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GROWTH PERFORMANCE AND GUT MORPHOLOGY OF BROILER CHICKENS FED ON PALM KERNEL RATION

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ABSTRACT

In Tanzania the poultry sector is constrained by several challenges, including the limited availability and high cost of conventional feed ingredients, particularly protein and energy sources such as sunflower seed cake and cottonseed cake, which are commonly used in poultry diet formulations. To address these challenges, it is essential to identify affordable and locally available alternatives to enhance the sustainability of poultry production. In this study, a feeding trial was conducted to assess the effects of replacing sunflower seed cake and cottonseed cake with palm kernel meal (PKM), a non-conventional feed ingredient, on the growth performance and gut morphology of broiler chickens. The experiment involved 195 one-day broiler chicks, which were randomly assigned to three dietary treatments in a completely randomized design (CRD), with each treatment replicated three times to minimize the effects of random variation. The dietary treatments were as follows: T1, a diet without PKM as a control; - T2, a diet formulated by substituting PKM for sunflower seed cake; - and T3, a diet made by substituting PKM for cotton-seed cake. Growth performance parameters, including weekly body weight gain and daily feed intake, were recorded throughout the feeding trial. At the end of the experiment, 15 chickens from each treatment were humanely slaughtered, and their gastrointestinal tracts (GIT) were collected for morphological assessment. Villus height, villus width, and crypt depth in the duodenum, jejunum, and ileum were measured to determine intestinal development. Results showed significant differences ($p < 0.05$) in growth performance and gut morphology among the treatments. Broilers fed a diet in which PKM replaced sunflower seed cake (T2) showed improved feed conversion ratio, higher body weight gain, and enhanced villus structure compared with those in the T1 and T3. The results of this study suggest that substituting sunflower seed cake with PKM can enhance growth performance and improve gut development in broiler chickens without causing adverse effects. These findings indicate that PKM could be a practical alternative protein source for poultry diets, especially in regions where conventional feed ingredients are scarce or expensive, supporting more sustainable and cost-effective poultry production.

Key words: palm kernel meal, chicken feed, growth performance, gut morphology

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INTRODUCTION

The poultry sector in Tanzania has developed into a significant part of the livestock sector, contributing to both food and economic growth [1]. The sector is mainly made up of local breeds and commercial poultry, with a total number of about 108.2 million chickens. 49.8 million of these chickens are local, and the remaining 58.5 million are commercial chickens [2]. As a result of increased demand for chicken meat brought on by population growth, the poultry sector has expanded [3]. However, the rapid growth of the sector caused by the glowing poultry population has been accompanied by persistent challenges with conventional feeds, particularly the inadequate and inconsistent supply, high feed costs and competition with other livestock species, including ruminants and non-ruminants. To mitigate the challenge, some initiatives have shifted to alternative, locally accessible non-conventional feeds in an attempt to minimize feed shortages and dependency on conventional protein sources like soybean meal, cottonseed cake, and sunflower seed cake, which are expensive and scarce. Palm kernel meal (PKM), a byproduct of oil extraction from oil palm (*Elaeis guineensis*), is a promising feed substitute due to its availability in oil palm-growing regions and its potential to lower feed costs without compromising nutritional quality [4]. Palm kernel meal provides moderate level of protein and serves as a useful source of energy and dietary fiber that supports gut health [5,6,7]. It, therefore, holds potential as a partial substitute for expensive protein sources such as soybean meal, sunflower, and cottonseed meal without negatively affecting poultry performance [8]. Moreover, the adaptability oil palm to arid and semi-arid environments makes it a sustainable resource in regions with limited water availability [9]. These characteristics support the sustainability and economic viability of poultry production in palm oil-producing regions.

Despite the potential of PKM, there is a lack of published research in Tanzania on its practical application in broiler diets, particularly regarding its effects on growth performance. While some studies have been conducted in other African countries to evaluate the nutritional content of PKM and its partial replacement in broiler diets, comprehensive performance evaluations under local Tanzanian conditions remain limited. This gap highlights a significant research opportunity, as understanding the impact of PKM use could enhance local poultry production systems, reduce feed costs, and improve feed accessibility.

Therefore, the primary objective of this study was to evaluate the effects of incorporating palm kernel meal (PKM) into broiler chicken diets on growth performance and gut morphology. The findings are intended to assist Tanzanian commercial poultry farmers in developing sustainable, cost-effective, and nutritionally balanced feeding strategies.

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MATERIALS AND METHODS

Ethical Approval

Ethical approval for this study was granted by the Tanzania Livestock Research Institute (TLRI), under reference number TLRI/CC.21/059.

