



RESEARCH ARTICLE

Effects of Dietary Supplementation with *Moringa oleifera* Leaf Meal and *Parkia biglobosa* Pulp Meal on the Egg Production Performance of ISA Brown Laying Hens During the Hot Season in Western Burkina Faso

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Abstract

Background and Objective: Heat stress is a major constraint to poultry production in tropical regions, adversely affecting laying performance and overall productivity. This study evaluated the effects of dietary supplementation with *Moringa oleifera* leaf meal and *Parkia biglobosa* pulp meal on the productive performance and egg quality of ISA Brown laying hens during the hot season in Burkina Faso.

Materials and Methods: A total of 372 ISA Brown laying hens, 19 weeks of age, were randomly allocated to one of three dietary treatments: a control diet (CT), a diet supplemented with 2% *Moringa oleifera* leaf meal (MLT) and a diet supplemented with 2% *Parkia biglobosa* pulp meal (PPT). Laying performance and egg quality traits were assessed throughout the experimental period.

Results: Overall, feed conversion ratio (FCR) was relatively high across all treatments but was significantly improved in the MLT group (4.78 ± 0.35) compared with the PPT (5.37 ± 0.43) and CT (5.82 ± 0.52) groups ($p < 0.05$). At 27 weeks of age, hens fed the MLT diet achieved the highest laying rate (73%), compared with 54 and 50% in the PPT and CT groups, respectively. In addition, the MLT diet produced significantly heavier eggs (51.28 ± 3.82 g) with a higher yolk colour index (7.06 ± 1.00) than the other dietary treatments ($p < 0.05$).

Conclusion: Dietary supplementation with *Moringa oleifera* leaf meal improved feed efficiency, laying performance and selected egg quality traits under hot environmental conditions. These findings indicate that *Moringa oleifera* leaf meal is a promising, sustainable and locally available feed additive for enhancing the productivity of laying hens exposed to tropical heat stress, with greater benefits than *Parkia biglobosa* pulp meal under the same conditions.

INTRODUCTION

Poultry production plays a vital role in ensuring food security and generating income in Burkina Faso, particularly in rapidly expanding urban areas such as Bobo-Dioulasso. Egg

production is a major component of the poultry sector, contributing substantially to household nutrition and the livelihoods of poultry farmers. Furthermore, poultry production is closely integrated with crop farming, as poultry manure serves as an important source of soil fertility for

smallholder production systems¹. According to FAOSTAT, Burkina Faso produced approximately 68.11 thousand tons of hen eggs in 2023, highlighting the increasing importance of the poultry industry within the national food system. Eggs are among the most affordable and accessible sources of high quality animal protein. However, egg consumption in many African countries remains below the global average because of limited purchasing power and prevailing economic constraints^{2,3}. In Burkina Faso, the affordability of eggs is further challenged by high production costs, largely attributable to the reliance on conventional feed ingredients, including fishmeal, soybean meal and cottonseed meal, whose availability and market prices are often unstable⁴. This situation has stimulated interest in identifying locally available, nutritionally valuable and cost effective feed resources that can reduce production costs while sustaining productivity.

Poultry production is further constrained by high ambient temperatures, particularly during the hot season, which extends from March to June in Burkina Faso and frequently exposes birds to heat stress. Heat stress reduces feed intake, impairs nutrient utilization and adversely affects laying performance, thereby resulting in substantial economic losses for producers⁵⁻⁷. Consequently, considerable attention has been directed toward nutritional strategies capable of enhancing the resilience of laying hens to thermal stress. In addition, consumer demand has increasingly shifted toward eggs with superior quality attributes, particularly attractive yolk pigmentation, which is strongly influenced by the dietary supply of natural pigments⁸.

The utilization of indigenous feed resources has long been recognized as a promising strategy for improving poultry production under tropical conditions, especially in Burkina Faso, where locally available feed ingredients have the potential to reduce feeding costs while improving nutrient supply^{9,10}. Among the alternative feed resources receiving increasing attention, *Moringa oleifera* leaves and *Parkia biglobosa* pulp are of particular interest because of their rich nutritional composition and potential functional properties. Several studies have demonstrated that these plant materials contain high concentrations of proteins, energy, vitamins, minerals and bioactive compounds, highlighting their considerable potential as poultry feed ingredients¹¹⁻¹³. They are also rich sources of carotenoids, polyphenols, vitamin C and essential minerals, which possess antioxidant properties and may help alleviate the adverse effects of heat stress. Consequently, the inclusion of these plant materials in poultry diets may not only improve bird health and survivability but also enhance laying performance and yolk pigmentation¹⁴.

