

Economic analysis needs to be conducted to evaluate the financial feasibility of ASM and ECS utilization on a commercial scale, considering the optimal efficiency point at 4.50% DM dosage. It is recommended to further evaluate fermentation profiles including lactic acid, acetic acid, and ammonia content to strengthen silage quality indicators.

AUTHOR'S CONTRIBUTIONS

SAD, IM and DF: Conceptualized and designed the study. FPA, MAH, and AM: Sample collection and laboratory analysis. SAD, RPH, AN, SD, and Suharlina: Data analysis and interpretation and manuscript preparation. SAD, IM, ZAB, and MJA: Drafted the manuscript. All authors actively participated in revision of the manuscript, provided intellectual input, and approved the final version for submission.

COMPETING INTERESTS

The authors declare that they have no competing interests.

ACKNOWLEDGMENTS

The authors express their gratitude to the Institute for Research and Community Service (LP2M) of Universitas Islam Negeri Sultan Syarif Kasim Riau for their support throughout this research. The authors also extend their appreciation to PT. Sei Deras Agrofarm for providing the concentrate for research materials.

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