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EFFECT OF POINT OF INTRODUCTION OF SUPPLEMENTAL ENZYME TO *Moringa oleifera* LAM LEAF MEAL ON THE GROWTH PERFORMANCE, NUTRIENT RETENTION AND ECONOMICS OF PRODUCTION OF BROILER CHICKENS

***[1]Babalola O. Kayode, [2]Ogungbesan, M. Ademola, [1]Obasa, A. Oreoluwa, [2]Apata, S. Ebunoluwa, [1]Mako A. Adejoke and [3]Babalola T. Folasade**

[1]Department of Animal Science Tai Solarin Federal University of Education, Ijagun, Ogun State, Nigeria.
[2]Department of Animal Production, College of Agricultural Sciences Olabisi Onabanjo University University Ago-iwoye Ogin State, Nigeria.
[3]Department of Agricultural Economics and Extension Tai Solarin University of Education, Ijagun Ogun State, Nigeria.

*Corresponding authors' email: obasaoa@tasued.edu.ng

ABSTRACT
The study was conducted to address the high cost of poultry feed and limitation associated with the utilization of *Moringa oleifera* leaf meal (MOLM) due to anti-nutritional factors. It investigated how the timing of enzyme supplementation influences growth performance, nutrient utilization, and profitability in broiler chickens fed MOLM-based diets. A total of 150 day-old broiler chicks were assigned to five treatments in a completely randomized design. Diets included 0% or 5% MOLM with enzyme supplementation introduced at different growth stages (day 1, week 2, 4, and 6). Growth performance, feed efficiency, nutrient retention and economic indices were evaluated over 8 weeks using standard analytical procedures. In conclusion, early introduction of enzyme supplemented MOLM at two week 2 significantly improved weight gain, feed efficiency, and profitability without affecting mortality or most nutrient retention parameters. Feed cost was reduced and net profit increased. The study revealed that proper timing of enzyme use enhances the economic and biological value of MOLM, supporting sustainable and cost effective poultry production.

Keywords: Broiler Chickens, Enzymes, Timing Of Introduction, Nutrient Retention, Moringa Leaf-Meal, Growth Performance

INTRODUCTION
Cost of feed remains the key limitation to profitable poultry production, accounting for approximately 60–75% of total cost of production. This is particularly notable in developing countries where reliance on imported feed ingredients has worsened price instability (Alagawany et al., 2023; Ravindran, 2022). This has therefore led to an increased search for unconventional, nutrient-dense, and locally available feed resources that can partially replace conventional feed ingredients without negatively influencing the performance of poultry birds.

Moringa oleifera Lam leaf meal (MOLM) has been spotted as a viable alternative due to its relatively high crude protein content (20–30%), balanced amino acid profile, and abundance of bioactive compounds such as flavonoids, carotenoids, and phenolics that exhibit antioxidant, antimicrobial, and immunomodulatory properties (Gadzirayi et al., 2022; Abbas et al., 2023). In addition, MOLM has been associated with improved gut morphology, enhanced oxidative status, and modulation of lipid metabolism, suggesting its potential usage as both a source of nutrient and functional feed additive.

However, the nutritional benefits of MOLM are not fully realized in monogastric animals due to some digestive limitations in monogastrics. The leaf is characterized by relatively high levels of structural carbohydrates which consists of cellulose and hemicellulose, as well as anti-nutritional factors such as tannins, saponins, and phytates. These components form complexes with proteins and minerals thereby reducing accessibility to endogenous enzymes. They also increase digesta viscosity, ultimately impairing nutrient digestibility and growth performance (Elbaz et al., 2023; Madubuike et al., 2022). These constraints make birds fed MOLM without some dietary modifications exhibit reduced feed conversion and suboptimal weight gain. Consequently, exogenous enzyme supplementation has been widely adopted as a strategy to overcome these constraints.

