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The Improvement of Broiler Performance with Modification of Particle Size and Palm Kernel Meal Levels

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ABSTRACT

Palm kernel meal (PKM) is a by-product of palm oil production and can be used as an energy source in broiler feed. However, the utilization of PKM in broiler feed has yet to be optimal due to its low nutrient digestibility. This study aims to evaluate the particle size and the levels of PKM in the feed to increase broiler performance. The particle sizes used in this study were 2.5 and 1 mm, and the levels were 5%, 10%, and 15%. An *in vivo* study was conducted using 1,440 Ross 308 broilers day 0-35, with an average initial weight of 47 grams. The study employed a completely randomized factorial design of 2x3, divided into 6 treatments consisting of (T1) 2.5 mm at 5% PKM as a control, (T2) 1 mm at 5% PKM, (T3) 2.5 mm at 10% PKM, (T4) 1 mm at 10% PKM, (T5) 2.5 mm at 15% PKM, and (T6) 1 mm at 15% PKM on feed. The studied variables were body weight (BW), feed intake (FI), feed conversion ratio (FCR), European production efficiency factor (EPEF), and carcass quality. Increasing PKM levels decreased the pellet durability index of broiler feed. During the starter stage (days 0-21), 1 mm PKM significantly improved FCR ($p<0.05$) compared to 2.5 mm, although PKM levels did not significantly affect broiler performances. In the finisher stage (days 22-35), 15% of PKM levels negatively impacted FCR and EPEF. Overall, from 0-35 days of age, the best broiler performances showed by treatment T2 with 1 mm particle size and 5% PKM.

Keywords: carcass quality; particle size; PKM; productive traits

INTRODUCTION

Currently, there is a tendency to use alternative sources of protein and energy to replace soybean meal and yellow corn in the diets of monogastric animals. Some developing countries produce agro-waste by-products, which could be favorable alternative feedstuffs (Alshelmani *et al.,* 2021). However, these by-products may contain non-starch polysaccharides (NSPs) such as xylans and mannans, as well as anti-nutritional factors, which have the potential to depress the growth of birds (Alshelmani *et al.,* 2017; Aftab & Bedford, 2018).

As the world's largest palm oil producer, Indonesia generates a by-product with a high nutritional value known as palm kernel meal (PKM). This by-product presents a promising alternative for sourcing inexpensive, abundant, high-quality feed ingredients. The advantage of PKM provides approximately 14%–18% of crude protein (CP) with a percentage ratio of essential to total amino acids of 36%, 12%–20% crude fiber (CF), 3%–9% ether extract (EE), and different amounts of various minerals that feasible to be used as a partial substitute of soybean meal (SBM) and corn in poultry nutrition (Azizi *et al.,* 2021; Safi *et al.,* 2022). Additionally, PKM is free from aflatoxins, is palatable by poultry, and has high potential as an energy source. The utilization of PKM in broiler feed is expected to be an alternative substitute when corn prices are high. The apparent metabolizable energy (AME) and nitrogen-corrected AME of PKM were determined to be 5.47 and 5.23 MJ/kg, respectively (Abdollahi *et al.,* 2015)

The limiting factor of PKM utilization is its low nutrient digestibility. Several factors affecting the nutrient digestibility of a feed ingredient include particle size, type of feed ingredient, and the content of fiber or anti-nutritional compounds present (Ravindran *et al.,* 2005). The recommendation is to grind raw materials to a particle size between 0.75 and 1.5 mm for optimal pelleting results and broiler performance. Finer grinding may improve pellet quality but can increase production costs and lead to higher fines if not managed properly (Novotny *et al.,* 2023).

Previous studies have been carried out to determine the right corn particle size for broilers (Chewnig *et al.,* 2012; Downs *et al.,* 2023), but until now, there has been no research regarding the particle size of PKM. Another issue to consider is that increasing the percentage of PKM in poultry feed can reduce the durability and strength of feed pellets, necessitating careful calculation of PKM levels in broiler feed formulations. *In vivo* testing is necessary to determine the maximum percentage of PKM in poultry feed formulations without compromising pellet durability. Previous studies have indicated that using up to 7.5% PKM in broiler feed does not adversely affect growth or intestinal health, and even at a 15% level, it does not alter intestinal morphology or litter quality (Yaophakdee *et al.,* 2018). The use of PKM in broiler feed can also increase the percentage of broiler carcasses compared to those without PKM (Hidayat, 2022). Increasing the percentage of PKM in poultry feed can reduce the durability and strength of feed pellets (Abdollahi *et al.,* 2016).