Study Location

The experiment was conducted at the Sokoine University of Agriculture (SUA), Morogoro, Tanzania. The area is located at approximately 6°S and 37°E, at an altitude of 500 – 600 meters above sea level.

Feed Ingredients and Formulation of Experimental Diets

The experimental diets were formulated to meet the nutrient requirements of broiler chickens according to established standards [10]. Palm kernel meal, a non-conventional feed ingredient, was sourced from Kigoma Municipality, located in the northwestern region of Tanzania, and incorporated into the diets. Palm kernel meal replaced sunflower seed cake or cottonseed cake at equivalent protein levels to maintain comparable crude protein (CP) and metabolizable energy (ME) values. The inclusion levels were determined based on nutrient composition of the ingredients, particularly protein and energy content, and by referencing similar studies conducted across Africa. All diets were pelleted and formulated for three feeding phases: starter (1-14 days), grower (15-28 days), and finisher (29-42 days). The experimental treatment consisted of a control diet without PKM (T1), a diet with PKM replacing sunflower seed cake (T2), and a diet with PKM replacing cottonseed cake (T3). The proximate composition of feed ingredients was analyzed before formulation according to the Association of Official Analytical Chemists (AOAC) [11]. Tables 1, 2, and 3 provide detailed information on the nutrient composition of the experimental diets.

Proximate analysis

A total of 250 g samples of palm kernel meal (PKM) and each of the three formulated experimental diets were collected and submitted to the Tanzania Veterinary Laboratory Agency (TVLA) for proximate analysis, mineral content determination, and amino acid profiling, following standard procedures [11].

Sample Size Determination

The sample size was estimated using the standard formula for comparing means [12]: $N = (2 \times k \times \sigma^2 \times (Z\alpha + Z\beta)^2) / \delta^2$, where N is the total number of experimental units, k is the number of treatment groups, σ^2 is the population variance, δ is the minimum detectable difference (effect size), $Z\alpha$ is the standard normal deviate corresponding to the level of confidence (1.96 for 95% confidence), and $Z\beta$ is the standard normal deviate corresponding to the statistical power ($1 - \beta$). In this study, the parameters used for sample size determination were: minimum detectable

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difference (δ)=2.46, number of treatment groups (k)=3, population variance (σ^2) =25 (corresponding to a standard deviation of 5), $Z\alpha$=1.96 (corresponding to a 95% confidence level), and $Z\beta$=0.84 (corresponding to statistical power of 0.80). Based on the values, the total sample size was calculated to be approximately 195 chicks, equivalent to 65 chicks per treatment group.

Experimental Layout and Broiler Chicken Management

A total of 195-day-old broiler chicks were obtained from a commercial hatchery in the Iringa Region, Tanzania. Upon arrival, each chick was individually weighed, tagged for identification, and randomly assigned to one of three dietary treatments in a completely randomized design, with 65 chicks per treatment. Each treatment was replicated three times, with approximately 22 chicks per replicate. The chicks were selected based on uniformity in initial body weight to minimize variation. Standard vaccination and biosecurity protocol were followed throughout the six-week feeding trial. Feed and clean water were provided *ad libitum*.

Growth Performance

Body weight and feed consumption were measured and, the data were used to calculate daily weight gain, total weight gain and feed conversion ratio. The initial body weight was obtained by weighing the birds in each replicate group at the beginning of the experiment. Weight gain was obtained by subtracting the average initial weight from the average final weight of broiler chickens. Average daily weight gain (ADG) was calculated by dividing the total weight gain by the duration of the trial days. Daily feed intake was measured by deducting the leftover feed from the total amount offered. Feed conversion ratio (FCR) for each replicate was computed as the ratio of feed intake to weight gain. Mortality was recorded throughout the experimental period to determine the mortality rates among the treatments.

Gut Morphology

Gut morphology was evaluated using forty-five randomly selected broiler chickens, with five chickens taken from each replicate, following standard procedures[13]. Approximately 2 cm segments from different parts of the small intestine (duodenum, jejunum, and ileum) were collected, rinsed in 0.9% saline solution, and fixed in 10% neutral buffered formalin for 72 hours at room temperature. The preserved samples were prepared for historical analysis in the laboratory by dehydrating them through a graded ascending series of alcohols (70%, 80%, 90%, 95%, and 100%), clearing with xylene, embedding in paraffin wax, and trimming. Tissue sections approximately 4μm thick were prepared using a microtome, mounted on glass slides, and stained with hematoxylin and eosin (H&E) for microscopic examination. A light microscope (Olympus Corporation, Model D21-CB, SN 0010842A2, Tokyo, Japan) equipped with an adjusted digital camera (Olympus U-TV0.5XC-3, SN OK73198, Tokyo Japan) was used to observe the slides. The captured images were analyzed using *cellSens standard* image analysis software, version 4.2 (Olympus Corporation, Tokyo, Japan) to measure the morphometric parameters including villi height (VH), villi width (VW), and crypt depth.