Enzymes such as cellulase, xylanase, and phytase function by hydrolyzing non-starch polysaccharides and phytate complexes, thereby releasing masked nutrients, improving metabolizable energy, and enhancing mineral bioavailability (Adeola and Cowieson, 2023). In addition, beyond nutrient release, enzyme supplementation has been linked to improved gut health through modulation of microbial populations and reduction of intestinal viscosity therefore presenting a more favorable environment for nutrient absorption (Bedford and Cowieson, 2022). Despite these established benefits, it has been observed that the efficacy of enzyme supplementation does not solely depend on enzyme type or dosage but also depends on the point of introduction into the feeding system (Chen et al., 2023). Also, enzymatic activities are highly sensitive to physicochemical conditions such as temperature, moisture, pH, and substrate availability (Ariaeenejad et al., 2024). For instance, enzymes incorporated during feed processing may be exposed to heat stress during pelleting, potentially reducing activity, whereas post-mixing or water-based application may alter enzyme substrate interaction dynamics and uniformity of distribution (Kiarie et al., 2023). In moringa oleifera based diets, where fiber encapsulation and anti-nutritional factors are key constraints, the timing and mode of enzyme delivery become critically important.

Therefore, a critical knowledge gap exists regarding how the point of enzyme introduction influences growth performance, and physiological responses in broilers fed *Moringa oleifera* Lam leaf meal diets. Addressing this gap is essential for optimizing feeding strategies and maximizing the economic and biological value of *Moringa oleifera* Lam leaf meal.

This study was therefore designed to evaluate the effect of different points of enzyme introduction on growth performance, nutrient retention and economic of production of broiler chickens fed MOLM-based diets. It was hypothesized that enzyme supplementation would enhance nutrient utilization and that its efficacy would vary significantly depending on the time of application.

MATERIALS AND METHODS

The Location of the Study

The experiment was carried out at the poultry unit of the Teaching and Research Farm of Obafemi Awolowo University, Ile- Ife, Osun State, Nigeria. It is located within Latitude 7^0 31'N and 7^0 46'N and Longitude 4^0 36`E and $4^0$ 56`E.The altitude of Ile-Ife ranges from 215 m to 457 m above sea level (Joseph *et al.*, 2014).

Processing of Test Ingredient

Freshly harvested young *Moringa oleifera* leaves cut in not less than 12 weeks after regeneration were obtained from Moringa plantation of the Teaching and Research farm of the Obafemi Awolowo University in Ile-Ife of Osun State. The leaves were air dried for ten (10) days and milled to obtain *Moringa oleifera* Leaf Meal (MOLM) and incorporated into broiler diets in which soya bean was replaced with *Moringa oleifera* leaf meal at 0% (control diet) and 5% respectively.

Management of Experimental Birds

A total of 150-day old broiler chicks of the Arbor Acres strain were procured from a reputable hatchery. Upon arrival, the birds were individually weighed and randomly allocated to five dietary treatments in a completely randomized design. Each treatment consisting of 30 birds were further divided into three replicates of 10 birds each. The control group (T1) was fed a standard basal diet formulated to contain 22% crude protein (CP) and 3100 kcal/kg metabolizable energy during the starter phase, and 19% CP with 2900 kcal/kg metabolizable energy during the finisher phase. In the experimental treatments (T2–T5), *Moringa oleifera* leaf meal (MOLM) was included at 5% as a partial replacement for soybean meal (SBM), with supplemental enzymes incorporated at different points of introduction depending on the treatment.The feeding trial lasted for eight (8) weeks, during which feed and water were provided *ad libitum* and necessary routine management practices were strictly followed.

Experimental Diets

Two diets were formulated, first diet was formulated without *Moringa oleifera* treated with enzyme, while the second diet was formulated with *Moringa oleifera* treated with enzyme (Pollyzyme) supplementation. The test ingredient (*Moringa oleifera* leaf meal) was included at 5% replacement of dietary soya bean while the enzyme (Pollyzyme) was included at 0.1% rate of inclusion according to the Manufacturer's recommendation.

Calculated composition and proximate analysis of the control and treatment diets are presented in Table 1.

