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SYSTEMATIC REVIEW

Palm kernel cake impact on ruminant physiology, feeding behavior, and muscle physicochemical traits: A meta-analysis

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Abstract

Background

The utilization of palm kernel cake (PKC) as a feed ingredient for ruminants has yielded inconsistent findings regarding its effects on animal physiology, feeding behavior, and meat quality. To address these discrepancies, a meta-analysis was conducted by synthesizing data from multiple studies that met specific inclusion criteria.

Methods

The analysis employed a mixed-model approach to evaluate the impact of PKC inclusion on nitrogen utilization, blood metabolites, feeding behavior, and the physicochemical properties of the *Longissimus* muscle in ruminants from 20 relevant articles. These articles originated from Google Scholar, Science Direct, and Springer Link using the keywords “palm kernel cake” and “ruminant.” The analysis was undertaken using the PROC MIXED procedure in SAS® OnDemand for Academics.

Results

The findings indicate that increasing PKC levels had no significant effects on feeding behavior, nitrogen utilization, blood metabolism, or muscle physicochemical traits. However, a quadratic response ($P < 0.05$) was observed for nitrogen excretion, absorbed nitrogen, and

cholesterol levels, suggesting a threshold beyond which PKC inclusion may affect metabolic efficiency. Notably, PKC did not alter meat color, a crucial determinant of consumer preference, implying that its market acceptability remains unchanged.

Conclusion

These results underscore the viability of PKC as a sustainable protein and fiber source in ruminant diets without compromising animal performance or product quality. Further investigations should explore the optimal inclusion levels of PKC to maximize its benefits while mitigating potential metabolic alterations.

Keywords

Meta-Analysis, Palm Kernel Cake, Large Ruminant, Small Ruminant, Feeding Behavior, Blood Metabolism, Nitrogen Utilization, Muscle Physicochemical Traits



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Introduction

Palm kernel cake (PKC) has been extensively recognized as one of the feed ingredients for ruminants. Such utilization is possible owing to the high availability of PKC itself.¹ This feed ingredient sourced from palm kernel oil industry waste has supported the implementation of a zero-waste system. The nutritional composition of PKC will contribute to animal performance, particularly considering that PKC is high in fiber, protein, and fat.²

Many studies on the usage of PKC focus on animal performance,^{3–5} digestibility,^{4,6} and productivity,^{7,8} while rarely addressing the metabolic response, feeding behavior, and physicochemical muscle of ruminants. Each of these variables is mutually interrelated with one another. Feed ingredients with high fiber fraction content such as PKC may affect the feeding behavior of animals. Neutral detergent fiber (NDF) content in feed affects the feeding and rumination time of cattle.⁹ The time required for rumination and mastication activities impacts feed ingestion, digestibility, and animal performance. Generally, when a great amount of feed is ruminated (normally requires 8–9 hours) feed intake tends to increase, which supports optimized animal performance.³ Protein utilization efficiency drops as nitrogen excretion in urine and feces rises. Moreover, blood urea and glucose levels provide signals regarding nitrogen and energy metabolism changes that affect muscle growth and the physicochemical properties of meat.¹⁰

Nevertheless, the outcome of these variable assessments has demonstrated inconsistencies. Some studies report that PKC does not affect feeding time, but increases the rumination time of cattle.⁵ Whereas other studies reported the opposite, PKC increased feeding time by a linear response, yet rumination time remained stable.³ Likewise, the impact on fecal nitrogen excretion in small ruminants remains unclear. One study showed that PKC leads to a decrease in fecal nitrogen excretion,⁷ while other studies have found no notable impact.¹¹ Given these discrepancies, meta-analysis studies are needed to systematically measure trends and resolve these conflicting findings,¹² such as several previous meta-analysis studies.^{13–15}

This meta-analysis intended to evaluate the impact of PKC on blood metabolites, nitrogen utilization, feeding behavior, and muscle physicochemicals in ruminants. The understanding of these responses will provide deep insights into physiological adaptation mechanisms and practical implications for ruminant feeding strategies.

Methods

Literature search

Relevant studies originating from various scientific journals and indexed in electronic databases, including Google Scholar (<https://scholar.google.com/>), Science Direct (<https://www.sciencedirect.com/>), and Springer Link (<https://link.springer.com/>) focusing on the impact of PKC inclusion in ruminant feed on physiology, feeding behavior, nitrogen utilization, and physicochemical properties of muscle.

The search was conducted using the keywords “palm kernel cake” and “ruminant.” Following the search, duplicate articles were identified using the pivot table feature in Microsoft Excel® Sheet 2021 (Microsoft Corp, Redmond, WA, USA; <https://www.microsoft.com>). Out of a total of 1916 articles, 106 were eliminated due to being identified as duplicates. Afterward, an initial screening process was completed based on the title and abstract, resulting in a final set of 132 articles being assessed for eligibility. This step was carried out by examining the entire text. A total of 112 articles were deleted since they measured irrelevant variables, lacked information, were non-animal studies, were not published in English, were inaccessible, and contained more than 500 g/kg of DM of PKC in small ruminants. This eventually left 20 articles with suitable data for the extraction process.^{3,5–7,11,16–30}

This meta-analysis was undertaken following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) selection standards^{31,32} illustrated in **Figure 1**. PRISMA 2020 checklist used to ensure transparency and completeness of reporting in this study.³² The following inclusion criteria were applied: peer-reviewed articles, *in vivo* experiments, articles published in English, no year limitation on publication, and clear information on the level of PKC inclusion. Exclusion criteria were as follows: *in vitro* experiment, book chapters, thesis, and other non-English articles.