Given their local availability, nutritional value and functional properties, the incorporation of *M. oleifera* leaf meal and *P. biglobosa* pulp meal into poultry feeding programs represents a potentially sustainable strategy for improving the productivity and profitability of table egg production under semi-intensive production systems in Burkina Faso. Nevertheless, despite the increasing interest in these alternative feed resources, information regarding their use in diets of laying hens exposed to severe heat stress remains limited, particularly under Burkinabe production conditions.

Therefore, the present study was conducted to address this knowledge gap by evaluating the effects of dietary supplementation with *M. oleifera* leaf meal and *P. biglobosa* pulp meal on the productive performance of Isa Brown laying hens. Specifically, the study assessed the effects of these dietary supplements on laying performance, egg physical characteristics and the economic efficiency of feed utilization.

MATERIALS AND METHODS

Site and study period: The experiment was conducted at the poultry research facility of the Institute for Rural Development, Nazi Boni University, located in the village of Nasso (11° 12' 38.77"N, 4° 25' 09.84"W), approximately 15 km from Bobo-Dioulasso, Burkina Faso. The study was carried out over a two-month period, from May to June, corresponding to the hottest season of the year.

Nasso is situated within the South Sudanian agroecological zone, which is characterized by relatively high annual rainfall, often exceeding 1,100 mm¹⁵. Despite this favorable rainfall regime, the area experiences high ambient temperatures, particularly during the dry season. In 2024, the average maximum ambient temperature was approximately 34.0°C, while peak temperatures during the hottest months approached 38°C^{16,17}. These climatic conditions are known to expose poultry to considerable heat stress, which may adversely affect their productive performance.

To accurately characterize the environmental conditions experienced by the birds throughout the experimental period, ambient temperature and relative humidity inside the poultry house were monitored daily using a data logger (HOBO U12-012, Onset Computer Corporation, Bourne, MA, USA). The device, with an accuracy of $\pm 0.35^{\circ}\text{C}$ for temperature and $\pm 2.5\%$ for relative humidity, was positioned at bird level in the center of the poultry house to obtain representative measurements of the microclimate. The logger operates within measurement ranges of -20 to 70°C for temperature and 5 to 95% for relative humidity. Temperature and relative humidity were recorded daily at 07:00 and 15:00 and were

subsequently used to calculate the temperature-humidity index (THI), a widely recognized indicator of heat stress in poultry. These measurements provided a comprehensive assessment of the thermal environment to which the hens were exposed.

Animals and experimental design: A total of 372 ISA Brown laying hens, 18 weeks of age, were reared specifically for this study. Throughout the rearing period, all birds received the recommended prophylactic treatments to ensure an adequate health status before the commencement of the experiment. The ISA Brown strain was selected because of its well-documented laying performance and its widespread use in local poultry production systems¹⁸.

The experiment was conducted using a randomized complete block design^{19,20}. Before treatment allocation, the birds underwent a two-week adaptation period to acclimate them to the experimental conditions. At the end of this period, all hens were individually weighed, sorted to ensure uniformity among experimental groups and randomly assigned to one of three dietary treatments:

- Control treatment (CT), receiving the standard layer diet;
- *Moringa oleifera* leaf treatment (MLT), receiving the standard diet supplemented with 2% *M. oleifera* leaf meal;
- *Parkia biglobosa* pulp treatment (PPT), receiving the standard diet supplemented with 2% *P. biglobosa* pulp meal.

Each dietary treatment consisted of 124 laying hens allocated to four replicates (blocks) of 31 birds each. Replicates were considered the experimental units for all statistical analyses.

To facilitate adaptation to the experimental diets, a transition period was implemented before the commencement of data collection.

The trial was conducted in a naturally ventilated, semi-open poultry house oriented along an east-west axis. To accommodate the experimental design while maintaining comparable rearing conditions among treatments, the facility was divided into three separate sections using wire-mesh partitions. This arrangement ensured that all birds were exposed to similar environmental conditions throughout the experimental period.

Bird health was monitored daily throughout the study. Suspected disease cases were initially identified through clinical observations and subsequently confirmed by postmortem examination following the procedures described by Zachary and McGavin²¹.