Table 1: Percentage Composition, Calculated and Proximate Analyses of Broilers' Starter and Finisher Feed

	B/STARTER		**B/ FINISHER**	
PARAMETERS	**CTRL**	**TRTS**	**CTRL**	**TRTS**
Maize	50.00	50.00	55.00	55.00
Ground nut cake	6.40	6.40	3.80	3.80
Soya bean meal	30.00	25.00	30.00	25.00
Moringa leaf Meal	Nil	5.00	Nil	5.00
Fish meal (72%)	2.00	2.00	1.00	1.00
Wheat offals	7.30	7.30	5.00	5.00
Bone meal	2.00	2.00	2.50	2.50
Limestone	1.50	1.50	2.00	2.00
Salt	0.25	0.25	0.25	0.25
Premix	0.25	0.25	0.25	0.25
Enzyme (Polyzyme)	Nil	0.10	Nil	0.10
Lysine	0.20	0.20	0.10	0.10
Methionine	0.10	0.10	0.10	0.10
TOTAL	**100**	**100**	**100**	**100**
Calculated analysis				
Crude Protein	23.16	22.17	21.38	20.49
Metabolizable Energy	2889.67	2832.74	2921.12	2871.19
PROXIMATE ANALYSIS				
Fat (%)	1.44	0.17	1.27	1.91
Ash (%)	10.51	6.12	9.23	4.37
Crude fibre (%)	6.92	9.73	9.66	10.94
Crude protein (%)	18.91	20.45	15.62	19.31
CHO content (%)	47.52	46.98	46.98	46.94

B/STARTER = Broiler starter, B/FINISHER = Broiler finisher, CTRL = Control,
TRTS = Treatments

Experimental Design and Treatment

Birds were weighed and assigned to five treatments in a Completely Randomized Design. Five treatment groups were replicated three times with ten (10) birds constituting a replicate. Weights of birds in the replicate groups were adjusted to give a near uniform weight. The feeding trials lasted for eight (8) weeks.

Two diets were allocated to the five treatments. Treatment 1 was the control which has a diet, without *Moringa oleifera* leaf meals and ENZYME, Treatments 2, 3, 4, and 5 had diets with 5% *Moringa oleifera* Leaf Meal inclusion which was used to replace soya bean meal (SBM) supplemented with

polyzyme (Exogenous enzymes) at the Manufacturer's recommended inclusion rate of 500g/ton (i.e. 0.05%). The time of introduction of this diet to the experimental birds then formed the treatments as follows:
Treatment 1- Without MOLM and ENZYME (Control)
Treatment 2- 5% MOLM with ENZYME introduced at day 1
Treatment 3- 5% MOLM with ENZYME introduced at week 2
Treatment 4- 5% MOLM with ENZYME introduced at week 4
Treatment 5- 5% MOLM with ENZYME introduced at week 6

Growth Performance

Birds were weighed individually at the beginning of the trial and weekly subsequently. Dry matter intake and mortality were recorded daily during the whole experiment. The final weight gain was determined by subtracting the initial weight of birds from the final weight. The feed conversion ratio (FCR) was calculated as the ratio of feed consumed to weight gain. Weekly feed conversion ratio was calculated by dividing the weekly feed consumption by weekly body weight changes.

The weekly cumulative feed conversion ratio was calculated by dividing total amount of feed consumed up to that particular week by the body weight gain record up to that week.

$$FCR = \frac{\text{Total feed consumed (g)}}{\text{Gain in body weight (g)}}$$

Whereas the efficiency of feed utilization (EFU) was calculated by dividing the average daily weight gained per bird by the average daily Dry Matter Intake per bird in (g).

Nutrient Balance/Retention Studies

The metabolic study was carried out from day 47 to day 52 of the age of the birds. Two birds per replicate were put in metabolic cages with wire floor. Birds had free access to feed and water throughout the experiment. Droppings from each replicate group of birds were collected on a wooden sheet placed under the cages. Droppings were collected in each 24-hour period for 5 consecutive days. The droppings collected were weighed, dried to constant weight and ground before chemical analysis.