Data extraction

The data from the included articles in this meta-analysis were integrated into the database. The data collected were as follows: authors, publication year, basal diet, animal, breed, country of origin, PKC inclusion level, and outcome data. A summary of the articles included and extracted in this meta-analysis is provided in Table S1 in Extended Data. The extracted data related to large ruminants were: (1) feeding behavior; and (2) physicochemical properties of the *Longissimus dorsi* muscle. In small ruminants consisted of: (1) feeding behavior; (2) nitrogen; (N) utilization; (3) weekly weight of suckling kids; (4) blood metabolites; (5) physicochemical of *Longissimus lumborum* muscle. PKC level is expressed as g/kg of dry matter (DM), different units (%) were first converted to similar units. Descriptive statistics of the impact of PKC on large and small ruminants are provided in **Table 1** and **Table 2**, respectively.

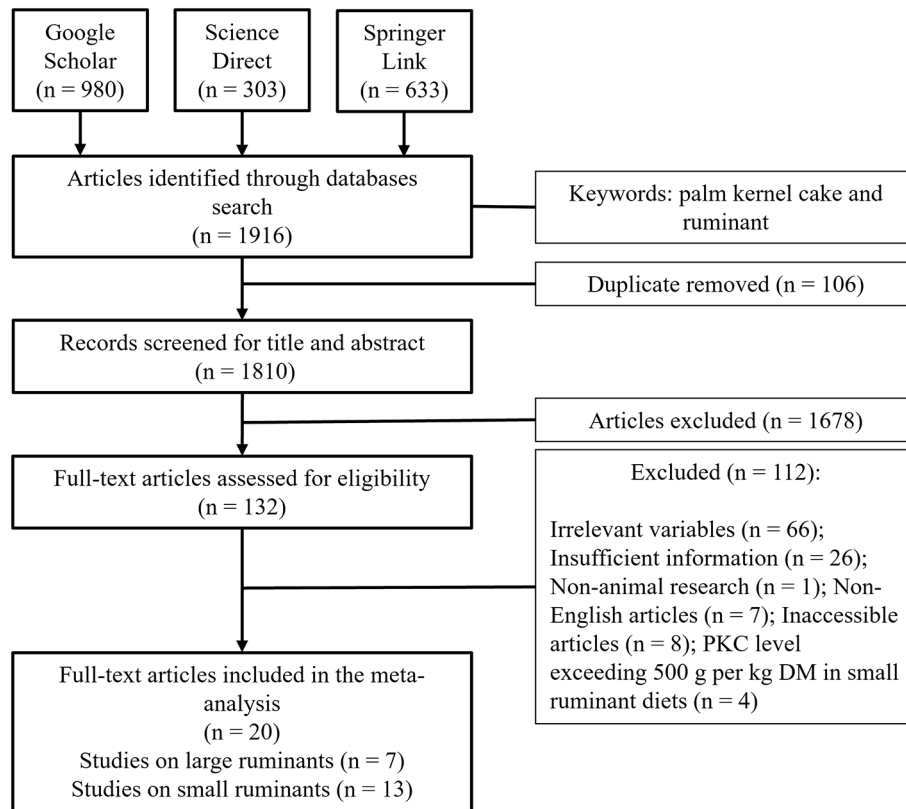


Figure 1. PRISMA flow chart of literature search strategy and study selection for the meta-analysis.

Statistical analysis

Data were processed using the mixed model procedure.³³ The analysis was undertaken using the PROC MIXED procedure in SAS® OnDemand for Academics (https://www.sas.com/en_us/software/on-demand-for-academics.html). Various studies were assumed as random effects, and the level of PKC as fixed effects. The statistical model employed is as follows:

$$Y_{ij} = B_0 + B_1 X_{ij} + s_i + b_i X_{ij} + e_{ij}$$

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.

Model statistics include the Akaike information criterion (AIC), P-value, and root means square error (RMSE). The statistical model was identified using a significance value of $P < 0.05$. Since AIC demonstrates the precision of the model, equations with a lower AIC value are preferred. The average prediction error is measured by RMSE; lower values denote higher model accuracy. The RMSE was calculated using the PROC GLM in SAS OnDemand for Academics.³³

The regression equation is presented in a series of tables that include variables, unit measurement, the number of studies (n), intercept, slope, standard error, P-value, RMSE, AIC, and the model fitted. In addition, the results are also visualized using graphs to illustrate the relationship between the variables and simplify the interpretation of trend patterns presented in the data.

Results

Large ruminant

The feeding behavior variables including rumination time, idle time, total feeding time, and rumination efficiency were not affected by adding PKC to large ruminants' feed. Nevertheless, the total chewing time (TCT) and intake efficiency (kg DM/h) were reduced by quadratic response ($P < 0.05$).

Table 1. Descriptive statistics of the influence of palm kernel cake on large ruminant.