Considering the importance of PKM particle size of raw materials in broiler feed production and determining the optimum level of PKM use in broiler feed. The particle size of feed ingredients is also a critical issue in nutrient absorption. Nutrient absorption involves breaking feed particles into smaller sizes and increasing their solubility chemically and mechanically (Blair, 2008). Reducing feed ingredients into finer particles can also enhance the physical quality of pellets and increase feed digestibility (Yasothai, 2018). Particle size is reduced using a hammer mill, which repeatedly breaks down the particles, increasing their number and expanding the surface area per unit volume, making them more accessible to digestive enzymes (Goodband *et al.,* 2002). This research aims to determine the effect of different particle sizes and varying levels of PKM on broiler performance and carcass quality.

MATERIALS AND METHODS

Ethical Approval

All experimental procedures were approved by the Animal Ethics Committee of IPB University according to the Guidelines for the Care and Use of Animals (Number: 044/KEH/SKE/X/2022).

Animal and Diets

A total number of 1,440 day-old Ross 308 chicks were obtained from a commercial hatchery with an average initial weight of 47 grams. Upon arrival, birds were group weighed and assigned to their respective treatments in 48-floor pens. Each treatment was replicated 8 times with 30 birds per replicate. The feeding study consisted of 6 dietary treatments designed as a 2 × 3 factorial arrangement, which included 2 types of PKM particle size (2.5 and 1 mm) and 3 levels of PKM in feed formulation (5%, 10%, and 15%) for the study. The treatments carried out were T1 PKM size 2.5 mm with a level of 5%, T2 PKM size 1 mm with a level of 5%, T3 PKM size 2.5 mm with a level of 10%, T4 PKM size 1 mm with a level of 10%, T5 PKM size 2.5 mm with a level of 15%, and T6 PKM size 1 mm with a level of 15%.

This study utilized local PKM mixed until homogeneous and divided into two parts. These parts were ground to two different sieve diameters of 2.5 and 1 mm. Samples from each treatment were collected for proximate analysis to determine their nutrient content (Table 1). This study was conducted with two periods and two feed forms: a starter period with crumbled feed for ages 0-21 days and a finisher period with pellet feed for ages 21-35. The composition of the trial feed is presented in Table 2.

According to the formula in Table 2, raw materials are put into a mixer machine with two mixing stages; the first stage is 100 seconds for mixing dry ingredients and then 120 seconds for mixing liquid ingredients. The homogenized raw materials are processed using a pellet machine for 12 minutes at a conditioner temperature of 80 ^{o}C and pelleted with a sieve diameter of 3.35 mm. Feed in the starter period (0-21 days) is given in crumble form to make it easier for the chicken to consume the feed. Crumble feed was made by crushing pelleted feed with a crumble machine. The nutritional composition of starter and finisher feed for broiler is presented in Tables 3 and 4.

Pellet Quality

Pellet quality testing is carried out by taking 300 grams of feed samples for each test. The pellets were sifted for 30 seconds with a tiered screen using retch screen number 6 with a hole diameter of 3.35 mm, 10 (2 mm diameter), and 18 (1 mm diameter). The feed remaining at the top is weighed and classified as unbroken pellets (UBP), calculated using a sieve, then weighed and calculated using the formula (Bringas *et al.,* 2007):
UBP (%)= [UBP (g) / Initial weight of sample] x 100%

The feed remaining on the second layer of the filter (2 mm) is grouped into broken pellet feed (BP) calculated using the formula:
BP (%)= [BP (g) / Initial weight of sample] x 100%

Feed particles measuring more than 1 mm are classified as dust and calculated using the formula:
Dust (%)= [Dust (g) / Initial weight of sample] x 100%

Dust samples that may be lost during sieving are considered missing dust and are called missing dust and are determined using a formula:
Missing dust (%) = 100 – [UBP (%) + BP (%) + Dust (%)]