Representative samples of excreta for each treatment were then analysed for proximate analysis using the procedures outlined by Association of Analytical Chemist (AOAC 2006). Apparent nutrient retention was determined for crude protein, fat, crude fibre, ash and nitrogen free extract using the equation below.

$$\text{Nutrient retention} = \frac{\text{Nutrient intake} - \text{Nutrient output} \times 100}{\text{Nutrient intake}}$$

Where: Nutrient intake (g) = Dry feed intake × Nutrient in diet
Nutrient output (g) = Dry feacal output × Nutrient in faeces

RESULTS AND DISCUSSION

Table 2 shows the effect of Moringa oleifera leaf meal (MOLM) supplemented with enzymes introduced at different growth phases on the performance of broiler chickens. There were no significant differences ($p > 0.05$) in initial body weight across all treatments, indicating that the birds were comparable at the start of the experiment and that subsequent responses were due to dietary treatments. Final body weight, body weight gain, and daily weight gain were significantly ($p < 0.05$) influenced by the treatments. Birds in T2 and T3 recorded significantly higher ($p < 0.05$) growth performance compared to those in T1, T4, and T5, which had a statistically similar ($p > 0.05$) weight. This finding suggests that introducing enzyme supplemented Moringa oleifera leaf meal during the early life stage of broiler chickens enhances growth performance. The enhanced performance observed in T2 and T3 can be attributed to better nutrient availability resulting from enzymatic degradation of fiber and anti-nutritional factors present in Moringa oleifera leaves. This finding of this study is in consonance with Hassan et al. (2022), who reported an improved growth performance in broilers fed *Moringa oleifera* leaf meal when compared with control birds. In addition, Tufarelli et al. (2023) demonstrated that the combination of Moringa oleifera leaf meal with exogenous enzymes (such as xylanase and cellulase) significantly influenced nutrient digestibility and growth performance. In relation to the present study, the superior performance in T2 and T3 indicates that the time of introduction of supplemental enzyme to MOML allowed birds a better utilization of the nutrients released.

Feed intake (total and daily dry matter intake) was significantly ($p < 0.05$) affected by treatment. Birds in T2, T3, and T4 showed significantly higher ($p < 0.05$) feed intake compared to those in T1 and T5, which had statistically similar ($p > 0.05$) values. The increased feed intake may be linked to improved palatability which improved voluntary intake thereby bringing about an increase in feed intake. In addition, early life introduction of supplemental enzyme to MOML brought about an early life enhanced gut function, which enhanced the breakdown of complex carbohydrates and improved nutrient digestibility. This result supports the findings of Olagunju et al. (2023) who reported increased feed intake in broilers fed Moringa oleifera leaf extract. Furthermore, Abd El-Hack et al. (2022) found that enzyme supplemented Moringa oleifera leaf meal improved feed intake by enhancing nutrient utilization and reducing gut viscosity. These findings align with the present study, where early to midlife timing of MOLM introduction (T2–T4) improved feed consumption.

Feed conversion ratio (FCR) and efficiency of feed utilization (EFU) were significantly ($p < 0.05$) influenced by the treatment. Birds in T2 and T3 recorded a significantly better FCR and higher EFU, while those in T1, T4 and T5 recorded significantly poorer FCR and lower EFU. This indicates that early to midlife introduction of MOLM with enzymes improves feed utilization efficiency. According to Cowieson et al. (2021), enzymes allow an improved breakdown of non-starch polysaccharides and release encapsulated nutrients, leading to better feed efficiency and conversion. In this present study, it can be suggested that birds in T2 and T3 are likely to have benefited from prolonged exposure to these effects, whereas delayed introduction (T4 and T5) impaired feed efficiency and conversion negatively.

Values obtained for mortality were not significantly ($p > 0.05$) affected by the different points of introduction of enzyme-supplemented Moringa oleifera leaf meal (MOLM). All treatment groups were statistically similar, indicating that neither early nor late inclusion of MOLM with enzyme supplementation had a negative effect on bird survival. The statistically similar and low values obtained within treatment groups in mortality aligns with findings by Sarker et al. (2021) and Chisoro et al., (2023) who reported that inclusion of *Moringa oleifera* leaf meal did not adversely affect survivability of broiler chickens. El-Tazi et al. (2022) opined that the reduction effect observed in mortality could be attributed to the antioxidant and antimicrobial properties in moringa oleifera which enhances immune functions.