Statistical Analysis

The data obtained were organized in an Excel spreadsheet and tested for normality and homogeneity of variance before analysis. The Shapiro – Wilk test was used to assess normality, while Levene's test was applied to evaluate homogeneity of variances among treatment groups. When assumptions of normality and homogeneity of variances were met, data were analyzed using one-way ANOVA in R software (version 4.5, 2025). Treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% significance level ($p<0.05$). Results were expressed as mean ± standard error of the mean (SEM).

RESULTS AND DISCUSSION

Chemical Composition of PKM

The findings of this study revealed that the PKM is composed of 0.0% ash, 8.7% crude fat, 11.3% crude fiber, 18.0% crude protein, 93.7% dry matter, 50% starch, 3.6% total sugar, and 3,650 Kcal per kg of dry matter as energy potential in a feed ingredient (Table 4). The chemical compositions of PKM showed variations between the previous and present studies (Table 4). The ash composition was 0.0%, significantly less than the values; 4 -6% [14] , 3.87% [5], 4 - 5% [15], 4.26% [16], and 2.78% [8]. Intense purification might be the cause of palm kernel meal containing low ash content. Chemical extraction can eliminate up to 34% of the ash content, although trace elements such as Ca, Mg, Fe, and P can still be found at extremely low concentrations [17]. All of these results reveal that, the low ash level is indicative of a PKM sample that has been highly refined or purified. Despite the 0.0% ash content, minerals were detected in the PKM sample, most likely due to the application of more sensitive mineral analysis.

The crude fat content was 8.7%, which falls within the reported range of 8 -17% and is comparable to previously reported values, including 9.29%, but remains higher than solvent-extracted values such as 2.81%, indicating that the sample was likely mechanically extracted [8, 16, 18]. The crude fiber content of 11.3% was slightly lower than the reported value of 15.43%, which may be attributed to partial de-fibering or finer processing methods[14]. The crude protein content of 18.0% aligns with values reported in the literature, typically ranging from 14 - 21%, with specific reports of 18.46% and 15 -19%, confirming palm kernel meal as a moderate protein source[5, 14, 18] . The dry matter content of 93.7% falls within the normal reported range with values such as 91%, 92%, and 97.84% [5, 16, 18].

The metabolizable energy (ME) content was 3650 Kcal/kg, which lies between higher reported values such as 4998 Kcal/kg and lower values including 2666.44 Kcal/kg and 2298 Kcal/Kg, possibly due to increased fat content and reduced fiber levels [8,14,18]. The starch content (50%) was considerably higher than the previously reported value of 11%, which may be explained by differences in, processing methods, raw material resources, or advancements in analytical techniques[19] .

Amino Acids and Mineral Composition of PKM

The PKM was also found to contain a moderate amount of essential amino acids, including 1.03% Lysine, 0.21% Tryptophan and 0.75% Methionine/Cysteine. It is also composed of minerals such as 0.21% Calcium, 0.06% Chlorine, 0.51% Potassium, 0.18% Magnesium, and 0.35% Phosphorus (Table 5). The lysine content of 1.03% was higher than the previously reported value of 0.37% [20]. Similarly, the value of 0.63% reported in previous studies was lower than that observed in the current study, while the tryptophan content of 0.21% was higher than the previously reported 0.09%[16]. The methionine/ cysteine level of 0.75% was also significantly higher than the earlier values of 0.22% and 0.09% reported in the literature [16, 20]. These findings are consistent with reports indicating the high protein quality potential of palm kernel meal in animal nutrition studies [5, 14].

Regarding the mineral compound, the calcium concentration 0.21% was lower than 0.38% as reported by Sundu *et al* [14] but higher than the concentration of 0.12% [6]. Chlorine was found at 0.065%, which was absent from the previous studies reviewed. This could mean that the ingredients were uncommonly measured or that the analytical sensitivity was high. The magnesium content observed in this study was 0.18%, which was higher than the 0.31% reported in one study but lower than the 0.18% reported in other studies [6, 14, 20]. The potassium content of 0.51% was lower than an earlier reported value of value 0.82% [21]. The phosphorus content (0.35%) was higher than 0.16% reported in one study but significantly lower than the 0.51% in other findings [14, 20].

