p-ISSN 1410-5659 e-ISSN 2621-5144
Published by:
Unpad Press

Jurnal Ilmu Ternak Universitas Padjadjaran, July 2025, 25(2):169-180
DOI: 10.24198/jit.v25i2.62160
Available online at http://jurnal.unpad.ac.id/jurnalilmuternak

A META-ANALYSIS ON THE EFFECT OF OIL PALM FRONDS AS SMALL RUMINANT FEED

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Abstract
Oil Palm fronds (OPF), the main waste product of oil palm plantations, have considerable promise as a feed for small ruminants. Unfortunately, due to the diversity of previous findings, a clear response pattern has still to be determined. For this reason, a meta-analysis was employed in the present study to synthesize existing findings regarding the effect of OPF as a feed for small ruminants. The database was constructed using data from ten published articles that fit the inclusion criteria. The applied statistical model was a mixed model. Findings revealed no significant effect (P>0.05) of OPF inclusion on nutrient intake, nutrient digestibility, animal performance, and nitrogen utilization. However, there is a linear tendency for dry matter intake (DMI) to increase by 0.31 g/day and for average daily gain (ADG) to decrease by 0.16 g/day for every 1 g/kg DM increase in OPF inclusion. The OPF inclusion levels examined across studies ranged from 100 to 600 g/kg of dry matter (DM), with an average inclusion of approximately 300 g/kg DM. Although no significant effects were observed, these findings suggest that OPF can be included in small ruminant feed up to the levels tested without adverse impacts.
Keywords: meta-analysis, oil palm fronds, small ruminant, feed

META ANALISIS PENGARUH PELEPAH KELAPA SAWIT SEBAGAI PAKAN TERNAK RUMINANSIA KECIL

Abstrak
Pelepah kelapa sawit sebagai limbah utama perkebunan kelapa sawit memiliki potensi yang menjanjikan sebagai pakan ruminansia kecil. Namun demikian, pola response yang jelas belum teridentifikasi karena keragaman temuan terdahulu. Oleh karena itu, dalam penelitian ini, meta-analisis digunakan untuk mesintesis temuan-temuan yang ada mengenai pengaruh pelepah kelapa sawit sebagai pakan ruminansia kecil. Basis data dibangun dengan menggunakan data yang berasal dari sepuluh artikel yang memenuhi kriteria inklusi. Model statistik yang digunakan adalah Mixed Model. Hasil penelitian mengungkapkan bahwa, tidak ditemukan efek signifikan (P>0.05) penyertaan pelepah kelapa sawit terhadap asupan nutrisi, kecernaan nutrisi, kinerja ternak, dan pemanfaatan nitrogen. Namun demikian, terdapat kecenderungan peningkatan 0.31 g/hari asupan bahan kering secara linier dan penurunan 0.16 g/hari secara linier pertambahan bobot badan harian setiap peningkatan 1 g/kg penyertaan pelepah kelapa sawit. Level inklusi pelepah kelapa sawit yang diuji dalam berbagai studi berkisar antara 100 hingga 600 g/kg bahan kering (BK), dengan rata-rata 300 g/kg BK. Meskipun tidak ditemukan pengaruh signifikan, temuan ini mengindikasikan bahwa pelepah kelapa sawit dapat disertakan dalam pakan ruminansia kecil hingga level yang telah diuji tanpa menimbulkan pengaruh negatif yang berarti.
Kata kunci**: **meta-analisis, pelepah kelapa sawit, ruminansia kecil, pakan

INTRODUCTION

OPF is a prominent waste of oil palm plantations due to its great potential as feed for ruminants. This potential arises from abundant production rates, especially in tropical regions, dietary fiber sources, and low production costs. In 2020, Indonesia generated approximately 28.9 million tons of OPF per year (Nabila *et al*., 2023). OPF has been widely used as one of the feed ingredients for fiber sources to substitute for grass (Rusli *et al*., 2021a). The high fibrous content requires scrutiny in its inclusion as ruminant feed. OPF contains 76.09% NDF, 57% ADF, and only 2.23% crude protein, making it a high-fiber, low-protein feed component (Haq *et al*., 2018).