The UBP value is directly proportional to the

Table 1. Nutritional content of palm kernel meal

Nutrient composition	Amount (% dry matter)
Moisture	6.54
Ash	4.40
Crude protein	15.51
Crude fat	8.24
Crude fiber	16.18
Neutral detergent fibre	73.89
Acid detergent fibre	31.99
Hemicellulose	41.90

Table 2. Feed formulation of experimental research for broiler (%)

Feed ingredients	Starter period			Finisher period		
	5%	10%	15%	5%	10%	15%
Corn	46.49	44.86	43.81	43.80	43.10	40.00
Palm kernel meal	5.00	10.00	15.00	5.00	10.00	15.00
Wheat	0.00	0.00	0.00	9.75	9.66	9.70
Soybean meal	28.70	27.50	28.20	19.75	19.65	19.34
Rice bran	3.67	1.95	0.00	4.16	1.98	0.00
Corn gluten meal	3.00	3.00	2.30	3.00	3.00	3.00
Limestone	0.95	0.90	0.90	1.00	1.00	0.95
Toxin binder	0.50	0.50	0.50	1.00	1.00	1.00
L-Lysine HCl	0.32	0.35	0.35	0.38	0.39	0.40
Wheat bran	3.00	1.80	0.00	4.23	2.05	1.55
Sodium bicarbonate	0.13	0.13	0.13	0.13	0.13	0.13
DL-Methionine 99%	0.21	0.21	0.21	0.17	0.17	0.16
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Mold inhibitor	0.15	0.15	0.15	0.15	0.15	0.15
Meat and bone meal	2.90	2.90	2.65	1.50	1.50	1.50
Lecithin: Crude palm oil (1:2)	0.99	0.99	1.00	0.99	0.99	0.99
Premix	0.28	0.28	0.28	0.28	0.28	0.28
Others	3.31	4.08	4.12	4.31	4.55	5.45
Total	100	100	100	100	100	100

Table 3. Nutrient composition of starter feed for broiler (% dry matter)

Items	Treatments					
	T1	T2	T3	T4	T5	T6
Nutrient content						
Moisture	11.61	11.49	11.24	11.46	11.67	11.48
Ash	6.53	6.53	6.92	6.56	6.74	6.73
Crude protein	22.26	22.26	22.42	22.03	22.29	22.48
Crude fat	5.54	5.45	6.19	6.10	6.08	5.97
Crude fiber	3.89	3.89	5.04	4.41	4.38	4.54
Calcium	0.92	0.92	1.06	1.00	1.15	1.04
Phosphorus	0.66	0.66	0.68	0.67	0.64	0.66
Calculated						
ME broiler (kcal/kg)	2,900	2,900	2,900	2,900	2,900	2,900
Crude protein	23.19	23.19	23.04	23.04	22.77	22.77
Crude fiber	3.90	3.90	4.48	4.48	5.00	5.00
Calcium	0.81	0.81	0.80	0.8	0.79	0.79
Total phosphorus	0.58	0.58	0.56	0.56	0.53	0.53
Available phosphorus	0.33	0.33	0.32	0.32	0.32	0.32
Isoleucine	0.86	0.86	0.85	0.85	0.85	0.85
Leucine	1.88	1.88	1.86	1.86	1.80	1.80
Lysine	1.27	1.27	1.27	1.27	1.27	1.27
Methionine	0.53	0.53	0.53	0.53	0.53	0.53
Cysteine	0.30	0.30	0.29	0.29	0.29	0.29
TSAA	0.83	0.83	0.83	0.83	0.82	0.82
Phenylalanine	1.02	1.02	1.01	1.01	1.00	1.00
Tyrosine	0.72	0.72	0.72	0.72	0.7	0.7
TAAA	1.74	1.74	0.83	0.83	1.7	1.7
Threonine	0.84	0.84	0.84	0.84	0.84	0.84
Tryptophan	0.24	0.24	0.23	0.23	0.23	0.23
Valina	0.96	0.96	0.96	0.96	0.95	0.95

Note: T1= 5% PKM 2.5 mm; T2= 5% PKM 1 mm; T3= 10% PKM 2.5 mm; T4= 10% PKM 1 mm; T5= 15% PKM 2.5 mm; T6= 15% PKM 1 mm; TSAA= Total Sulfuric Amino Acids; TAAA= Total Aromatic Amino Acids.