Variables	Unit	n	Mean	SD	Min	Max
Feeding behavior						
Rumination	min/d	20	449.88	45.75	375.00	522.00
Idle	min/d	16	637.76	121.84	503.00	872.00
TFT	min/d	16	329.44	101.62	193.00	477.97
TCT	min/d	12	758.15	115.38	568.00	874.69
IE	kg DM/h	12	0.89	0.48	0.25	1.30
IE	kg NDF/h	12	0.38	0.24	0.15	0.74
RE	kg DM/h	12	0.66	0.36	0.28	1.13
RE	kg NDF/h	12	0.31	0.22	0.13	0.63
Physicochemical composition of <i>Longissimus dorsi</i> muscle						
pH		8	5.65	0.08	5.60	5.78
Cooking loss	%	8	33.14	1.45	30.96	35.60
WHC	%	8	69.65	1.01	68.60	71.90
Lightness (L*)		8	36.87	1.67	35.44	39.32
Redness (a*)		8	17.05	2.78	12.26	19.70
Yellowness (b*)		8	4.66	1.84	2.86	6.50
Moisture	%	12	71.53	1.52	68.82	73.73
Ash	%	12	1.16	0.22	0.82	1.48
Protein	%	12	20.50	2.75	16.55	23.30
Total lipids	%	12	5.39	2.01	3.33	8.84
Cholesterol	mg/100 g	8	35.55	5.09	28.14	41.11

n, number of studies; SD, standard deviation; Min, minimum; Max, maximum; DM, dry matter; NDF, neutral detergent fiber; TFT, total feeding time; TCT, total chewing time; IE, intake efficiency; RE, rumination efficiency; WHC, water-holding capacity.

Table 2. Descriptive statistics of the influence of palm kernel cake on small ruminant.

Variables	Unit	n	Mean	SD	Min	Max
Feeding Behavior						
Rumination	min/d	16	363.41	30.43	303.70	402.00
Idle	min/d	16	848.43	75.68	744.00	984.00
TFT	min/d	16	229.91	56.28	144.00	322.00
IE	kg DM/h	16	285.63	83.60	148.40	476.30
IE	kg NDF/h	16	96.35	33.66	46.70	160.30
RE	kg DM/h	16	147.24	62.16	77.90	290.50
RE	kg NDF/h	16	50.84	26.66	23.80	97.20
Blood metabolites						
Glucose	mg/dL	17	54.09	16.37	18.30	65.87
PCV	%	17	30.42	4.87	25.00	43.33
BUN	mg/dL	21	29.66	15.77	14.72	64.20
Triglycerides	mg/dL	9	18.86	8.54	6.20	28.10
Cholesterol	mg/dL	9	53.80	36.78	18.18	109.90
Albumin	g/dL	17	2.06	0.49	1.40	2.70
Total protein	g/dL	17	5.98	1.27	3.73	8.00

Table 2. *Continued*

Variables	Unit	n	Mean	SD	Min	Max
Globulin	g/dL	17	4.01	1.21	2.40	6.70
Albumin:globulin		12	0.48	0.11	0.30	0.60
Nitrogen utilization						
Total N Intake	g/d	19	20.37	10.48	12.90	50.60
NE fecal N	g/d	19	5.75	1.93	3.63	10.50
NE urinary N	g/d	19	7.19	6.62	1.43	21.10
NE absorbed N	g/d	11	16.76	11.20	8.13	40.10
NE retained N	g/d	19	6.60	4.32	-4.02	18.80
NO absorbed N	% N Intake	7	68.62	5.70	58.72	74.76
NO retained N	% N Intake	7	54.88	5.76	45.12	63.83
Physicochemical composition of <i>Longissimus lumborum</i> muscle						
pH _{45 min}		8	6.96	0.21	6.70	7.20
pH _{24 h}		8	5.83	0.17	5.60	6.00
Lightness (L*)		8	40.18	1.34	38.10	42.20
Redness (a*)		8	21.86	1.57	19.90	24.00
Yellowness (b*)		8	7.28	0.45	6.60	7.80
Moisture	%	8	73.50	2.41	70.60	75.80
Ash	%	8	1.04	0.05	1.00	1.10
Protein	%	8	18.89	0.64	17.70	19.70
Total lipids	%	8	2.89	0.95	2.00	4.50
Weekly weight of suckling kids						
W1	kg	8	1.07	0.65	0.60	1.93
W2	kg	8	1.65	0.70	0.80	2.51
W3	kg	8	2.51	0.90	1.20	4.00
W4	kg	8	2.74	0.70	1.90	3.71
W5	kg	8	3.35	0.80	2.40	4.41
W6	kg	8	3.66	0.89	2.70	4.81
W7	kg	8	4.01	1.02	3.00	5.32
W8	kg	8	4.33	1.09	3.20	5.80
W9	kg	8	4.72	1.21	3.60	6.40
W10	kg	8	4.98	1.43	3.80	7.00
W11	kg	8	5.32	1.60	3.70	7.70
W12	kg	8	5.66	1.70	4.20	8.40
W13	kg	8	5.99	1.89	4.40	9.20
W14	kg	8	6.31	1.94	4.67	9.50
W15	kg	8	6.51	2.04	4.67	9.70
W16	kg	8	6.88	2.42	4.70	11.10
Mean	kg	8	4.34	1.28	3.12	6.23

n, number of studies; SD, standard deviation; Min, minimum; Max, maximum; DM, dry matter; NDF, neutral detergent fiber; TFT, total feeding time; IE, intake efficiency; RE, rumination efficiency; PCV, packed cell volume; BUN, blood urea nitrogen; N, nitrogen; NE, nitrogen excretion; NO, nitrogen output; W, week.

The physicochemical composition of the *Longissimus dorsi* muscle (pH value, cooking loss, water holding capacity, the color items, the chemical components) was not significantly influenced by the varying level of PKC inclusion in large ruminants' feed. The effect of the PKC inclusion on the feeding behavior and the physicochemical composition of the *Longissimus dorsi* muscle of large ruminants is shown in [Table 3](#).