The observed differences in chemical, amino acid and mineral compositions could be due to analytical techniques, environmental factors such as soil type, climate, or processing conditions (mechanical versus solvent extraction). Generally, the enhanced amino acid profile discovered in this study indicates that PKM may be a more effective source of protein or dietary minerals , particularly for monogastric animals, where lysine and methionine levels are important [21].

Effects of PKM on Growth Performance of Broiler Chicken

Significant differences ($p < 0.05$) were observed among treatments (Table 6) for final body weight, total weight gain (TWG), average daily gain (ADG), and feed conversion ratio (FCR). Broilers fed a diet in which PKM was partially replaced by sunflower seed cake (T2) achieved the best growth performance. Compared with the control (T1), T2 broilers had 9.5% higher final body weight and 9.8% higher TWG and ADG. Feed consumption increased slightly by 2.5%, while FCR improved by 7.8%, indicating enhanced feed efficiency. Mortality was reduced by 44.5% in T2 compared with T1, reflecting better overall chickens' health.

The superior performance of birds observed in T2 may be attributed to the balanced energy-protein ratio and moderate fiber content in PKM, which likely improved intestinal motility and nutrient digestibility [22]. Palm kernel meal contains moderate levels of residual oil and fermentable fibers such as β-mannan, which have been associated with enhanced gut function and nutrient absorption [23]. The β-mannan components act as prebiotics, promoting beneficial gut microflora and stimulating immune response in the intestinal mucosa [22]. Moreover, the moderate fat content of PKM contributes to higher dietary energy density, thereby improving nutrient utilization efficiency [24].

The findings are consistent with studies conducted in Nigeria and Ghana, which reported that partial replacement of conventional feed cakes with palm kernel meal improves feed utilization and growth performance [24, 25]. However, this study provides additional contextual evidence by confirming relevance by confirming the efficacy of PKM under Tanzanian production conditions, where feed cost and ingredient availability are major constraints [26].

Based on these results, inclusion of up to 8% PKM in broiler diets does not adversely affect broiler performance under Tanzanian conditions. For optimal nutrient utilization, PKM- based diets may be supplemented with enzymes such as β-mannanase to reduce the effects of dietary fiber and enhance digestibility [14].

Feed cost analysis indicated that replacing sunflower seed cake or cottonseed cake with PKM substantially reduced the cost of poultry feed. In this study, sunflower seed cake was priced at 1,200 Tsh/kg, cottonseed cake at 1,500 Tsh/kg, and PKM at 350 Tsh/kg. Incorporating PKM into poultry diets allows a farmer to save approximately 70.8% compared with sunflower seed cake and 76.7% compared with cottonseed cake, resulting in a significant reduction in total feed costs. These findings demonstrate the economic advantage of PKM under Tanzanian conditions for both smallholder and commercial farmers. Therefore, inclusion of PKM in broiler diets may lower production costs and enhance profitability, supporting national efforts towards sustainable poultry production [26].

Effects of PKM on Gut Morphology of Broiler Chickens

There were significant differences ($p < 0.05$) among the dietary treatments in the jejunum and ileum (Appendix 2 and 3), whereas no significant variations were observed in the duodenum (Appendix 1). In the jejunum, broilers fed the T2 diet showed greater villus height and width, accompanied by reduced crypt depth compared with the control group (T1). Quantitatively, villus height increased by 8.8% and 16.6%, respectively, while crypt depth decreased by 25.9%. These results suggest enhanced intestinal stability and absorptive capacity. A higher villus-to-crypt ratio is often associated with improved intestinal function and maturity [27].

In the ileum, T2 significantly increased villus height and crypt depth by 43.7% and 38.2%, respectively, relatively, compared with T1, indicating a larger absorptive surface area and active epithelial regeneration [28]. Although difference in villus width were not statistically significant ($p > 0.05$), broilers fed T2 and T3 diets exhibited numerically narrower villi than the control (Appendix 2), indicating structural adaptations that enhance nutrient absorption. Similar findings were reported in chickens fed microencapsulated *Enterococcus faecalis,* which showed longer ileal villi and deeper crypts, associated with improved nutrient utilization [29].

The duodenum showed no significant differences among treatments, although broilers fed the T2 and T3 diets showed a numerical increase in villus height, width, and crypt depth compared with the control (Appendix 1). This limited response is consistent with previous findings showing that the duodenal segments often exhibit fewer morphological adaptations to dietary changes compared to the jejunum and ileum[30].