Table 4. Nutrient composition of finisher feed for broiler (% dry matter)

Items	Treatments					
	T1	T2	T3	T4	T5	T6
Nutrient content						
Moisture	11.62	11.66	11.69	11.68	11.33	11.44
Ash	6.30	6.38	6.42	6.56	6.48	6.55
Crude protein	19.64	19.7	19.58	19.47	19.51	19.67
Crude fat	5.28	5.30	5.54	5.56	6.39	6.40
Crude fiber	3.80	3.99	4.25	4.35	4.52	4.69
Calcium	1.01	0.93	1.10	0.97	1.16	1.07
Phosphorus	0.59	0.58	0.60	0.59	0.59	0.57
Calculated						
ME broiler (kcal/kg)	2,900	2,900	2,900	2,900	2,900	2,900
Crude protein	20.07	20.07	20.05	20.05	20.06	20.06
Crude fiber	3.87	3.87	4.34	4.34	4.96	4.96
Calcium	0.66	0.66	0.66	0.66	0.65	0.65
Total phosphorus	0.51	0.51	0.47	0.47	0.44	0.44
Available phosphorus	0.24	0.24	0.23	0.23	0.22	0.22
Isoleucine	0.73	0.73	0.73	0.73	0.73	0.73
Leucine	1.64	1.64	1.65	1.65	1.64	1.64
Lysine	1.10	1.10	1.10	1.10	1.10	1.10
Methionine	0.45	0.45	0.46	0.46	0.45	0.45
Cysteine	0.27	0.27	0.27	0.27	0.27	0.27
TSAA	0.73	0.73	0.73	0.73	0.72	0.72
Phenylalanine	0.88	0.88	0.88	0.88	0.88	0.88
Tyrosine	0.61	0.61	0.61	0.61	0.61	0.61
TAAA	1.49	1.49	1.49	1.49	1.49	1.49
Threonine	0.73	0.73	0.72	0.72	0.72	0.72
Tryptophan	0.20	0.20	0.20	0.20	0.20	0.20
Valine	0.82	0.82	0.83	0.83	0.84	0.84

Note: T1= 5% PKM 2.5 mm; T2= 5% PKM 1 mm; T3= 10% PKM 2.5 mm; T4= 10% PKM 1 mm; T5= 15% PKM 2.5 mm; T6= 15% PKM 1 mm; TSAA= Total Sulfuric Amino Acids; TAAA= Total Aromatic Amino Acids.

quality of the feed. In contrast, the value of broken pellets, dust, and missing duat is inversely proportional to the quality of the pellets.

Pellet durability was presented as a pellet durability index (PDI) of each pelleted diet, which was collected before cooling and cooled to room temperature (25 °C) to determine the pellet durability index (PDI). Samples were sieved through a 4-mm diameter hole sieve, and 250 g of retained pellets were submitted for durability test. A total of 5 samples of each experimental diet were placed in a tumbling can device (13 × 13 × 60 cm) and simultaneously tumbled for10 min at 60 revolutions per minute (rpm), sieved, and weighed for PDI determination (Netto *et al.,* 2019). The PDI was calculated as follows:

PDI (%)= [Pellet (g) / Initial weight of sample] x 100%

Particle Size Test Procedure

The testing of the geometric mean diameter (GMD) and geometric standard deviation (GSD) was conducted by taking a one kg test sample and sieving it using a shaker (Retsch GmBh and Co KG, Germany). The weight of the PKM that did not pass through each sieve was recorded to calculate the average diameter.

Statistical Analysis

The study employed a completely randomized factorial design of 2 x 3. Data collection was analyzed by variance analysis using the mixed procedure of SAS (SAS 9.2, SAS Institute Inc., Cary, North Carolina, USA). Tukey's test assessed significant differences among treatments. Statistical significance was considered at $p<0.05$. Results are expressed as group means and the standard error of the mean.