Table 3. Regression equations of palm kernel cake on feeding behavior and physicochemical composition of muscle of large ruminant.

Variables	Unit	n	Parameter estimates				Model estimates			M
			Int	SE Int	Slope	SE slope	p-value	RMSE	AIC	
Feeding behavior										
Rumination	min/d	20	440.25	21.30	0.3627	0.1953	0.086	62.96	201.6	L
Idle	min/d	16	652.66	68.12	-0.2489	0.1916	0.223	41.47	163.4	L
TFT	min/d	16	312.28	61.84	0.0394	0.2525	0.879	66.02	171.9	L
TCT	min/d	12	723.54	79.79	-0.00125	0.000446	0.026	34.31	115.4	Q
					0.5822	0.1036	0.001			
IE	kg DM/h	12	0.91	0.35	-0.00001	0.000002	0.001	0.17	10.8	Q
					0.001023	0.000356	0.024			
IE	kg NDF/h	12	0.35	0.18	-0.000003	0.000001	0.032	0.07	2.9	Q
					0.000809	0.000247	0.014			
RE	kg DM/h	12	0.69	0.26	0.000212	0.000485	0.675	0.12	13.8	L
RE	kg NDF/h	12	0.31	0.16	0.000236	0.000246	0.369	0.05	2.4	L
Physicochemical composition of <i>Longissimus dorsi</i> muscle										
pH		8	5.60	0.06	0.000474	0.000765	0.569	0.14	23.3	L
Cooking loss	%	8	33.24	1.09	0.008962	0.02152	0.699	4.20	55.2	L
WHC	%	8	70.61	0.64	-0.02423	0.01014	0.075	2.80	48.6	L
Lightness (L*)		8	35.69	1.35	0.02215	0.01782	0.282	3.70	54.8	L
Redness (a*)		8	17.01	2.31	0.02058	0.0128	0.183	3.51	53.5	L
Yellowness (b*)		8	4.51	1.70	0.004052	0.002243	0.145	0.54	39.0	L
Moisture	%	12	71.54	1.03	0.004576	0.009247	0.636	2.19	63.8	L
Ash	%	12	1.14	0.15	0.000492	0.000582	0.425	0.14	17.8	L
Protein	%	12	20.35	1.70	0.000896	0.006415	0.893	1.46	61.3	L
Total lipids	%	12	5.02	1.35	0.01292	0.01	0.237	2.52	66.0	L
Cholesterol	mg/100 g	8	34.21	4.23	0.02832	0.03652	0.481	6.92	62.5	L

n, number of studies; Int, intercept; SE, standard error; RMSE, root mean square error; AIC, Akaike information criterion; M, model; L, linear; Q, quadratic; TFT, total feeding time; TCT, total chewing time; IE, intake efficiency; RE, rumination efficiency; WHC, water-holding capacity.

Small ruminant

The feeding behavior variables including rumination time, idle time, total feeding time, intake efficiency, and rumination efficiency were not affected by adding PKC to small ruminants' feed (Table 4). The PKC inclusion in small ruminants' feed insignificantly affected N utilization (total N intake; NE fecal N, NE-urinary N, NE-retained N, N Output (NO) absorbed, NO-retained). However, PKC inclusion had a significant quadratic effect on NE-absorbed N ($P < 0.05$) (Table 5).

From the first week to the sixteenth week, a significant quadratic response ($P < 0.05$) of the weekly weight of suckling kids was observed only in the first (W1), second (W2), fourth (W4), fifth (W5), seventh (W7), and eighth weeks (W8), while the others did not show a significant response due to the PKC inclusion in the diet of goat dams (Table 5).

Small ruminants consuming PKC did not significantly influence the blood metabolites such as glucose, packed cell volume (PCV), blood urea nitrogen (BUN), triglycerides, albumin, total protein, globulin, and albumin: globulin ratio, except cholesterol that affect by quadratic response ($P < 0.05$) (Table 4). The physicochemical composition of the *Longissimus lumborum* muscle i.e. pH value, lightness, redness, moisture, ash, protein, and total lipids was insignificantly altered by the PKC inclusion in small ruminants' feed, except yellowness that linearly reduced ($P < 0.05$) (Table 5).

Table 4. Regression equations of palm kernel cake on feeding behavior, blood metabolites, nitrogen utilization, and physicochemical composition of muscle of small ruminant.