Regarding dietary preferences, both sheep and goats show moderate feeding tendencies, favoring grasses, broad-leaved plants, herbaceous species, and shrubs. Other than that, small ruminants show efficient selection behavior, selecting mild and appetizing plant components over fibrous ones; they are unable to consistently consume large amounts of fibrous material (Dias-Silva & Filho, 2021). Thus, several researchers have explored the utilization of OPF in small ruminants.

Unfortunately, there are some contradictions regarding the effect of OPF feeding on small ruminants. The inclusion of OPF in sheep diets has been reported to significantly affect final body weight and ADG (Jafari *et al*., 2018). In contrast, other studies observed no change in ADG with OPF addition in sheep (Hassim *et al*., 2013). Similarly, in goats, no significant effect on ADG was found in some studies (Ebrahimi *et al*., 2015), while others reported differing responses between goats fed grass-based diets and those receiving OPF (Musnandar *et al*., 2011).

These contradictory findings suggest that a meta-analysis is required to develop integrated data and address the gaps. Meta-analysis is advisable to synthesize previous findings, to obtain clarifying evidence of contrary findings (Sauvant *et al*., 2008). This approach has been widely applied in animal nutrition research, including studies on agricultural by-products as ruminant feed, such as coffee pulp (Fhonna *et al*., 2024), palm kernel cake (Fhonna *et al*., 2025; Vargas & Mezzomo, 2023), and distiller's dried grains with solubles (DDGS) (Malik *et al*., 2024). This meta-analysis aims to evaluate the effects of OPF inclusion in small ruminant diets on performance, nutrient intake and digestibility, nitrogen utilization, carcass characteristics, and fatty acid composition of the *Longissimus dorsi*, *Biceps femoris* muscles, and subcutaneous fat.

MATERIALS AND METHODS

Database Development

The database was developed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Liberati *et al*., 2009; Page *et al*., 2021). All data in this study were collected from published articles. The articles were selected through Google Scholar, ScienceDirect, and Springer Link using the two keywords "oil palm fronds" and "ruminant." Afterward, selection was made through title and abstract screening and full-text review.

Inclusion and Exclusion Criteria

The articles listed for inclusion in this meta-analysis fulfilled several criteria. Inclusion and exclusion criteria were based on the timeline, document type, language of publication, sample used, type of experiment, and accessibility. The inclusion criteria for articles consisted of: (1) there is no publication period; (2) peer-reviewed research article; (3) published in English; (4) *in vivo* experiments on small ruminants; (5) the article is accessible; (6) reported OPF inclusion level.

Selection Procedure and Data Extraction

During the search and selection process using keywords, a total of 1269 articles were obtained. Subsequently, 89 of them were removed due to duplication, resulting in a total of 1180 articles that were selected based on title and abstract. After removing 1151 articles, only 29 articles were further reviewed based on the full text. At this stage, eleven articles were removed due to irrelevant studies. There was one article that was a review that was excluded. Two articles at this stage were also removed because the level of OPF inclusion was unclear. Furthermore, four *in vitro* study articles were also excluded. Lastly, one article was inaccessible. As a result, only ten articles were extracted and included in the database. The articles consisted of four articles with experiments on sheep (Hassim *et al*., 2013; Jafari *et al*., 2018; Mahgoub *et al*., 1998; Meng *et al*., 2018) and six articles on goats (Baysi *et al*., 2021; Ebrahimi *et al*., 2015; Hamchara *et al*., 2018; Musnandar *et al*., 2011; Noosen & Baysi, 2022; Rusli *et al*., 2021b). This selection process is presented in Figure 1.

The OPF inclusion level in this study used g/kg DM as the unit; hence, other units were exchanged for the same units applied. This was also implemented for all parameters included in the study. When the unit of measurement is already the same for each parameter, then the statistical analysis can be done simultaneously. The parameters measured in this meta-analysis consisted of: (1) nutrient intake; (2) animal performance; (3) nutrient digestibility; (4) nitrogen utilization (N utilization); (5) carcass characteristics; (6) fatty acids of *Longissimus dorsi* muscle, *biceps femoris* muscle, and subcutaneous fat. The descriptive statistics of the effects of OPF on small ruminants are presented in Table 1 and Table 2.