RESULTS

The geometric mean diameter of ground PKM is shown in Table 5. PKM milled using a 2.5 mm diameter sieve produced a GMD size of 0.48 with a GSD value of 1.67. PKM milled using a 1 mm diameter sieve produces particles with a GMD of 0.29 and is more homogeneous with a GSD value of 1.40. The feed pellet quality results are presented in Table 6. For the unbroken pellet (UBP) parameter, treatments T1 and T2 showed significantly higher results of 97.24% and 97.02%, respectively, compared to T5 and T6, which were lower at 95.06% and 93.84%. The difference in particle size between 2.5 mm and 1 mm did not significantly affect UBP. However, the difference in PKM levels in the feed significantly impacted UBP values, with the use of PKM at levels of 5% and 10% showing higher UBP compared to the 15% PKM level.

The broken pellet (BP) parameter in each treatment, T1, T2, and T3, showed lower values, 1.78%, 1.62%, and 2.24%, significantly different from treatments T5 and T6, which were 3.52% and 4.30%, respectively. The difference in particle size between PKM 2.5 and 1 mm showed no significant variation. However, the different PKM levels demonstrated significant differences among treatments, with the highest values observed for PKM level 15%, followed by 10%, and the lowest levels of 5%, 3.91%, 2.29%, and 1.70%, respectively.

The percentage of dust formed from each treatment indicates the highest value at T6, which is 1.68%, and is significantly different from treatments T1 and T2, which are 0.76% and 0.74%, respectively. The particle size factor of PKM does not significantly differ from the formed dust. However, the 15% PKM level significantly affects dust formation by 1.37% compared to the 5% PKM level, which is 0.75%. Meanwhile, the PDI parameter shows that treatments T1, T2, T3, and T4 significantly affect T5 and T6. The PKM level factor in broiler feed at 5% and 10% levels also shows significant differences compared to the 15% level.

According to the data in Table 7, no significant differences existed between the treatments given during the starter period. Both the factors of PKM level and particle size were also relatively not significantly different, except for feed conversion ratio (FCR). The difference in particle size of PKM significantly impacted FCR, with PKM particle size of 2.5 mm having a higher FCR and being significantly different from the 1 mm particle size.

Table 5. The geometric mean diameter of palm kernel meal

Parameter	Particle size	
	1 mm	2.5 mm
GMD (mm)	0.29	0.48
GSD (mm)	1.40	1.67

Note: GMD= Geometric mean diameter, GSD= Geometric standard deviation.

Observations on the finisher period indicated that the FI parameter does not differ significantly from other parameters. The parameters gain, ADG, and EPEF showed similar patterns, with treatment T1 showing significantly higher values than T5, while other treatments are relatively not significantly different. Contrary to the FCR parameter, treatment T5 shows significantly higher values than T1, whereas other treatments are not significantly different.

Observations on the differences in PKM particles between 2.5 and 1 mm during the finisher period indicate that broiler performance is not significantly different from broiler parameters. However, the PKM level in the feed significantly influences gain, ADG, and EPEF, with PKM 5% being higher than PKM 15%. Contrarily, in terms of FCR, the levels of PKM 10% and 15% are significantly higher than the 5% PKM level.

The 1 mm PKM particle size showed significantly better feed efficiency ($p<0.05$) compared to the 2.5 mm size at the starter period. This indicates that reducing the PKM particle size can improve broiler performance. Differences in particle size and PKM levels in the broiler feed formulation did not significantly affect the percentages of carcass, gizzard, and liver, as shown in Table 8. The particle size of PKM significantly affected the percentage of abdominal fat. Broilers given PKM with a 1 mm particle size produced more abdominal fat than those given PKM with a 2.5 mm particle size.