Variables	Unit	n	Parameter estimates				Model estimates			M
			Int	SE Int	Slope	SE slope	p-value	RMSE	AIC	
Feeding behavior										
Rumination	min/d	16	351.00	15.05	0.1127	0.2134	0.609	86.31	168.7	L
Idle	min/d	16	873.79	41.85	-0.1793	0.3499	0.620	138.59	187.7	L
TFT	min/d	16	212.37	32.23	0.1327	0.172	0.458	67.89	172.2	L
IE	kg DM/h	16	358.66	29.15	-0.7001	0.3189	0.053	129.57	182.7	L
IE	kg NDF/h	16	103.21	17.52	-0.06423	0.0787	0.433	31.20	153.1	L
RE	kg DM/h	16	167.80	30.14	-0.09094	0.1727	0.610	68.99	172.1	L
RE	kg NDF/h	16	50.82	13.84	0.02057	0.03652	0.586	14.89	136.8	L
Blood metabolites										
Glucose	mg/dL	17	58.92	8.51	-0.04099	0.0323	0.231	8.47	131.7	L
Packed cell volume	%	17	27.93	3.14	0.03594	0.03314	0.301	10.10	124.5	L
Blood urea nitrogen	mg/dL	21	32.44	7.52	-0.03137	0.018	0.103	5.52	147.6	L
Triglycerides	mg/dL	9	14.86	6.45	0.07061	0.05017	0.218	14.43	79	L
Cholesterol	mg/dL	9	61.90	30.26	0.000591	0.00022	0.043	30.72	86.7	Q
					-0.1689	0.07787	0.082			
Albumin	g/dL	17	2.41	0.24	-0.00354	0.001998	0.104	0.75	54.8	L
Total protein	g/dL	17	6.23	0.63	-0.00421	0.003528	0.257	1.37	73.6	L
Globulin	g/dL	17	3.83	0.60	0.000316	0.003986	0.938	1.48	75.5	L
Albumin:globulin		12	0.53	0.08	-0.00042	0.0004	0.332	0.13	19.2	L
Nitrogen (N) utilization										
Total N Intake	g/d	19	25.77	4.06	-0.04018	0.03103	0.220	11.46	147	L
NE fecal N	g/d	19	7.41	0.80	-0.01429	0.008438	0.116	3.21	100.1	L
NE urinary N	g/d	19	6.67	2.69	0.009247	0.007441	0.238	2.99	111.3	L
NE absorbed N	g/d	11	32.18	5.24	0.000243	0.000081	0.024	10.35	86.5	Q
					-0.1402	0.03516	0.007			
NE retained N	g/d	19	9.11	1.90	-0.0205	0.02238	0.378	8.72	128.6	L
NO absorbed N	% N intake	7	57.56	11.19	0.1527	0.09728	0.215	9.77	58.9	L
NO retained N	% N intake	7	43.04	13.66	0.1482	0.1162	0.292	10.37	60.6	L
Physicochemical composition of <i>Longissimus lumborum</i> muscle										
pH _{45 min}		8	7.05	0.19	-0.00123	0.000546	0.087	0.20	29.5	L
pH _{24 h}		8	5.86	0.15	-0.00017	0.000484	0.748	0.133	28.1	L
Lightness (L*)		8	40.18	0.88	-0.01312	0.007032	0.135	3.09	52.7	L
Redness (a*)		8	22.28	1.40	-0.00744	0.007656	0.386	2.30	54.5	L
Yellowness (b*)		8	7.45	0.15	-0.00775	0.002378	0.031	1.41	37.2	L
Moisture	%	8	73.30	2.24	0.003083	0.004438	0.525	1.27	51.2	L

Table 4. *Continued*

Variables	Unit	n	Parameter estimates				Model estimates			M
			Int	SE Int	Slope	SE slope	p-value	RMSE	AIC	
Ash	%	8	1.06	0.03	0.000104	0.000461	0.832	0.13	22.7	L
Protein	%	8	18.56	0.54	0.005479	0.00356	0.199	1.18	46.4	L
Total lipids	%	8	3.41	0.79	-0.00848	0.005952	0.227	1.93	51.2	L

n, number of studies; Int, intercept; SE, standard error; RMSE, root mean square error; AIC, Akaike information criterion; M, model; L, linear; Q, quadratic; TFT, total feeding time; IE, intake efficiency; RE, rumination efficiency; NE, nitrogen excretion; NO, nitrogen output.

Table 5. Regression equations of palm kernel cake on the weekly weight of suckling kids of small ruminant.

Variables	Unit	n	Parameter estimates				Model estimates			M
			Int	SE Int	Slope	SE slope	p-value	RMSE	AIC	
W1	kg	8	1.23	0.63	-0.00000002	0	<.0001	0.07	29.8	Q
					0.00001	0.000397	0.981			
W2	kg	8	1.82	0.59	-0.000007	0.000002	0.023	0.28	34.8	Q
					0.001667	0.000755	0.092			
W3	kg	8	2.58	0.47	0.009879	0.008586	0.314	1.45	1.8E308	L
W4	kg	8	2.70	0.60	-0.00001	0.000003	0.020	0.50	39.3	Q
					0.004499	0.001316	0.027			
W5	kg	8	3.28	0.66	-0.00002	0.000004	0.012	0.63	40.2	Q
					0.005811	0.001445	0.016			
W6	kg	8	3.79	0.80	0.002577	0.001678	0.199	0.41	41.8	L
W7	kg	8	4.17	0.94	-0.000007	0.000001	0.005	0.27	32.7	Q
					0.002366	0.000519	0.010			
W8	kg	8	4.44	0.97	-0.00001	0.000003	0.021	0.48	40	Q
					0.004015	0.001282	0.035			
W9	kg	8	4.79	1.10	0.004861	0.002403	0.113	0.64	45.3	L
W10	kg	8	4.92	1.33	0.00696	0.002864	0.072	0.78	47.1	L
W11	kg	8	5.39	1.51	0.005173	0.004582	0.322	0.92	51.1	L
W12	kg	8	5.75	1.57	0.006135	0.004469	0.242	0.98	51	L
W13	kg	8	5.98	1.71	0.008737	0.005685	0.199	1.29	53	L
W14	kg	8	6.30	1.76	0.009039	0.005166	0.155	1.24	52.3	L
W15	kg	8	6.47	1.81	0.01082	0.005042	0.099	1.37	52.2	L
W16	kg	8	6.84	2.12	0.01293	0.007638	0.166	1.85	55.8	L
Mean	kg	8	4.39	1.15	0.005506	0.002095	0.058	0.65	44.3	L

n, number of studies; Int, intercept; SE, standard error; RMSE, root mean square error; AIC, Akaike information criterion; M, model; L, linear; Q, quadratic; W, week.