Statistical analysis

Data was processed using the mixed model method (St-Pierre, 2001). Analysis were conducted using the PROC MIXED procedure in SAS® OnDemand for Academics. OPF inclusion level was considered a fixed effect, while different studies were considered a random effect. The mathematical model used is as follows:

$$Y_{ij} = B_0 + B_1X_{ij} + s_i + b_iX_{ij} + e_{ij}$$

Where Y_{ij}= dependent variable; B_0= overall intercept; B_1= linear regression coefficient of Y on X; X_{ij}= value of the continuous predictor variable; s_i= random effect of study i; b_i= random effect of study on the regression coefficient of Y on X in study i; and e_{ij} =the unexplained residual error.

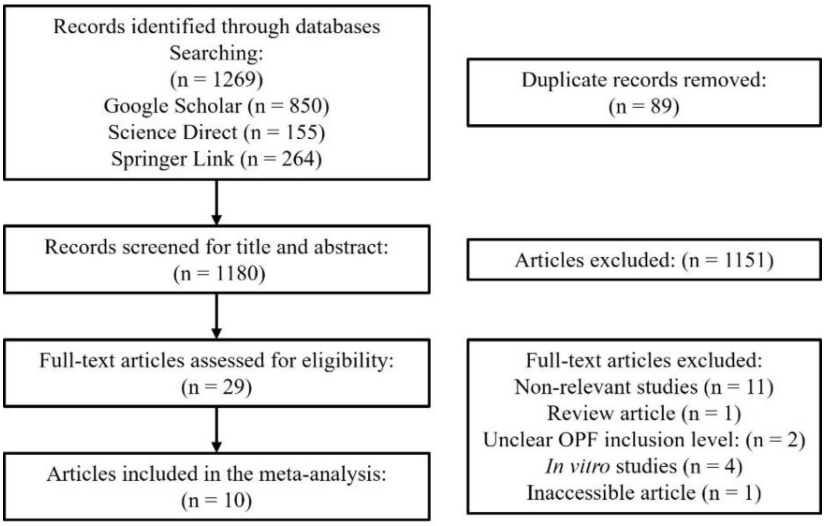

Figure 1. The preferred reporting items for systematic reviews and meta-analysis (PRISMA) diagram flow of the selection process

Table 1. Descriptive statistics of the influence of oil palm fronds on nutrient intake, performance, nutrient digestibility, and nitrogen utilization

Response Variables	Unit	n	Mean	SD	Min	Max
Nutrient intake						
DMI	g/d	16	971.47	221.16	522.80	1292.60
OMI	g/d	10	980.85	222.12	487.87	1194.70
CPI	g/d	10	169.79	57.14	57.60	220.60
EEI	g/d	10	25.60	8.39	10.16	36.70
NDFI	g/d	10	488.71	178.15	176.18	660.00
ADFI	g/d	10	251.53	75.57	105.03	330.00
Performance						
IW	kg	8	18.65	3.06	16.07	22.57
FW	kg	11	23.95	5.20	16.68	30.42

Response Variables	Unit	n	Mean	SD	Min	Max
Total gain	kg	8	20.56	24.80	5.65	77.24
ADG	g/d	13	77.92	23.85	35.37	120.71
Digestibility						
DMD	%	7	67.68	8.93	49.20	75.40
OMD	%	7	69.35	8.54	51.70	75.80
CPD	%	7	64.06	13.30	37.20	75.14
NDFD	%	7	62.36	5.83	55.21	71.80
ADFD	%	7	46.22	5.40	34.23	49.20
N balance						
Total NI	g/d	7	24.68	10.14	9.20	34.22
N excretion						
NE feses	g/d	7	7.62	2.12	4.66	10.61
NE urine	g/d	7	5.96	1.28	3.42	7.67
Total NE	g/d	7	13.57	2.50	10.60	16.58
N absorption		7	17.06	8.40	4.55	25.77
N retention		7	11.10	8.88	-1.93	19.98
N absoption (% NI)		7	64.05	13.30	37.20	75.13
N retention (%NI)		7	31.22	38.45	-45.70	63.37

Note: n = Number of studies, SD = Standard deviation, Min = Minimum, Max = Maximum, DMI = Dry matter intake, OMI = Organic matter intake, CPI = Crude protein intake, EEI = Ether extract intake, NDFI = Neutral detergent fiber intake, ADFI = Acid detergent fiber intake, IW = Initial weight, FW = Final weight, ADG = Average daily gain, DMD = Dry matter digestibility, OMD = Organic matter digestibility, CPD = Crude protein digestibility, NDFD = Neutral detergent fiber digestibility, ADFD = Acid detergent fiber digestibility, NI = Nitrogen intake, NE = Nitrogen excretion.