Additives selection and diet formulation: *Parkia biglobosa* pulp meal and *Moringa oleifera* leaf meal were selected as plant-derived feed resources because of their nutritional value and functional properties. Both ingredients are rich sources of energy, vitamin C, carotenoids and other bioactive compounds and possess antioxidant, immunostimulatory and metabolic regulatory properties^{22,23}. An inclusion level of 2% was selected based on previous studies to minimize potential antinutritional effects while ensuring practical applicability under field conditions.

Fresh *M. oleifera* leaves were purchased from a local market for 3,500 XOF (5.83 USD, 1 USD ≈ 557.5 XOF) and processed to obtain 2 kg of leaf meal. In addition, 1 kg of *P. biglobosa* pulp powder was purchased for 125 XOF (0.21 USD).

The experimental diets were formulated using UNE-FORME MONOGASTRIC software, which incorporates the Microsoft Excel Solver optimization tool²⁴. Nutrient requirements were established according to the recommendations of Leeson and Summers²⁵ and the ISA management guide for commercial laying hens.

The three experimental diets were formulated to be isonitrogenous and isoenergetic. The ingredient composition of diets is presented in Table 1. Diet formulation was adapted from locally recommended poultry feeding practices and the technical guidelines previously developed by the former Centre de Promotion de l'Aviculture Villageoise (CPAVI), Ministry of Animal and Fishery Resources of Burkina Faso²⁶. The estimated nutritional composition of the experimental and control diet is presented in Table 2.

Table 1: Composition of experimental and control diet for laying hens

Ingredients	Diets (%)		
	CT	MLT	PPT
Maize	60.6	60.15	59
Wheat bran	6.75	6.2	6.25
Fishmeal	4	4	4.2
Cottonseed meal	8.3	8.1	8.7
Soybean meal	11.5	10.7	11
Iron sulfate	0.5	0.5	0.5
Salt	0.3	0.3	0.3
Dicalcium phosphate	0.3	0.3	0.3
L-Lysine	0.1	0.1	0.1
DL-Methionine	0.2	0.2	0.2
Premix*	0.25	0.25	0.25
Oyster shells	7.2	7.2	7.2
<i>M. oleifera</i> leaf meal	0	2	0
<i>P. biglobosa</i> pulp meal	0	0	2
Total	100	100	100

CT: Control treatment, MLT: 2% *M. oleifera* leaf treatment, PPT: 2% *P. biglobosa* pulp treatment, (*) Made of minerals, vitamins, amino acids and trace elements

Table 2: Estimated chemical composition of the formulated diets

Nutrient	*Nutritional requirements	CT	MLT	PPT
	(reference values)			
ME (kcal/kg.DM ⁻¹)	2,800	2,832	2,813	2,829
Crude protein (%)	18.00	17.88	17.89	17.93
Crude fat (%)	3.00	3.19	3.26	3.14
Fiber (%)	3.00	3.27	3.55	3.36
Lysine	0.95	0.95	0.95	0.95
Methionine	0.48	0.48	0.48	0.48
Calcium (%)	3.6	3.58	3.62	3.59
Available phosphorus (%)	0.35	0.33	0.34	0.32

*Leeson and Summers²⁷ and ISA²⁵

Data collection: The variables recorded during the experimental period included ambient temperature, relative humidity, feed intake, laying rate, egg weight, egg component weights, egg yolk volume and yolk colour index. The formulas used to calculate some key parameters are presented below. Percentage data were subjected to arcsine square root transformation prior to analysis of variance (ANOVA) to satisfy the assumptions of normality and homogeneity of variance.

The quantities of feed offered and feed refusals were weighed each morning using an electronic balance with an accuracy of ± 5 g. Eggs were collected and counted daily at 17:00 h to determine laying performance and egg production parameters.

Temperature Humidity Index (THI): THI was calculated using the equation proposed by the National Research Council²⁸, adapted for the assessment of heat stress in poultry:

$$THI = (1.8T + 32) - [(0.55 - 0.0055 \times HR) \times (1.8T - 26)] \quad (1)$$

where, T represents the ambient temperature ($^{\circ}\text{C}$) and HR, the relative humidity (%)²⁸.