Discussion

Large ruminant

Although PKC contains high NDF, acid detergent fiber (ADF), and fat, the rumination process is not impaired. High lignin and fat content in the diet can prevent the degradation process of DM in the rumen which leads to increased rumination as the disappearance occurs.⁵ Whereas Lisboa et al.³ found that TCT was not affected by the inclusion of PKC in the diet, this meta-analysis suggested that TCT would decrease at certain levels of PKC inclusion. A diet containing a high NDF content tends to be consumed rapidly as the particles are resistant to mechanical breakdown. This consequently increases rumination activity to minimize the particle size of the diet.³⁴

Increasing the feeding time provides more time for the cattle to chew to reduce the feed particles, improving digestibility.³⁵ The current study indicates that feeding time is constant, however, chewing time is reduced. This is probably attributed to the small particle size of PKC, making it easier to masticate and minimize feed particles.

This meta-analysis suggests that feed containing PKC does not alter the ultimate pH and color parameters of meat. The propionic acid contributes to liver and muscle glycogen deposition, which ultimately affects the pH of the meat. A reduction in dietary energy sources for ruminants causes a decrease in propionic acid production in the rumen. Substituting PKC with grain sorghum led to an improvement in pH due to a decrease in propionic acid production leading to fewer glycogen deposits. This increase was not high enough to affect cooking loss and water holding capacity which remained stable. Water retention in myofibrils was unchanged, resulting in stable lightness.²⁶ Water retention is one of the factors that influence the lightness of meat.³⁶

Along with pH, age and physiological condition of the animals also affect meat color parameters.³⁷ Color is one of the consumer considerations in meat purchases. PKC has no impact on color, hence the demand does not decrease as compared to meat from non-PKC-treated animals.²⁸

Although insignificant, there was an upward trend in all three-color parameters (Figure 2). Diets contribute to this aspect, such as forages that contain carotenoids that can produce a yellow color in beef fat.³⁸ Thus, this meta-analysis indicates that PKC has a limited contribution to the accumulation of dietary carotenoids, due to its low concentration of 2.24–3.46 ppm,³⁹ resulting in no change in meat color parameter values. Besides, the intensity of yellowness is also affected by the concentration of intramuscular fat.⁴⁰ Beef has higher intramuscular fat than goat meat and lamb.⁴¹ Physical activity also affects meat color, extensively farmed animals produce darker meat color than intensively farmed ones.⁴²

Furthermore, this meta-analysis found that the proximate components of meat were not altered due to the feeding of PKC. Meat moisture is inversely linked to fat content. The higher the fat the lower the water content, due to fat deposition. When fat is low, water content increases, however, it is susceptible to moisture loss due to a lack of fat protection.²⁸ The level of DM intake contributes to this as it influences the energy intake required for fat deposition. PKC is unable to fulfill the energy needs for this matter.²⁸

The dietary fat content of PKC did not alter the muscle cholesterol content of steers, as the cholesterol endogenous synthesis is mostly predisposed by acetyl.²⁶ In contrast, heifers show an elevated muscle fat content.⁵ Other than sex differences, a likely explanation includes differences in the level of PKC inclusion in the diet. Lisboa et al.²⁶ experimented by adding PKC up to 90 g/kg of DM, while Soares et al.⁵ applied much higher, 240 g/kg of DM. Lauric acid in PKC promotes propionic acid synthesis in the rumen, a precursor of intramuscular fat synthesis in ruminants.^{43,44}

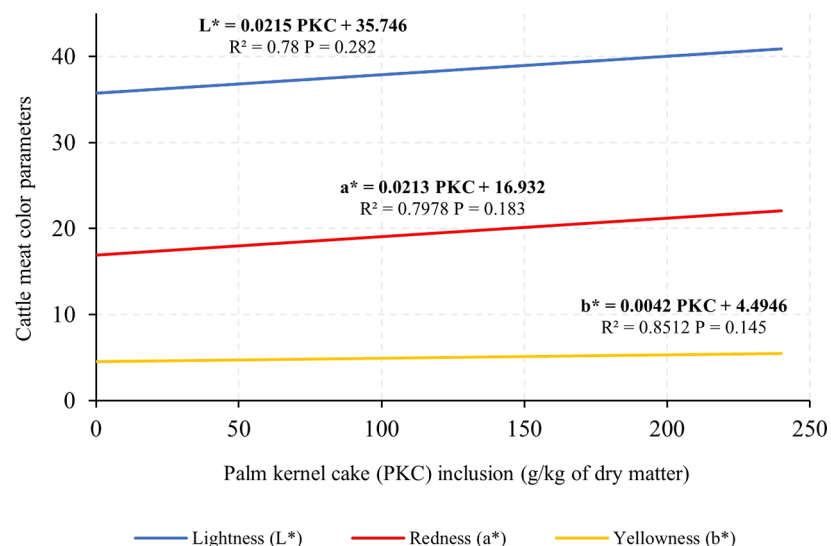


Figure 2. Impact of palm kernel cake (PKC) inclusion on cattle meat color parameters.