Table2: Performance Characteristics of Broiler Chickens Fed *Moringa Oleifera* Lam Leaf Meal with Enzymes Introduced at Different Stages of Growth

PARAMETERS	T1	T2	T3	T4	T5	SEM
Initial weight (g/bird)	42.20	42.37	42.10	42.15	42.10	0.05
Final body weight (g/bird)	1489.67^{b}	1595.33^{a}	1616.67^{a}	1453.67^{b}	1441.33^{b}	31.74
Body weight changes (g/bird)	1447.43b	1552.97a	1574.57a	1411.52b	1399.23b	31.71
Daily weight changes(g)	25.85^{b}	27.75^{a}	28.12^{a}	25.21^{b}	25.31^{b}	0.54
Total DMI (g/bird)	3435.47^{b}	3621.10^{a}	3576.33^{a}	3549.33^{a}	3495.00^{b}	17.45
Daily DMI (g)	61.35^{b}	64.66^{a}	63.86^{a}	63.38^{a}	62.41^{b}	0.06
Feed conversion ratio	2.39b	2.34b	2.28b	2.52a	2.52a	0.05
Efficiency of feed utilization	0.33^{b}	0.35^{a}	0.36^{a}	0.32^{b}	0.32^{b}	0.01
Mortality (%)	0.02	0.00	0.00	0.00	0.02	0.01

^{a,b,c,d,} means with different superscripts on the same row differ significantly (P<0.05),
T1=Without *Moringa oleifera* leaf meal & enzyme (control), T2= 5% *Moringa oleifera* leaf meal introduced at day 1, T3= 5% *Moringa oleifera* leaf meal introduced at week 2, T4= 5% *Moringa oleifera* leaf meal introduced at week 4, T5= 5% *Moringa oleifera* leaf meal introduced at week 6, SEM = Standard error of mean, DMI= Dry matter intake, MOLM = *Moringa oleifera* leaf meal

Table 3 presents the effect of *Moringa oleifera* leaf meal (MOLM) supplemented with enzymes at different points of introduction on nutrient retention in broiler chickens.

Results obtained for dry matter, ash, crude fibre, and crude protein retention were not significantly (p > 0.05) affected by the treatments. The non-significant (p > 0.05) differences observed in dry matter retention across treatments suggest that the overall digestibility of the diets was not affected by the time of introduction of enzyme-supplemented Moringa oleifera leaf meal. This result corresponds with report of Adeola and Cowieson (2023), who emphasized that exogenous enzyme supplementation often stabilizes total tract digestibility, resulting in minimal variation in dry matter utilization across dietary treatments. In the same vein, the absence of significant differences in ash retention indicates that mineral utilization was not adversely affected by the different feeding strategies. This is result is in consonance with reports by Kiarie et al. **(2023)**, who noted that enzyme supplementation enhances mineral availability (particularly phosphorus and calcium) in a relatively uniform manner, thereby limiting treatment-related variability in ash retention. Also, the non-significant effect of the time of introduction of supplemental enzyme to MOML on crude fibre retention of broiler birds suggests that enzyme supplementation may have effectively mitigated the anti-nutritional effects of fibre present in *Moringa oleifera* leaf meal across all treatments. This observation aligns with Bedford and Cowieson (2022), who reported that carbohydrase enzymes such as xylanase and cellulase improves fibre degradation consistently. This could be attributed to the comparable fibre digestibility irrespective of feeding phase or timing of inclusion. In addition, the lack of significant differences in crude protein retention indicates that protein utilization from *Moringa oleifera* leaf meal remained stable across treatments. According to Abbas et al. (2023), Moringa *oleifera* possesses a well-balanced amino acid profile and relatively high digestibility, thereby making protein utilization less sensitive to variations in dietary manipulations. The result of this study is in consonance with the findings of Alagawany et al. (2023) who observed that moderate inclusion of *Moringa oleifera* leaf meal does not significantly alter protein digestibility in broiler chickens.