Daily feed intake (DFI): DFI was calculated as:

$$DFI (g) = \frac{Qd - Qr}{n} \quad (2)$$

Where:

Qd : Quantity of feed distributed (g)

Qr : Quantity of feed refused (g)

n : Number of hens in the batch

Feed conversion ratio (FCR): FCR was calculated as:

$$FCR = \frac{\text{Feed intake (kg)}}{\text{Number of eggs} \times \text{Average egg weight}} \quad (3)$$

Laying rate (LR): LR was expressed as a percentage and calculated according to the method described by Effiong *et al.*²⁹ using the following formula:

$$LR (\%) = \frac{\text{Number of eggs produced}}{\text{Number of hens} \times \text{number of days}} \times 100 \quad (4)$$

Egg weight: Weights of egg and its individual components (yolk, albumen and shell) were measured using a precision balance with an accuracy of 0.001 g.

Egg size: Egg size was evaluated by measuring its width (minor diameter) and length (major diameter) using a digital caliper with an accuracy of ± 0.02 mm.

Egg volume: Egg volume was calculated according to the method described by Narushin *et al.*³⁰ using the following formula:

$$V = 0.5202 \times L \times B^2 - 0.4065 \quad (5)$$

Where:

L : Length

B : Width

Yolk colour was evaluated using the DSM Roch Colour FanTM and scored on a scale ranging from 1 (pale yellow) to 15 (deep orange)³¹.

Statistical analyses: All data were analyzed using MINITAB statistical software (Version 19.2020.1). Descriptive statistics were generated and data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure. Prior to analysis, the assumptions of normality and homogeneity of variance were verified. When significant treatment effects were detected, mean values were separated using Tukey's multiple comparison test at a significance level of 5%.

Ethical statement: All animal procedures performed in this study were conducted in accordance with internationally recognized guidelines for the care and use of animals in research. Throughout the experimental period, particular attention was given to safeguarding bird welfare by minimizing stress, discomfort and unnecessary suffering, especially under the high ambient temperatures experienced during the hot season. Feed and water were provided *ad libitum*, housing, husbandry and health management practices were implemented in accordance with established poultry welfare recommendations.

RESULTS

Climatic conditions during the study: The microclimatic conditions recorded throughout the experimental period are presented in Fig. 1 and 2. Ambient temperature inside the poultry house ranged from 26.6 to 32.1°C and showed only slight temporal fluctuations (Fig. 1). In contrast, the THI exhibited greater variation, ranging from 72 to 83. Although THI values remained relatively low until March, they increased markedly from early April onward and consistently exceeded 75 thereafter (Fig. 2), indicating the progressive intensification of heat stress conditions during the latter part of the study.

Effects of the inclusion of *M. oleifera* leaf meal and *P. biglobosa* pulp meal on feed intake: The effects of the dietary treatments on Daily Feed Intake (DFI) and Feed Conversion Ratio (FCR) are presented in Fig. 3. Dietary supplementation significantly affected DFI, with hens fed the

M. oleifera leaf meal diet exhibiting the highest feed intake (90.8 g DM/hen/day), followed by those receiving the *P. biglobosa* pulp diet (88.2 g DM/hen/day). In contrast, hens in the control treatment (CT) consumed the least amount of feed (84.2 g DM/hen/day). Feed intake was significantly greater in both supplemented groups than in the control group ($p = 0.016$).

Although, FCR tended to decline in the supplemented groups, the differences were not statistically significant ($p = 0.063$). The lowest FCR was recorded in the MLT group (4.92), indicating greater feed utilization efficiency, followed by the PPT group (5.37), whereas the control group exhibited the highest FCR (5.83).

Estimated nutrient and energy intakes were generally comparable among the three dietary treatments. Nevertheless, slightly higher nutrient and energy intakes were observed in the supplemented groups, particularly in hens receiving the *M. oleifera* leaf meal diet (Table 3).