Small ruminant

In goats, which are more selective, they tend to avoid feed containing PKC and spend time sorting instead of consuming it straight away. This causes long idle and feeding times, suggesting PKC is poorly accepted by the animals.^{7,11,19} Ruminant feeding time depends on the fiber fraction of the diet. The high fiber fraction will increase retention time; thus, the rumination process will take longer time. In this study, the same pattern was observed: feeding, idling, and rumination times were all unchanged, resulting in unchanged nutrient intake. In the end, it also affects the characteristics of rumen fermentation. Therefore, the intake of small ruminants is reflected in their feeding behavior.⁴⁵ Goats and sheep have different chewing behaviors yet are identical when it comes to the process of breaking down feed particles. The duration of feed destruction, rumination, and bolus formation differed between species and was significantly higher in sheep compared to goats. The number of rumination chews per day in goats was 20% lower than in sheep.⁴⁶

It is known that the efficiency of N utilization in ruminants is considered relatively poor. The lack of efficiency implies the performance of the animals and the environment.⁴⁷ The inclusion of PKC did not change the efficiency of N utilization of small ruminants. Despite its high protein content, PKC neither contributed to increasing nor even decreasing the overall protein quality of the feed. PKC inclusion affected NE absorption quadratically, where an increase at moderate levels was followed by a decrease at high levels, in line with the NE pattern reported by Rodrigues et al.¹¹ Nitrogen absorption efficiency at moderate levels is likely supported by the balance of energy and protein, while at high levels the imbalance decreases efficiency.⁴⁸

Fecal nitrogen excretion is not only due to high indigestible nitrogen in the diet but also because the total nutrient intake is decreased. When PKC was included in the diet, although it increased the indigestible neutral detergent fiber (iNDF) content, it did not affect the overall nutrient intake, leaving nitrogen consumption unchanged. This ultimately explains the unchanged amount of nitrogen excreted in the feces, even though the percentage of undigested nitrogen in the diet increased.⁷ In addition, the recycling of nitrogen through the rumen or saliva may contribute to keeping nitrogen efficiency in other variables unaffected.⁴⁹ Therefore, since adding PKC to the diet does not change various measurements of N utilization variables, PKC provides a sufficiently stable protein source without increasing N excretion and decreasing N absorption in small ruminants.

The nutrient intake by the lactating goats affects the suckling kid's body weight since the quality and quantity of milk produced depends on the nutrients obtained by the dam. A nutrient-rich diet, containing energy and protein, supports better milk production, which in turn sustains the growth of goat kids.⁵⁰ However, milk production does oftentimes increase in the second and third weeks after labor, the dam reaches maximum milk production and drops sharply in the eighth to tenth week. This indicates that the optimal growth of goat kids cannot depend solely on milk.⁵¹ Additionally, maternal traits will also affect the growth of young goats. Maternal weight and milk production are considered important maternal attributes that influence suckling kid's growth.⁵²

In addition, the diet will affect animal and human health as consumers. Changes in blood cholesterol levels may be related to the fat component of PKC, which can affect lipid metabolism in the body. An increase or decrease in cholesterol can occur in response to the fat composition of the diet. Although the measured cholesterol value is below normal limits (53.80 mg/dL), it is close to normal values. Ideal serum cholesterol in healthy adult goats ranges from 64.5 to 93.11 mg/dL.⁵³ This suggests that despite the influence of PKC, fat metabolism remains within safe conditions for goat health, without causing significant negative effects on their metabolic status. Giving PKC had no significant effect on glucose, albumin, and total blood protein in small ruminants. The stability of these variables indicates that liver function and metabolism remain normal, thus indicating no copper toxicity.⁵⁴ This is likely due to adaptation mechanisms or the level of copper within the feed still being in the safe tolerance range for small ruminants.

PCV is an important indicator of animal health, indicating the presence or absence of blood disorders. When the PCV percentage is below the normal limit, it signifies the animal is having anemia. Conversely, animals experience symptoms of polycythemia, abnormal red blood cell synthesis, when PCV exceeds the threshold. The ideal range of PCV percentage is 22–38%.⁵⁵ This meta-analysis discovered that PKC in small ruminant feeds remained unchanged with the average value still within the healthy range of 30.42%.

Glucose levels reflect the energy status of goats. Glucose has a major role in the production and reproductive performance of animals.²⁴ Animals that consume high-energy feed tend to increase blood glucose concentration. Conversely, blood glucose concentration decreases if the animal suffers from starvation or ingests low-energy feed.⁵⁶ Our study showed that the addition of PKC in the diet of small ruminants made no difference in blood glucose concentration. The average blood glucose level of 54.09 mg/dL in this meta-analysis was still within the normal range of 50–75 mg/dL.⁵⁷ This means that the consumption of PKC maintains the normal energy status of livestock. In line with the findings by Chanjula et al.,²⁴ the inclusion of PKC did not negatively affect the energy status of goats.

Furthermore, regarding the meat quality of small ruminants fed PKC, the results were similar to large ruminants. The pH value is the most important indicator in assessing meat quality, as it can affect texture, color, and storability.⁵⁸ In line with this meta-analysis, the ultimate pH and chemical composition of the *longissimus lumborum* muscle did not change with the inclusion of PKC up to 360 g/kg of DM. However, protein content increased with greater levels of PKC inclusion, whereas yellowness and lightness underwent significant quadratic changes.¹⁶

The color is the first sensory attribute that most consumers use in their preference for meat.⁵⁹ It depends on species, age, animal physiology, diet, physical activity, carcass weight, intramuscular fat, and ultimate pH.^{40–42,60} Significant changes that are less favorable to consumers will impact meat demand and sales. However, this meta-analysis concluded that PKC does not have a noticeable impact on meat color, except for yellowness (Figure 3).