Conversely, fat retention was significantly (p < 0.05) influenced by treatment effect. Birds in T2 showed significantly higher fat retention, while those in T4 and T5 recorded significantly lower values. This pattern suggests that introducing enzyme-supplemented MOLM early in life enhances lipid utilization, whereas delaying its introduction reduces the efficiency of fat digestion. According to Attia et al., (2022) early life exposure of broiler birds to enzymes allows them to better adapt their digestive processes to the breakdown of plant-based lipids, thereby improving lipid utilization efficiency. Zhang et al. (2022) reported that enzyme supplementation improved lipid utilization and a reduced intestinal viscosity thereby enhancing nutrient absorption. This result corroborates the findings of Elbaz et al. (2023), who reported improved fat digestibility in broilers fed enzyme treated *Moringa oleifera* diets.

Values obtained for crude protein did not show significant differences (P>0.05) among the treatments. The absence of significant differences in crude protein suggests that protein utilization from MOLM remained stable across treatments. The result is consistent with the findings of Abbas et al., (2023), who reported that Moringa oleifera leaf meal has a balanced amino acid profile and good digestibility. In addition, Alagawany et al., (2023) indicated that mild inclusion levels of Moringa oleifera in diets of broiler birds do not negatively affect protein utilization and assimilation in broilers. Values obtained for Crude fiber retention was also not significantly affected (P>0.05) by the time of introduction of supplemental enzyme to MOML. This suggests that enzyme supplementation was effective in alleviating the constraints associated with fiber digestion in monogastric animals. According to Walker et al., (2024), exogenous enzymes improve fiber utilization by breaking down non-starch polysaccharides and reducing their anti-nutritional effects, these therefore creates a more favorable gut environment.

Table 3: Nutrient Retention of Broiler Chickens Fed Supplemental Enzyme to *Moringa oleifera* Lam Leaf Meal

PARAMETERS	T1	T2	T3	T4	T5	SEM
Dry matter (%)	90.99	91.01	90.25	89.97	88.82	0.49
Fat (%)	5.82^{ab}	8.80^{a}	5.17^{ab}	2.51^{b}	3.44^{b}	0.73
Ash (%)	7.72	7.81	7.62	6.84	6.72	0.45
Crude fibre (%)	10.12	11.31	10.68	9.82	9.14	0.47
Crude protein (%)	7.23	7.66	6.92	6.11	5.62	0.47

PARAMETERS	T1	T2	T3	T4	T5	SEM
NFE (%)	60.1^{ab}	55.46^{bc}	59.86^{b}	64.69^{a}	63.90^{a}	0.99

^{a,b,c} means with different superscripts on the same row differ significantly (P<0.05)

T1=Without *Moringa oleifera* leaf meal & enzyme (control), T2= 5% *Moringa oleifera* leaf meal introduced at day 1, T3= 5% *Moringa oleifera* leaf meal introduced at week 2, T4= 5% *Moringa oleifera* leaf meal introduced at week 4, T5= 5% *Moringa oleifera* leaf meal introduced at week 6, SEM = Standard error of mean, DMI= Dry matter intake, MOLM = *Moringa oleifera* leaf meal.

Economic of Production of broiler chickens fed supplemental enzyme to *Moringa oleifera* Lam. leaf meal is presented in table 4. Values obtained for total dry matter intake differed significantly (P < 0.05), with birds in T2 (3.62 kg/bird), T3 (3.57 kg/bird), and T4 (3.55 kg/bird) recording higher feed intake compared to T1 (3.43 kg/bird) and T5 (3.49 kg/bird). The increased intake in early life and mid-life introduction groups suggests improved palatability and enhanced digestive efficiency, likely mediated by enzyme supplementation which aided in the breaking down of fibrous components in MOLM. Values obtained for feed cost per kilogram was significantly reduced (P < 0.05) in T2 (₦153.00/kg) and T3 (₦153.50/kg) when compared to T1 (₦160.10/kg) and T5 (₦157.50/kg). This indicates the economic advantage of incorporating *Moringa oleifera* leaf meal as a partial replacement for conventional protein sources. This result is in consonance with the report of Khalid et al. (2022) who reported that replacing soybean meal with *Moringa oleifera* leaf meal reduced cost of feeding without compromising the performance of the birds. This highlights its potential as a cost effective alternative in broiler diets. The cost of dry matter intake was significantly higher (P<0.05) in T2 (₦553.85) regardless of the low feed cost per kilogram obtained from it. The higher cost of feed obtained in T2 is driven by its significantly higher feed consumption. This however, did not translate into economic loss, as birds in T2 exhibited improved body weight gain, indicating effective nutrient conversion.