Table 6. Feed pellet quality with modification of particle size and palm kernel meal levels (%)

Variables	PKM level (%)	PKM particle size (mm)		Mean of PKM level
		2.5	1	
UBP	5	97.24±0.97^{a}	97.02±0.55^{a}	97.13±0.71^{a}
	10	96.04±0.93^{ab}	96.52±0.56^{ab}	96.28±0.73^{a}
	15	95.06±0.19^{bc}	93.84±0.26^{c}	94.45±0.70^{b}
	Mean of particle size	96.11±1.16	95.79±1.54	
BP	5	1.78±0.59^{c}	1.62±0.49^{c}	1.70±0.49^{c}
	10	2.34±0.45^{bc}	2.24±0.08^{c}	2.29±0.30^{b}
	15	3.52±0.13^{ab}	4.30±0.21^{a}	3.91±0.45^{a}
	Mean of particle size	2.55±0.86	2.72±1.24	
Dust	5	0.76±0.28^{b}	0.74±0.25^{b}	0.75±0.24^{b}
	10	1.46±0.49^{ab}	0.98±0.41^{ab}	1.22±0.48^{ab}
	15	1.06±0.08^{ab}	1.68±0.28^{a}	1.37±0.39^{a}
	Mean of particle size	1.09±0.42	1.13±0.51	
Missing dust	5	0.22±0.11	0.62±0.76	0.42±0.53
	10	0.16±0.08	0.26±0.17	0.21±0.13
	15	0.36±0.06	0.18±0.16	0.27±0.15
	Mean of particle size	0.25±0.12	0.35±0.45	
PDI	5	95.07±0.99^{a}	95.04±0.98^{a}	95.05±0.88^{a}
	10	94.18±0.29^{a}	95.15±0.33^{a}	94.66±0.60^{a}
	15	89.03±0.12^{b}	88.13±0.18^{b}	88.58±0.50^{b}
	Mean of particle size	92.76±2.87	92.77±3.52	

Note: PKM= palm kernel meal; UBP= unbroken pellet; BP= broken pellet; PDI= pellet durability index. Means with different superscripts differ significantly ($p<0.05$).

Table 7. Broiler performance with modification of particle size and palm kernel meal levels

Variables		PKM level (%)	PKM particle size (mm)		Mean of PKM level
			2.5	1	
Initial weight (g/bird)			47.75	47.75	
Starter (21 days)	BW (g/bird)	5	1,087±41.9	1,080±41.8	1,083±40.5
		10	1,092±21.4	1,105±23.6	1,098±22.7
		15	1,095±27.9	1,079±31.7	1,087±30.1
		Mean of particle size	1,091±29.8	1,087±34.3	
	ADG (g/bird)	5	49.5±2.0	49.1±2.0	49.3±1.9
		10	49.7±1.0	50.4±1.1	50.0±1.1
		15	49.9±1.3	49.1±1.5	49.5±1.4
		Mean of particle size	49.7±1.4	49.5±1.6	
	FI (g/bird)	5	1,315±54.2	1,302±55.4	1,308±53.3
		10	1,358±46.5	1,334±24.6	1347±38.7
		15	1,348±47.3	1,316±41.4	1331±45.7
		Mean of particle size	1,341±50.5	1,317±43.1	
	FCR	5	1.23±0.02	1.23±0.03	1.23±0.03
		10	1.25±0.02	1.22±0.02	1.23±0.03
		15	1.25±0.04	1.23±0.03	1.24±0.04
		Mean of particle size	1.24±0.03^{a}	1.23±0.03^{b}	
	EPEF	5	414±25.9	407±18.9	411±21.9
		10	410±7.70	427±17.7	418±15.5
		15	403±15.8	413±22.4	408±19.7
		Mean of particle size	409±17.5	416±20.7	
Finisher (15 days)	Gain (g/bird)	5	1,259±59.6^{a}	1,231±63.6^{ab}	1,244±61.2^{a}
		10	1,235±53.5^{ab}	1,212±40.8^{ab}	1,224±48.6^{ab}
		15	1,168±48.1^{b}	1,211±62.4^{ab}	1,189±58.0^{b}
		Mean of particle size	1,221±65.2	1,219±55.1	
	ADG (g/bird)	5	96.8±4.6^{a}	94.7±4.9^{ab}	95.7±4.7^{a}
		10	95.0±4.1^{ab}	93.2±3.1^{ab}	94.2±3.7^{ab}
		15	89.8±3.7^{b}	93.1±4.8^{ab}	91.5±4.5^{b}
		Mean of particle size	93.9±5.0	93.7±4.2	
	FI (g/bird)	5	2,102±76.2	2,064±91.4	2,082±84.0
		10	2,133±52.8	2,102±59.6	2,118±57.5
		15	2,078±106.3	2,066±71.9	2,072±87.4
		Mean of particle size	2,106±80.8	2,077±74.8	
	FCR	5	1.67±0.04^{b}	1.68±0.04^{b}	1.67±0.04^{b}
		10	1.73±0.04^{ab}	1.73±0.03^{ab}	1.73±0.04^{a}
		15	1.78±0.07^{a}	1.71±0.05^{ab}	1.74±0.07^{a}
		Mean of particle size	1.73±0.07	1.70±0.05	
	EPEF	5	572±40.7^{a}	556±40.3^{ab}	1.67±0.04^{b}
		10	545±31.7^{ab}	525±27.9^{ab}	1.73±0.04^{a}
		15	500±30.4^{b}	541±43.3^{ab}	1.74±0.07^{a}
		Mean of particle size	1.73±0.07	1.70±0.05	
Overal (35 days)	FW (g/bird)	5	2,342±92.7	2,311±87.5	2,325±88.1
		10	2,327±73.3	2,317±59.5	2322±65.0
		15	2,263±73.4	2,293±73.3	2278 ±72.2
		Mean of particle size	2,311±83.4	2,308±72.1	
	ADG (g/bird)	5	67.5±2.7	66.6±2.6	67.0±2.6
		10	67.0±2.1	66.8±1.7	66.9±1.9
		15	65.2±2.2	66.0±2.2	65.6±2.1
		Mean of particle size	66.6±2.5	66.5±2.1	
	FI (g/bird)	5	3,410±128.8	3,360±129.2	3,390±127.1
		10	3,490±94.8	3,430±74.8	3,460±87.7
		15	3,420±147.2	3,380±94.4	3,400±120.9
		Mean of particle size	3,440±122.8	3,390±103.1	
	FCR	5	1.46±0.02^{bc}	1.46±0.04^{c}	1.46±0.03^{b}
		10	1.50±0.02^{ab}	1.48 ±0.02^{abc}	1.49±0.02^{a}
		15	1.51±0.04^{a}	1.47±0.02^{abc}	1.49±0.04^{a}
		Mean of particle size	1.49±0.04^{a}	1.47±0.03^{b}	
	EPEF	5	459±29.4^{a}	455±27.9^{a}	457±27.7^{a}
		10	447±15.2^{ab}	447±25.7^{ab}	447±20.0^{ab}
		15	423±12.4^{b}	447±23.3^{abc}	435±21.8^{b}
		Mean of particle size	443±24.3	450±24.9	