The T2 diet yielded the most favorable histomorphological outcomes across intestinal segments. The taller villi, shallower jejunal crypts, and deeper ileal crypts observed in broilers fed the T2 diet indicate enhanced absorptive efficiency, nutrient utilization, and gut health. These findings demonstrate that partial replacement of sunflower seed cake with PKM in broiler diets can positively influence intestinal morphology, thereby promoting improved feed efficiency and growth performance.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

This study revealed that inclusion of PKM in broiler diets as partial replacement for sunflower seed cake or cotton-seed cake significantly improved growth performance, feed efficiency, and intestinal morphology in broiler chickens. Broilers fed the T2 diet achieved approximately 9.5% higher final body weight, 9.8% greater total weight gain, and higher average daily gain compared with those fed the control diet (T1). Feed conversion efficiency was also improved by 7.8%, while mortality was reduced by 44.5%. The enhanced villus development observed in PKM-fed chickens further supports improved nutrient absorption and gut health.

These results confirm that PKM is a sustainable and cost-effective non-conventional protein source capable of reducing feed costs and dependence on conventional feeds in Tanzania. Its local availability, cost-effectiveness, and nutritional potential

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particularly its moderate protein content and favorable amino acid profile, make it a valuable feed resource for both smallholder and commercial poultry systems.

Future research should focus on determining the optimal PKM inclusion levels under different management systems, assessing long-term effects on meat quality and carcass yield, and evaluating its impact on farm-level profitability and environmental sustainability.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to the content of this article.

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Table 1: Percentage composition of broilers starter diet with incorporation of PKM

Ingredients	T1	T2	T3
Maize	40	40	40
Maize bran	31	27	26
Sunflower seed cake	4	0	4
Cotton-seed cake	4	5	0
Palm kernel meal (PKM)	0	8	8
Soybean	4	4	4
Fish meal	6	7	8
Blood meal	9	7	8
Salt	0.5	0.5	0.5
Limestone	0.88	0.88	1
Bone meal	0.5	0.5	0.5
Premix	0.1	0.1	0.1
Lysine	0.01	0.01	0.01
Methionine	0.0.1	0.01	0.01
Total	100	100	100
Chemical composition			
DM	89.2	89.2	89.2
Crude Protein	23.4	23.4	23.4
Crude Fat	4.8	4.3	4.3
Crude Fiber	4.1	4.2	4.2
Ash	12.1	11.7	12.1
Starch	31.6	31.8	31.8
Total sugar	3.9	3.8	3.8
ME (Kcal/kg)	2695	2672	2672

DM = Dry matter, ME = Metabolizable energy

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Table 2: Percentage composition of broilers grower's diet with incorporation of PKM

Ingredients	T1	T2	T3
Maize	41	40	40
Maize bran	31	29	29
Sunflower seed cake	4	0	4
Cotton seed cake	5	4	0
Palm kernel meal (PKM)	0	7	7
Soybean	4	4	5
Fish meal	6	6	6
Blood meal	7	8	7
Salt	0.5	0.5	0.5
Limestone	0.88	0.88	0.88
Bone meal	0.5	0.5	0.5
Premix	0.10	0.1	0.10
Lysine	0.01	0.01	0.01
Methionine	0.01	0.01	0.01
Total	100	100	100
Chemical compositions			
DM	88.9	89.3	89.1
Crude Protein	22.2	20.3	21.6
Crude Fat	4.1	6.2	4.5
Crude Fiber	3.0	3.6	3.4
Ash	8.9	11.4	9.5
Starch	37.7	34.1	36.6
Total Sugar	4.1	3.8	3.9
ME (Kcal/kg)	2863	2797	2819

DM = Dry matter, ME = Metabolizable energy

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Table 3: Percentage composition of broilers finisher diet with incorporation of PKM

Ingredients	T1	T2	T3
Maize	42	41	40
Maize bran	31	31	30
Sunflower seed cake	4	0	4
Cotton seed cake	5	4	0
Palm kernel meal (PKM)	0	6	6
Soybean	4	4	5
Fish meal	6	5	6
Blood meal	6	7	7
Salt	0.5	0.5	0.5
Limestone	0.88	0.88	0.88
Bone meal	0.5	0.5	0.5
Premix	0.10	0.10	0.10
Lysine	0.01	0.01	0.01
Methionine	0.01	0.01	0.01
Total	100	100	100
Chemical composition			
DM	89.4	88.7	89.4
Crude Protein	22.5	22.1	22.3
Crude Fat	3.0	4.4	4.3
Crude Fiber	3.0	4.0	4.3
Ash	8.2	7.4	9.6
Starch	39.9	40.6	38.9
Total Sugar	3.8	4.2	3.3
ME (Kcal/kg)	2868	2757	2743