Table 2. Descriptive statistics of the influence of oil palm fronds on carcass characteristics, fatty acids of *Longissimus dorsi* muscle, *biceps femoris* muscle, and subcutaneous fat

Response Variables	Unit	n	Mean	SD	Min	Max
Carcass characteristics						
Carcass weight	kg	7	7.53	0.62	6.41	8.22
Warm carcass pH, 0 h		7	6.58	0.18	6.27	6.79
Chilled carcass pH, 24 h		7	5.97	0.44	5.55	6.47
***Longissimus dorsi* muscle**						
C16:0	g/100 g	5	0.41	0.17	0.14	0.56
C18:0	g/100 g	5	0.32	0.08	0.23	0.46
PUFA n-6	g/100 g	5	0.19	0.06	0.15	0.26
Total FA	g/100 g	6	1.85	0.53	1.19	2.37
***Biceps femoris* muscle**						
UFA/SFA ratio		6	1.23	0.15	1.00	1.36
Total FA	g/100 g	6	1.97	0.11	1.81	2.08
Subcutaneous fat						
C18:0	g/100 g	6	15.79	4.18	9.80	20.20
UFA/SFA ratio		6	0.93	0.21	0.59	1.17
Total FA	g/100 g	6	53.07	3.50	48.22	57.30

Note: n = Number of studies, SD = Standard deviation, Min = Minimum, Max = Maximum, PUFA = Polyunsaturated fatty acids, SFA = Saturated fatty acids, UFA = Unsaturated fatty acids, FA = Fatty acids.

RESULTS AND DISCUSSION

This meta-analysis discovered no significant effect of feeding OPF to small ruminants on nutrient intake, performance, nutrient digestibility, N utilization, carcass characteristics, fatty acids of *Longissimus dorsi* muscle, *biceps femoris* muscle, and subcutaneous fat (P>0.05). Studies included in this meta-analysis reported OPF inclusion levels ranging from 100 to 600 g/kg DM, with an average level of approximately 300 g/kg DM. The regression equations on the effect of OPF on nutrient intake, performance, nutrient digestibility, N utilization, carcass characteristics, fatty acids of *Longissimus dorsi* muscle, *biceps femoris* muscle, and subcutaneous fat are presented in Table 3, Table 4, and Table 5, respectively.

Considering that goats are the most selective of ruminants, they favor leafy plants. The results obtained from this meta-analysis are interesting because OPF is a feed ingredient derived from waste, which goats naturally do not particularly prefer. This implies that despite the lack of improvement in intake patterns, OPF has promising value as a forage substitute since it does not

Table 2. Regression equations on the effect of oil palm fronds on nutrient intake, performance, and nutrient digestibility

Response variables	Unit	n	Parameter Estimates				Model Estimates		
			Intercept	SE Intercept	Slope	SE slope	*P*-value	RMSE	AIC
Nutrient intake									
DMI	g/d	16	926.9	95.1206	0.312	0.5564	0.589	286.47	217.3
OMI	g/d	10	863.29	140.3	-0.08931	1.0018	0.932	236.55	133.1
CPI	g/d	10	152.39	39.9106	-0.04118	0.1663	0.814	39.02	110.4
EEI	g/d	10	21.9474	4.5333	-0.03353	0.04391	0.480	12.10	87.6
NDFI	g/d	10	418.43	121.69	-0.5615	0.7471	0.486	199.32	129
ADFI	g/d	10	213.8	53.3126	-0.02569	0.243	0.920	58.55	115.1
Performance									
IW	kg	8	18.3631	1.8184	0.002421	0.002164	0.345	0.85	56.3
FW	kg	11	25.8736	2.5002	-0.00883	0.01163	0.482	5.30	87.6
total gain	kg	8	6.8503	15.0383	0.3266	0.1404	0.103	73.57	88.3
ADG	g/d	13	91.2652	12.4741	-0.1598	0.1268	0.248	64.83	138.5
Digestibility									
DMD	%	7	58.9224	3.9424	0.1137	0.05259	0.119	11.48	64.7
OMD	%	7	60.9228	3.5626	0.1298	0.05359	0.094	11.59	1.8×10^{308}
CPD	%	7	53.1006	9.9775	0.1046	0.05528	0.155	11.46	67.5
NDFD	%	7	57.433	2.423	0.05881	0.05324	0.350	8.11	1.8×10^{308}
ADFD	%	7	41.6137	4.1142	0.06288	0.04488	0.256	10.26	64.1