Note: BW= body weight; ADG= average daily gain; FI= feed intake; FCR= feed convertion ratio; EPEF= European production efficiency factor; FW= final weight. Means with different superscripts differ significantly ($p<0.05$).

Table 8. Carcass and visceral organs percentage of broiler with modification of particle size and palm kernel meal levels

Percentage of	PKM level (%)	PKM particle size (mm)		Mean of PKM level
		2.5	1	
Carcas	5	72.79±3.09	73.51±2.62	73.15±2.73
	10	74.62±4.39	76.49±3.87	75.55±4.02
	15	75.92±5.30	74.59±4.43	75.26±4.66
	Mean of particle size	74.44±4.25	74.86±3.67	
Gizzard	5	1.09±0.14	0.98±0.07	1.04±0.12
	10	1.28±0.22	1.15±0.17	1.22±0.20
	15	1.08±0.22	1.25±0.14	1.17±0.19
	Mean of particle size	1.15±0.21	1.13±0.17	
Liver	5	1.98±0.24	2.03±0.20	2.01±0.21
	10	2.14±0.27	2.02±0.41	2.08±0.34
	15	1.79±0.23	2.10±0.26	1.95±0.28
	Mean of particle size	1.97±0.27	2.05±0.28	
Abdominal Fat	5	1.10±0.18	1.23±0.25	1.16±0.22
	10	0.91±0.43	1.34±0.21	1.12±0.39
	15	1.11±0.17	1.25±0.27	1.18±0.23
	Mean of particle size	1.04±0.28^{b}	1.27±0.23^{a}	

Note: PKM= palm kernel meal. Means in the same row with different superscripts differ significantly ($p<0.05$).