DM = Dry matter, ME = Metabolizable energy

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Table 4: Chemical composition of PKM

Chemical composition	Dry Matter	Crude protein	Crude Fat	Crude Fiber	Ash	Starch	Total Sugar	ME (Kcal/KgDM)
Percentage (%)	93.7	18.0	8.7	11.3	0.0	50	3.6	3,650

Table: 5 Amino acid and mineral composition of PKM

Amino acid and mineral compositions	Lysine	Tryptophan	Methionine/ Cystine	Ca	Cl	K	Mg	P
Percentage (%)	1.03	0.21	0.75	0.21	0.06	0.51	0.18	0.35

Ca = calcium, Cl = Chlorine, K = Potassium, Mg = Magnesium, P = Phosphorus

Table 6: Effects of PKM on performance parameters of broilers

Parameters	Treatment groups				
	T1	T2	T3	SEM	P-values
Final live weight (g/bird)	1515.983^{b}	1675.250^{a}	1569.283^{b}	29.0325	0.000569
TWG (g/bird)	1475.967^{b}	1635.533^{a}	1530.767^{b}	29.0325	0.000569
ADG (g/day)	35.1406^{b}	38.94127^{a}	36.44683^{b}	0.6912	0.000569
Feed consumption (g/bird)	3236.439^{b}	3319.662^{a}	3125.029^{c}	13.96127	0.00002e-11
FCR	2.245879^{a}	2.070009^{b}	2.083535^{b}	0.04247	0.00577
Mortality (%)	4.61539^{a}	2.56410^{c}	3.58974^{b}	1.07e-15	2e-16

^{abc}Means with different superscripts within a row are significantly different from each other at $P < 0.05$, SEM = standard error of the mean, *P*-value = probability value. T1 (no PKM), T2 (PKM replaced sunflower seed cake), T3 (PKM replaced cotton seed cake), FCR (feed conversion ratio), TWG = total weight gain, ADG = average daily gain, FCR = feed conversion ratio

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Table 7: Effects of PKM on gut morphology of broiler chickens

Intestinal sections	Parameters(µm)	Treatment groups			SEM	P-values
		T1	T2	T3		
Duodenum	Villi Height	1436.481[a]	1587.236[a]	1585.706[a]	67.680	0.2155
	Villi Width	234.737[a]	267.219[a]	225.8160[a]	12.867	0.0764
	Crypt Depth	266.505[a]	325.014[a]	320.2371[a]	18.073	0.0572
Jejunum	Villi Height	1198.174[b]	1313.258[a]	1259.329[ab]	23.927	0.0089
	Villi Width	178.723[b]	214.269[a]	189.346[ab]	9.049	0.0302
	Crypt Depth	216.846[b]	172.174[a]	217.044[b]	12.693	0.0043
Ileum	Villi Height	628.017[b]	1114.541[a]	837.5819[b]	63.105	6.156e-05
	Villi Width	235.32[a]	282.35[a]	250.71[a]	18.483	0.2070
	Crypt Depth	161.081[b]	260.675[a]	188.7139[b]	9.6491	4.727e-07

[abc]Means with different superscripts within a row are significantly different from each other at $p < 0.05$, SEM = standard error of the mean, *P*-value = probability value. T1 (no PKM), T2 (PKM replaced sunflower seed cake), T3 (PKM replaced cotton seed cake seed cake)

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APPENDICES

Appendix 1

<table>
<tr><td></td><td>Treatment T1</td><td>Treatment T2</td><td>Treatment T3</td></tr>
<tr><td>Duodenum</td><td>

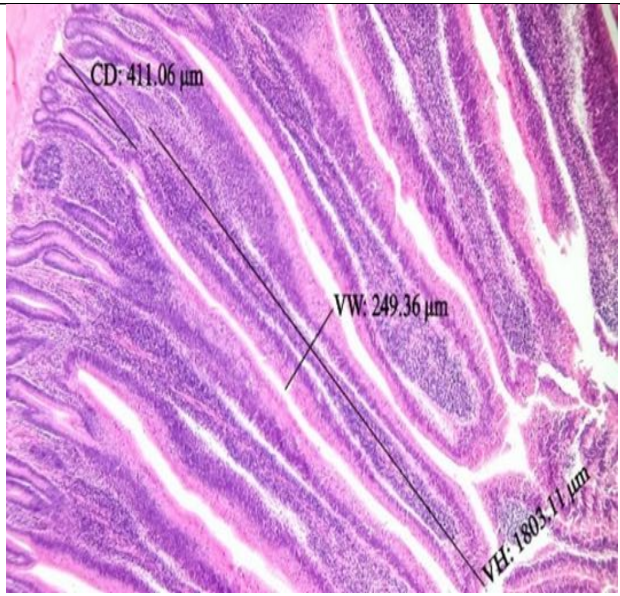
Figure 1(a): Photo showing villi height, width and crypt depth</td><td>