Values obtained for cost of production were not significantly influenced by the inclusion of enzyme supplemented MOML at different introduction point. This suggests that MOLM inclusion at 5% in the diet of broilers does not influence production. However, income per bird was significantly highest (P < 0.05) in T3 (₦1300), followed by T2 (₦1266.67), while T1, T4, and T5 recorded significantly lower values (₦1233.33) respectively. This superior income obtained in T3 is associated with its higher body weight gain. This confirms that growth performance is a primary driver of revenue in broiler production systems. The result obtained in this study corresponds with the reported by Elghandour et al. (2022), where broilers fed *Moringa oleifera* based diets recorded an increased feed consumption, which lead to increase in production cost but with better overall performance and efficiency. This indicates that higher production cost under MOLM inclusion is not necessarily detrimental but may reflect enhanced nutrient utilization and metabolic activity.

In addition, net profit was also significantly highest (P < 0.05) in T3 (₦351.49), followed by T2 (₦312.81), while T1 (₦283.66), T4 (₦283.60), and T5 (₦283.13) recorded statistically similar values. The higher profitability in T3 indicates an optimal balance between feed cost, feed intake, and growth performance. According to Adeleye et al. (2023), precise timing of dietary interventions with phytogenic additives is an essential factor in maximizing economic returns in broiler production. In addition, Zhang et al. (2024) reported that well planned early phase feeding improves feed conversion and profitability more than late dietary modifications. Conversely, the low cost of production recorded in T3 despite having a significantly higher weight gain when compared with birds on control diet aligns with its optimized balance between feed intake and feed efficiency. This finding agrees the reports of Oloruntola et al. (2023) and Khanal et al. (2022) who both reported that partial replacement of conventional protein sources with *Moringa oleifera* leaf meal reduced feed cost and total production cost without compromising growth performance. Furthermore, Abd El-Hack et al. (2022) reported that inclusion of *Moringa oleifera* leaf meal in broiler diets can reduce the cost of feed formulation and consequently lower the cost of production per unit of weight gain. This is in tandem with the present result where T3 (week 2 introduction) recorded an optimal performance. This suggests that the timing of MOLM inclusion plays a critical role in determining how effectively cost-savings results into production efficiency. The relatively similar production costs observed in T1, T4, and T5 when compared with T3 further strengthens the assertion that late inclusion of MOLM does not significantly bring down cost of production. This may however, limit the economic advantage due to poorer growth performance. This corresponds with the report of Elghandour et al. (2022) who opined that while alternative feed ingredients such as *Moringa oleifera* can reduce feed cost, their benefits are maximized only when birds are physiologically adapted to utilize them efficiently.

This study provides clear evidence that enzyme-supplemented *Moringa oleifera* leaf meal (MOLM) can be effectively incorporated into broiler diets without compromising bird health, nutrient utilization, or overall production stability. What stands out, however, is that *when* MOLM is introduced matters just as much as *how much* is included.

CONCLUSION

Introducing MOLM at the early stages of growth especially at week 2 of age, gave the best outcomes. Birds at this stage appear to have adapted better to the dietary treatments resulting in improved feed intake, better weight gain and more efficient feed utilization. This suggests that early exposure allows the digestive system to adjust to the fibrous nature of *Moringa oleifera*, especially when supported by enzyme supplementation that boosts nutrient release and absorption.

However, delayed introduction of enzyme supplemented MOLM reduced its effectiveness. Birds introduced late to the diet showed reduced growth and feed efficiency. This indicates that the benefits of MOLM are not automatic, they actually depend largely on aligning the time of introduction of enzyme supplemented MOML with the physiological development of the birds.

From the economic perspective, although MOLM inclusion did not drastically lower the overall cost of production, however, it significantly reduced cost of production and more largely enhanced profitability when introduced at the appropriate time. The highest income and net profit recorded at week 2 reflects an optimal interaction between feed cost, intake, and growth performance. This implied that the birds were not just eating more, they converted what they eat more efficiently.

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