DISCUSSION

Most feed ingredients are ground with a hammer mill or roller mill to reduce particle size in the poultry feed industry, fitted with screen sizes ranging from 1.0 to 5.0 mm (Lyu *et al.,* 2020). The particle size reduction of feed ingredients can provide numerous advantages in feed processing and increase nutrient digestibility (Naeem *et al*., 2024; Bautil *et al.,* 2023). Smaller and more homogeneous particle sizes can improve pellet quality because, during the conditioning process, the hot steam can penetrate all parts of the feed ingredients evenly, resulting in a more uniform degree of cooking (Ebbing *et al*., 2022).

Goodband *et al*. (2002) stated that increasing the number of particles by reducing the particle size expands the surface area per unit volume, thereby facilitating access to digestive enzymes. In general, the observation results in this study show that the quality of pellets was not significantly different between PKM particle sizes of 1 and 2.5 mm. In the 1 to 2.5 mm size range, it is relatively safe for the expected production result of broiler pellets. On the other hand, fine grinding requires more energy, which can increase production costs. The additional energy required for milling can offset some savings from improved feed efficiency (Svihus *et al.,* 2024).

However, the use of PKM levels is negatively correlated with pellet quality; as the PKM level in the formulation increases, the quality of the pellets gradually decreases. Palm kernel shells contain high lignin, which can decrease the pellet's durability index (Wang *et al.,* 2023). The pellet strength test results showed that feed using 5% and 10% PKM had durability values ranging from 94% to 95%, better than pellets containing 15% PKM with durability values of 88% to 89%. Pellet strength is considered good if it achieves a pellet durability index between 80% and 90%, and the best pellet quality is indicated by a durability index of more than 96% (Haetami *et al.,* 2017). The texture and physical properties of PKM can also pose challenges during the pelleting process. Contaminants like palm shells can contribute to a gritty texture, which may affect the palatability and acceptability of the feed (Adrizal *et al.,* 2011). Additionally, the hard texture of PKM can complicate the grinding process, making it less amenable to pelleting without prior treatment or modification.

Performance results showed that the utilization of PKM up to 15% can be used in broiler feed without reducing performance at the starter period. The parameter that influenced this period was the particle size of the PKM factor. Particles of smaller size are significantly better in feed efficiency than larger particles. The results showed that although particle size did not significantly affect body weight, feed consumption, and EPEF, it significantly affected feed efficiency. Palm kernel meal is a viable alternative feed ingredient for broilers, capable of replacing conventional feedstuffs like soybean meal and maize up to certain levels without compromising performance. PKM can be included in up to 16% of broiler diets without deleterious effects on growth performance (Abdollahi *et al*., 2016).

Physiologically, the use of PKM also does not significantly influence the percentage of carcass, gizzard, liver, and abdominal fat. Different particle sizes did not influence the relative weight of the gizzards (Ovi *et al*., 2021). Based on research, Silitonga *et al*. (2015) also show that including PKM in feed does not impact carcass, gizzard, or liver percentages. The inclusion of PKM in feed has relatively no significant impact on the physiological condition of broiler digestion. The use of up to 15% PKM in feed is relatively safe for broiler physiology. Studies have shown that broilers fed diets with finer particle sizes tend to exhibit higher levels of abdominal fat. For example, research indicated that diets with fine particle sizes increased abdominal fat accumulation compared to diets with larger particle sizes.

This suggests that finer particles may lead to overconsumption and inefficient energy use, resulting in fat deposition (Oliveira *et al.*, 2022). This indicates that energy absorption in feed using 1 mm PKM was higher than 2.5 mm PKM. These findings align with those of El-Senousey *et al*. (2019), who stated that increased energy in feed does not significantly affect carcass percentage but significantly impacts abdominal fat and intramuscular fat as energy retention.

CONCLUSION

In conclusion, to optimize PKM utilization for the best performance and carcass quality in broiler, it is essential to modify the particle size to 1 mm and limit its inclusion in feed formulations to a maximum of 5%.

CONFLICT OF INTEREST

Nahrowi and Sumiati serve as editors of the Tropical Animal Science Journal but have no role in the decision to publish this article. The authors also declare no conflict of interest regarding any financial, personal, or other relationships with other people or organizations related to the material presented in the manuscript.

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