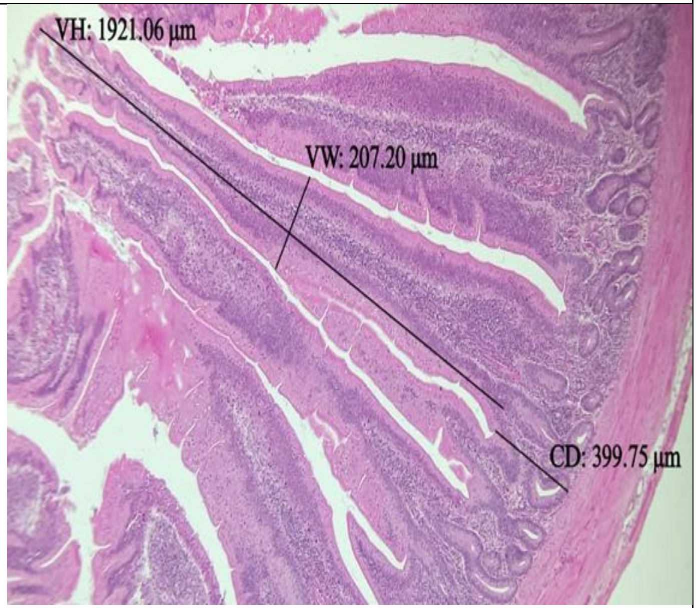
Figure 1(b): Photo showing villi height, width and crypt depth</td><td>

Figure 1(c): Photo showing villi height, width and crypt depth</td></tr>
</table>

Figure 1: Histomicrograph of the duodenum showing villus height, width and crypt depth of broiler chickens fed dietary treatments T1, T2 and T3

Observations were made using a light microscope at 10x eyepiece and 4x objective lens, with 40x total magnification (Olympus Corporation, Model D21-CB, SN 0010842A2, Tokyo, Japan) equipped with a digital camera (Olympus U-TV0.5XC-3, SN OK73198, Tokyo Japan)

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Appendix 2

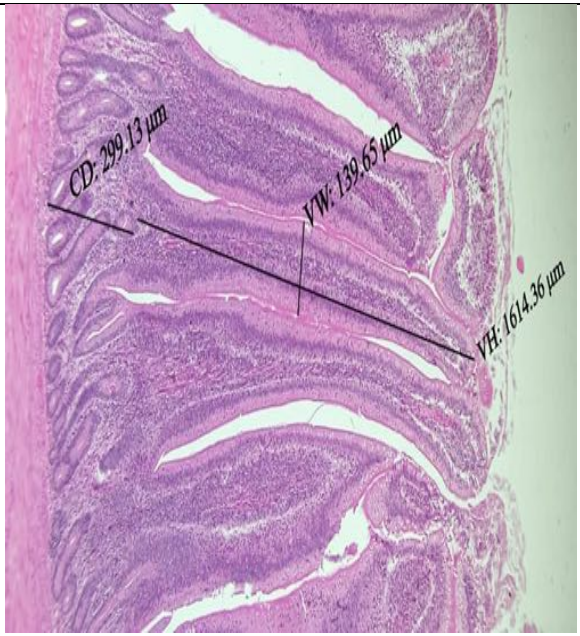
<table>
<tr><td></td><td>Treatment T1</td><td>Treatment T2</td><td>Treatment T3</td></tr>
<tr><td>Jejunum</td><td>