Note: n = Number of studies, SE = Standard error, RMSE = Root mean square error; AIC = Akaike information criterion, DMI = Dry matter intake, OMI = Organic matter intake, CPI = Crude protein intake, EEI = Ether extract intake, NDFI = Neutral detergent fiber intake, ADFI = Acid detergent fiber intake, IW = Initial weight, FW = Final weight, ADG = Average daily gain, DMD = Dry matter digestibility, OMD = Organic matter digestibility, CPD = Crude protein digestibility, NDFD = Neutral detergent fiber digestibility, ADFD = Acid detergent fiber digestibility.

Table 3. Regression equations on the effect of oil palm fronds on nitrogen utilization

Response variables	Unit	n	Parameter estimates				Model estimates		
			Intercept	SE Intercept	Slope	SE slope	*P*-value	RMSE	AIC
N balance									
Total NI	g/d	7	20.9897	9.8118	-0.00718	0.03377	0.845	6.77	64.5
N excretion									
NE feses	g/d	7	7.9322	2.0406	-0.02104	0.01141	0.163	3.27	54.8
NE urine	g/d	7	6.384	0.961	-0.01365	0.01277	0.363	2.60	53.4
Total NE	g/d	7	14.5696	1.981	-0.02394	0.02273	0.370	5.28	58.5
N absorption		7	13.0752	7.8526	0.01452	0.0276	0.635	4.96	62.9
N retention		7	6.5219	8.2689	0.02147	0.01977	0.357	3.53	61
N absoption (% NI)		7	53.1005	10.0015	0.104	0.05511	0.156	11.41	67.4
N Retention (%NI)		7	4.5509	32.4907	0.1659	0.1505	0.351	27.09	75.9

Note: n = Number of studies, SE = Standard error; RMSE = Root mean square error; AIC = Akaike information criterion; NI = Nitrogen intake, NE = Nitrogen excretion.

Table 4. Regression equations on the effect of oil palm fronds on carcass characteristics, fatty acids of *Longissimus dorsi* muscle, *biceps femoris* muscle, and subcutaneous fat

Response variables	Unit	n	Parameter estimates				Model estimates		
			Intercept	SE Intercept	Slope	SE slope	*P*-value	RMSE	AIC
Carcass characteristics									
Carcass weight	kg	7	7.2767	0.6431	-0.00084	0.002013	0.705	0.78	47.3
Warm carcass pH, 0 h		7	6.5506	0.1339	0.000192	0.000932	0.850	0.30	38.3
Chilled carcass pH, 24 h		7	6.0225	0.408	-0.00009	0.000319	0.788	0.11	34.3
***Longissimus dorsi* muscle**									
C16:0	g/100 g	5	0.5054	0.07423	0.000065	0.00018	0.780	0.17	34.5
C18:0	g/100 g	5	0.2997	0.02682	-0.00051	0.001443	0.783	0.16	1.8×10^{308}
PUFA n-6	g/100 g	5	0.2071	0.04991	-0.00002	0.000064	0.782	0.02	31.6
Total FA	g/100 g	6	1.7424	0.4972	-0.002	0.003162	0.592	0.46	40.4
Biceps femoris muscle									
UFA/SFA ratio		6	1.1692	0.1317	-0.00005	0.001099	0.968	0.15	33.4
Total FA	g/100 g	6	2.0345	0.08898	-0.001	0.001362	0.539	0.20	33
Subcutaneous fat									
C18:0	g/100 g	6	14.394	3.8175	-0.0118	0.01837	0.586	2.91	51.5
UFA/SFA ratio		6	0.7854	0.1756	0.00242	0.000803	0.095	0.23	32.8
Total FA	g/100 g	6	55.0993	2.5215	-0.0089	0.01782	0.667	2.78	50.5

Note: n = Number of studies, SE = Standard error; RMSE = Root mean square error; AIC = Akaike information criterion; PUFA = Polyunsaturated fatty acids, SFA = Saturated fatty acids, UFA = Unsaturated fatty acids, FA = Fatty acids.