Carotenoids; β -carotene and lutein are the most common carotenoids in plants, chemical compounds that have distinctive colors of yellow and orange, altering the yellowness parameter of meat.³⁸ PKC contains lower carotenoids than forage, thus contributing no effect in increasing yellowish color. PKC contains merely 2.24–3.46 ppm of carotenoids³⁹ while forages such as *Digitaria decumbens* and *Cynodon dactylon* in the humid tropics contain 149 ppm of β -carotene and 185 ppm of lutein.⁶¹ As PKC in the diet rises, the yellowness of goat meat decreases significantly, as carotenoid accumulation presumably drops. Goat meat from goats fed alfalfa hay contained higher yellowness than those fed hay and concentrated alfalfa meal and yellow corn.⁶⁰

Moreover, goat meat also has lower intramuscular fat than beef and lamb.⁴¹ This caused goat meat to darken due to low lightness.^{40,41} The fat color is lighter than the muscle, making the fat content able to raise the lightness value of the meat.⁴² Likewise, the high pH in goat meat also causes the meat color to be darker.⁴¹

An increase in redness value implies an increase in oxymyoglobin, which produces a vibrant red color and prevents further oxidation to metmyoglobin, which inhibits the color from browning. The meat appears fresher in this condition.⁶² Nevertheless, the lightness, redness, and yellowness values in the present meta-analysis are close to the average values reported in previous studies, ~34–44.5 for lightness; ~7.8–23.2 for redness; and ~7.3–10.4 for yellowness.^{16,40,62–64}

Proximate composition measurements are also important for assessing the nutritional quality of meat, as they are also related to the nutritional value of feed. However, PKC does not directly contribute to changes in the nutritional composition of meat,¹⁷ resulting in stable meat-proximate components. Also, the water content will be higher in muscles with a larger structure, yet they will undergo higher cooking losses,¹⁶ ultimately affecting lightness. However, no change in lightness was still found due to the addition of PKC.

The limited number of studies reporting the effect of PKC on meat color parameters limits the scope of this meta-analysis compared to other variables. However, the meta-analysis approach still provides a comprehensive preliminary picture.

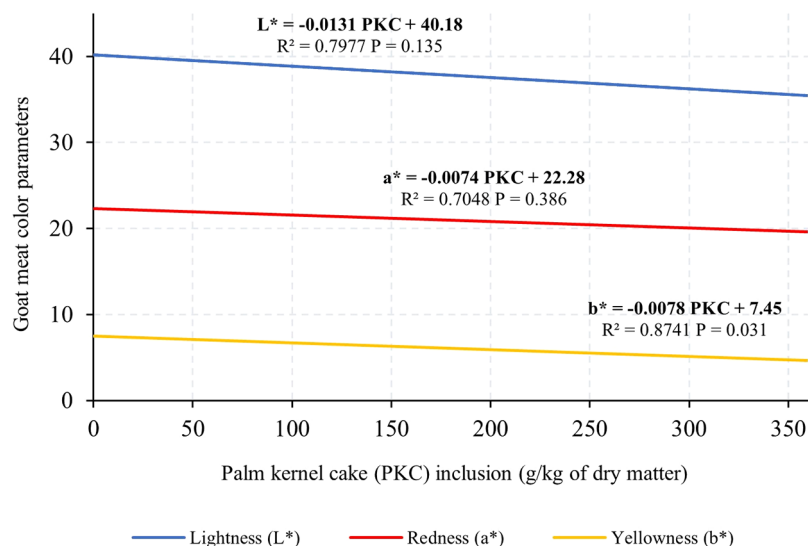


Figure 3. Impact of palm kernel cake (PKC) inclusion on goat meat color parameters.

Further studies with broader data coverage, especially related to meat color parameters, will further strengthen the understanding of the effect of PKC on ruminant meat color.

Conclusion

This meta-analysis suggests that PKC may be incorporated as a sustainable source of fiber and protein in ruminant diets without interfering with the metabolic process and animal productivity. Regarding consumer preferences and health, the meat color remains unchanged, indicating unchanged acceptance by consumers. However, a more detailed investigation of consumer demand for meat from animals consuming PKC should be conducted. Moreover, blood cholesterol levels did not exceed the acceptable threshold that could adversely affect consumer health. The ideal PKC inclusion levels should be investigated further to optimize its advantages while mitigating potential metabolic alterations.

Ethics and consent

Ethical approval and consent were not required.

Software availability

Microsoft Excel® 2021 (Microsoft Corporation, Redmond, WA, USA; <https://www.microsoft.com>) was used to identify duplicate articles. As an alternative, Google Sheets (Google LLC; <https://docs.google.com/spreadsheets/>) can perform similar functions.

Data availability

Underlying data

No data are associated with this article.

Extended data

Figshare: Extended data for “Palm kernel cake impact on ruminant physiology, feeding behavior, and muscle physico-chemical traits: A meta-analysis.” <https://doi.org/10.6084/m9.figshare.28636160.v2>⁶⁵

Data are available under the terms of the [Creative Commons Attribution 4.0 International license](#) (CC BY 4.0).

Reporting guidelines

Figshare: PRISMA checklist for “Palm kernel cake impact on ruminant physiology, feeding behavior, and muscle physicochemical traits: A meta-analysis.” <https://doi.org/10.6084/m9.figshare.28636409.v1>⁶⁶

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