Figure 2(a): Photo showing villi height, width and crypt depth</td><td>

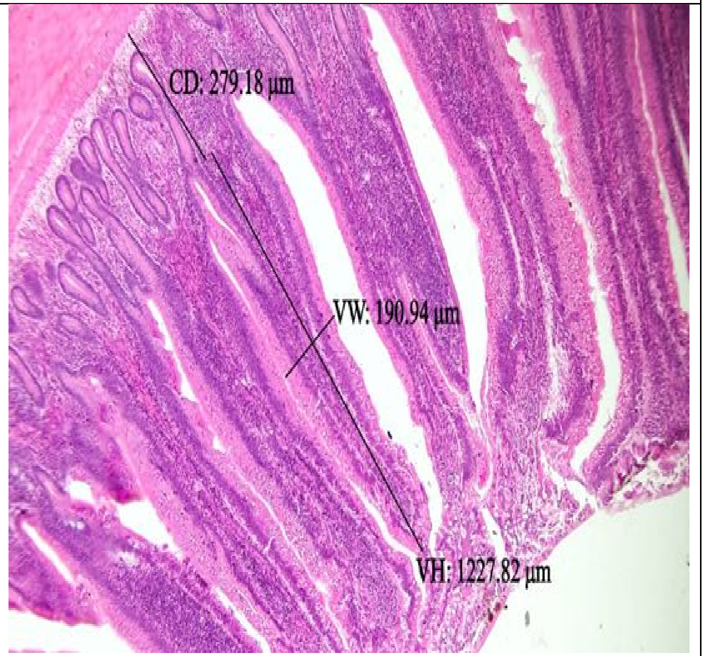
Figure 2(b): Photo showing villi height, width and crypt depth</td><td>

Figure 2(c): Photo showing villi height, width and crypt depth</td></tr>
</table>

Figure 2: Histotomicrograph of the jejunum showing villus height, width and crypt depth of broiler chickens fed dietary treatments T1, T2 and T3

Observations were made using a light microscope at 10x eyepiece and 4x objective lens, with 40x total magnification (Olympus Corporation, Model D21-CB, SN 0010842A2, Tokyo, Japan) equipped with a digital camera (Olympus U-TV0.5XC-3, SN OK73198, Tokyo Japan)

Appendix 3

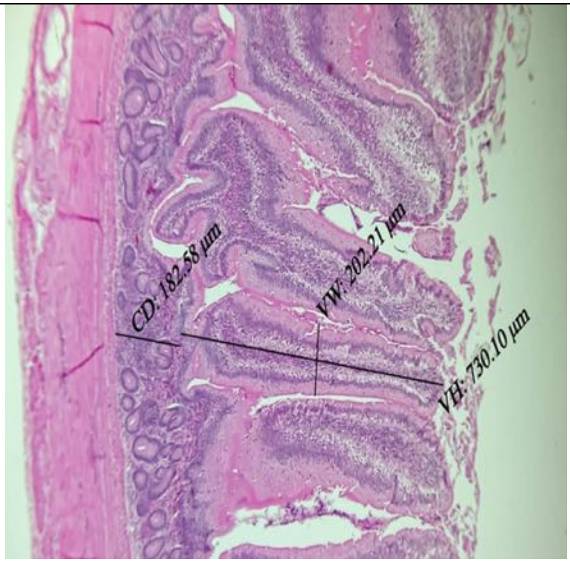
<table>
<tr><td></td><td>Treatment T1</td><td>Treatment T2</td><td>Treatment T3</td></tr>
<tr><td>Ileum</td><td>

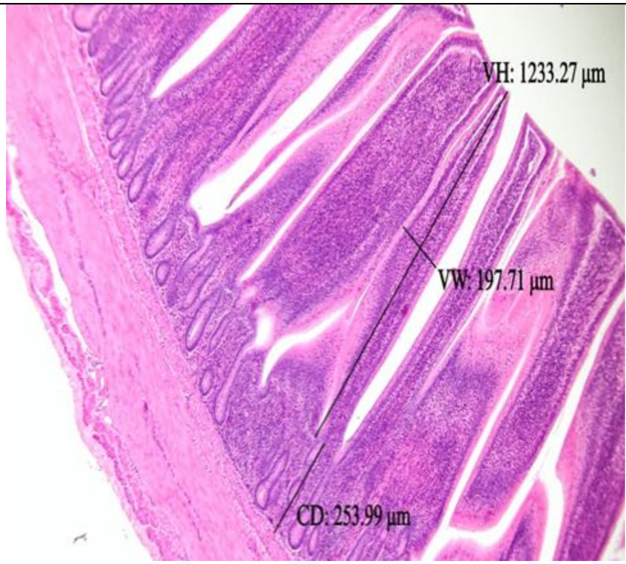
Figure 3(a): Photo showing villi height, width and crypt depth</td><td>

Figure 3(b): Photo showing villi height, width and crypt depth</td><td>

Figure 3(c): Photo showing villi height, width and crypt depth</td></tr>
</table>

Figure 3: Histomicrograph of the ileum showing villus height, width and crypt depth of broiler chickens fed dietary treatments T1, T2 and T3

Observations were made using a light microscope at 10x eyepiece and 4x objective lens, with 40x total magnification (Olympus Corporation, Model D21-CB, SN 0010842A2, Tokyo, Japan) equipped with a digital camera (Olympus U-TV0.5XC-3, SN OK73198, Tokyo Japan