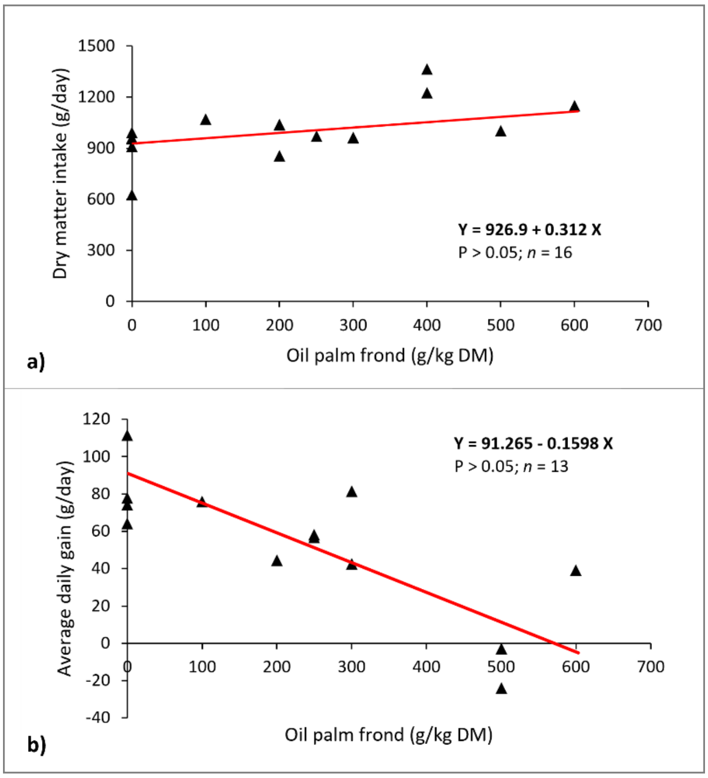

Figure 2. Effect of oil palm frond inclusion on dry matter intake and average daily gain in small ruminants compromise nutrient intake.

However, there is a linear tendency for DMI to increase by 0.31 g/day for every 1 g/kg DM increase in OPF inclusion (Figure 2a). Similar results of this meta-analysis were reported by Hamchara *et al*. (2018)**,** that all components of nutrient intake of goats consuming OPF remained stable.

The lack of significant effect on DMI may be attributed to reduced palatability due to the high NDF content and the increased rumen retention time. A higher fiber fraction prolongs rumen retention and stimulates extended rumination activity due to the rumen filling mechanism (Khaskheli *et al*., 2020; Krone *et al*., 2024). Although OPF is rich in lignin, which exerts a rumen-filling effect, animals are capable of adjusting their feeding behavior accordingly.

On the contrary, Noosen and Baysi (2022) reported that significant increases were observed in DMI and all other nutrient intakes of goat-fed OPF, except crude protein intake (CPI). Although at the highest OPF inclusion level of 400 g/kg of DM, CPI also showed the highest value. According to their investigation, although OPF was high in neutral detergent fiber (NDF), the increase in DMI and all other nutrient intakes was influenced by the water content of the feed. Feed with OPF inclusion contains 60–70% DM, lower by 20–30% than feed without OPF (90% DM). This occurs because moisture in the feed can improve texture and disguise less favorable flavors (Lahr *et al*., 1983).

With the same pattern, nutrient digestibility also remained unchanged. The results of this meta-analysis are in line with previous research. It was found that dairy goats consuming OPF did not affect the nutrient digestibility (Baysi *et al*., 2021)**.** CPI is recognized to influence nutrient uptake in the rumen, as it can increase bacterial population and microbial protein synthesis. However, the results of this study showed that CPI did not alter due to the inclusion of OPF in the diet. This also explains the stability of nutrient uptake.

The opposite result was found by Hamchara *et al*. (2018), it was mentioned that there was a significant change in the nutrient digestibility of feed containing 100–300 g/kg of DM of fermented OPF. This difference is suspected due to the contribution of one of the feed processing technologies, fermentation. Fermentation is widely known to be one of the solutions to improve the quality of high-fiber feed ingredients sourced from agricultural and plantation waste.

OPF treated with *Lentinus sajor-caju* fungus produced OPF with higher crude protein content and lower crude fiber fraction. This allows rumen microorganisms to degrade the feed more efficiently, aided by the increased protein supply to support their activities. NDF digestibility was shown to increase with the addition of 400 g/kg of DM OPF in the feed (Baysi *et al*., 2021). Although this study did not show a significant change in NDF digestibility, there was an increasing tendency.

The feeding of OPF to small ruminants resulted in stable total gain and ADG; however, there is a downward trend in ADG, although not significant (Figure 2b). This is confirmed by previous findings, that the inclusion of 500 g/kg of DM OPF in sheep significantly reduced the 69% ADG and total gain (Jafari *et al*., 2018). Growth performance (e.g., ADG) depends on the extent to which nutrients are digested. Nutrient digestibility itself is influenced by internal factors (such as animal species and breed) and external factors (such as feed quality and composition) (Khaskheli *et al*., 2020). The inclusion of OPF did not affect feed intake and nutrient digestibility; therefore, the growth performance of the animals remained unchanged.

The unchanged or reduced ADG suggests a possible imbalance in nutrient availability, particularly digestible protein and energy. OPF's high fiber content could lead to reduced feed efficiency due to lower rumen digestibility, despite higher intake. Supplementary feeding is essential to support animal performance, particularly in terms of body weight gain. Supplementation with energy and protein sources helps improve the nutritional balance, thereby enhancing body weight gain (Khaskheli *et al*., 2020).

The balance of energy and protein in feed greatly affects the growth rate of sheep and carcass characteristics. However, although each feed treatment containing OPF has been formulated with balanced gross energy, the effectiveness of its availability to animals is varied (Jafari *et al*., 2018). In contrast, Hassim *et al*. (2013) found that OPF had no adverse effect on the decline in ADG of sheep. OPF included in goat feed also did not interfere with growth, ADG remained stable (Ebrahimi *et al*., 2015)

In a study conducted by Hassim *et al*. (2013), carcass weight also did not change as animals consumed OPF. However, the inclusion of 300–600 g/kg of DM fermented OPF provided better growth, characterized by a larger carcass weight compared to feed without OPF (Musnandar *et al*., 2011). Fermented OPF supplementation has been reported to improve nutrient digestibility (Hamchara *et al*., 2018), while also contributing to enhanced growth performance and increased carcass weight in goats. This occurred due to the goats consuming fermented OPF receiving higher CPI. The crude protein content of the OPF-based feed was 13% higher than the field grass-based feed. This is likely due to enhanced fiber breakdown and microbial protein synthesis during the fermentation process.

The results of this meta-analysis are similar to previous studies, which found that there was no effect of OPF on carcass pH in both warm and chilled (Hassim *et al*., 2013; Jafari *et al*., 2018). It is known that animals consuming commercial pellets will accumulate more glycogen, which will lower the pH compared to the carcasses of animals consuming grass (Wiklund *et al*., 2001).

Oleic, stearic, and palmitic acids are the main fatty acids in goat tissues (Abubakr *et al*., 2015; Adeyemi *et al*., 2015). Feed is one of the factors that affect the fatty acid composition of ruminant tissues, apart from breed, sex, and environment (Rusli *et al*., 2021b). Previous research showed that stearic acid (C18:0) was higher in the addition of 200 g/kg of DM of non-treated OPF in goat feed, while palmitic acids (C16:0) were in line with this study, as both inclusion and pretreatment levels did not change the concentration of these compounds in the *Longissimus dorsi* muscle (Rusli *et al*., 2021b).

Since OPF contains low fat, there is no significant contribution to increasing polyunsaturated fatty acids (PUFA) in goat tissues. Feeds that do not contain OPF favor the accumulation of unsaturated fatty acids (UFA), especially PUFA n-6, in muscle tissue due to the biohydrogenation of PUFA to saturated fatty acids (SFA) (Meng *et al*., 2018). There was no change in the UFA/SFA ratio in the *Longissimus dorsi* and *biceps femoris* muscles of sheep fed OPF; however, an increase in stearic acid (C18:0) was observed. This occurred for the same reason, biohydrogenation of PUFA to SFA (stearic acid) in the rumen.

However, once OPF is biologically treated, the accumulation of monounsaturated fatty acids (MUFA) and PUFA in the meat can increase, making it healthier for consumption (Rusli *et al*., 2021 b). This is associated with the high fiber fraction content in OPF. OPF contains 74% NDF and 52% acid detergent fiber (ADF) (Ebrahimi *et al*., 2015). Rumen fermentation activity will increase when animals consume high-fiber feed, resulting in more active anaerobic microbial populations, including biohydrogenation microbes (Abdallah *et al*., 2020).

Furthermore, the content of secondary metabolite compounds such as tannins and phenolics in OPF (Ebrahimi *et al*., 2015) contributes to preventing PUFA biohydrogenation, thereby preventing PUFA from being converted into SFA excessively. This ultimately affects the UFA/SFA ratio, where UFA will be higher in production than SFA in biologically treated OPF. The higher UFA compared to SFA makes the meat healthier. Whereas OPF without fermentation or other pretreatment contains more crude fiber, which stimulates the biohydrogenation process, more PUFA is converted into SFA, especially palmitic acid (C16:0). Fermented OPF produced higher UFA in muscle tissue and subcutaneous fat of goats compared to untreated and physically treated, characterized by a high UFA/SFA ratio (Rusli *et al*., 2021 b).

In addition, this finding is also similar to the study conducted on sheep, where total nitrogen intake (NI), nitrogen excretion (NE), and nitrogen absorption were not significantly different when fed diets containing OPF (Hamchara *et al*., 2018). However, nitrogen retention increased. The amount of nitrogen stored in the body depends on NI and the availability of fermentable carbohydrates in the feed (Sarwar *et al*., 2003). Nitrogen retention is the most commonly used indicator to measure the protein status of ruminants. Differences in feed will affect nitrogen metabolism in the body of the animal (Hamchara *et al*., 2018). Previous findings contradict the results of this meta-analysis, where they found that total NI, nitrogen absorption, and nitrogen retention increased as the level of OPF inclusion in dairy goat diets increased, while NE urine and feces remained stable (Baysi *et al*., 2021).

This meta-analysis evaluated goats and sheep collectively as small ruminants. Therefore, differences in the response to OPF consumption may exist between these two species. Such variation may be influenced by species physiological characteristics, feeding behavior, and dietary preferences. Goats are more selective in their forage choices and tend to prefer dicotyledonous plants. Physiologically, goats are better adapted to digest low-fiber feeds and generally consume more feed with greater efficiency than sheep (Krone *et al*., 2024). Goats also spend more time eating, whereas rumination time is higher in sheep than in goats (Khaskheli *et al*., 2020). However, due to the limited number of relevant studies and insufficient interspecies comparisons, subgroup analyses were not feasible in this study. Therefore, the results are presented as overall effects in small ruminants, highlighting the need for further studies to confirm differences in responses between species.

CONCLUSIONS

OPF appears to be a viable alternative feed ingredient for small ruminants, as its inclusion did not significantly affect feed intake, digestibility, animal performance, or nitrogen utilization. Despite its high crude fiber content, small ruminants seem to tolerate OPF reasonably well, with no major negative impacts observed. OPF can be incorporated into small ruminant diets at levels up to 600 g/kg DM. Moreover, fermentation of OPF could be a promising strategy to improve its nutritional value and reduce fiber limitations. However, given the limited number of studies available for some variables, the results should be interpreted cautiously. Further research should focus on optimizing processing methods, evaluating long-term animal health and product quality, and assessing economic feasibility to support practical application in the field.

ACKNOWLEDGMENT

The authors thank the Institute of Research and Community Service of Universitas Syiah Kuala (LPPM USK) for the financial support through the *Penelitian Program Riset Unggulan USK Percepatan Doktor* (PRUU-PD) scheme 2024 (451/UN11.2.1/PG.01.03/SPK/PTNBH/2024).

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