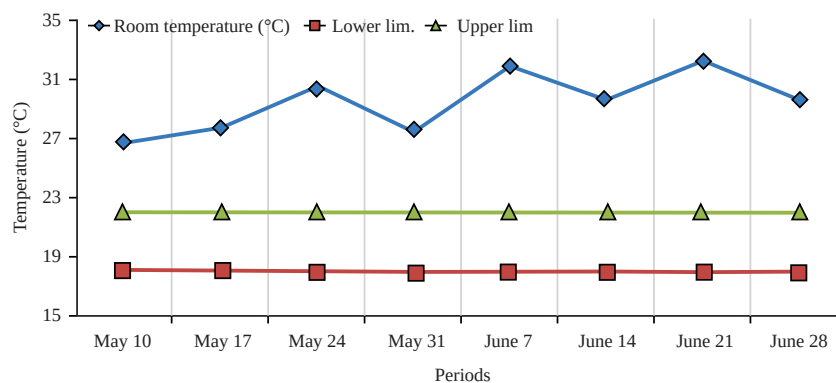


Fig. 1: Variation in hen house temperature during the experimental period

Lower lim: Lower limit of thermal comfort, Upper lim: Upper limit of thermal comfort

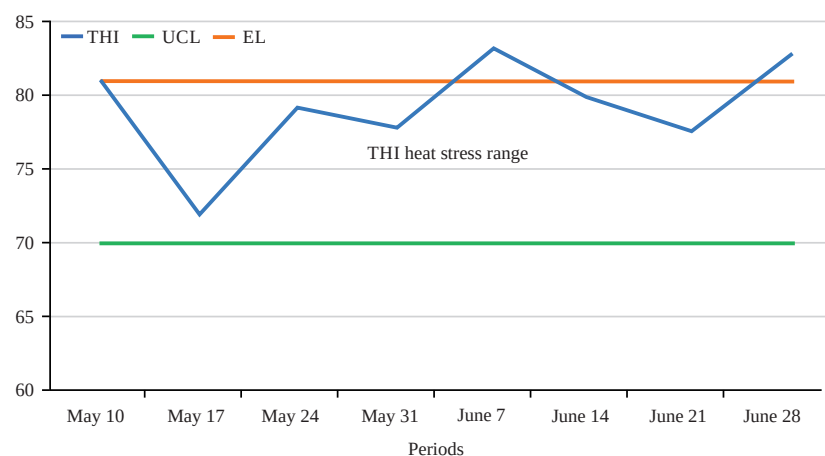


Fig. 2: Temperature-humidity index variation

THI: Temperature-humidity index observed, UCL: Upper comfort limit of THI and EL: Emergency level of THI

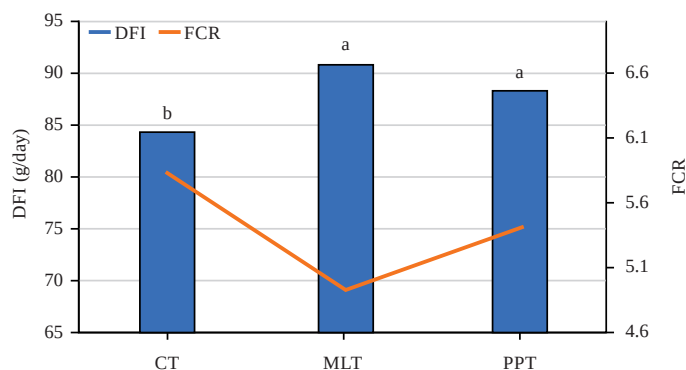


Fig. 3: Effects of dietary inclusion of *Moringa oleifera* leaf meal and *Parkia biglobosa* pulp meal on daily feed intake and feed conversion ratio of laying hens (n = 372)

DFI: Daily feed intake (g/day), FCR: Feed conversion ratio, CT: Control treatment without additive, MLT: Treatment with 2% incorporation of *M. oleifera* leaf meal and PPT: Treatment with 2% incorporation of dry *P. biglobosa* pulp meal

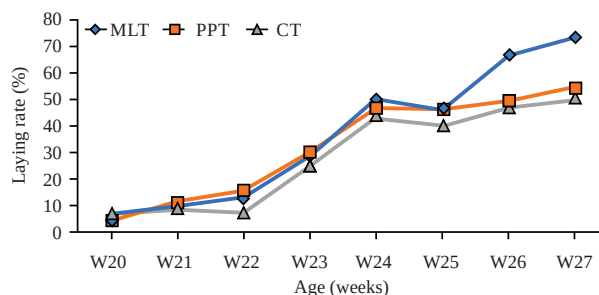


Fig. 4: Temporal changes in laying rate according to dietary treatment (n = 372)

CT: control treatment without additive, MLT: Treatment with 2% incorporation of *M. oleifera* leaf powder and PPT: Treatment with 2% incorporation of dry *P. biglobosa* pulp

Table 3: Effects of dietary inclusion of *Moringa oleifera* leaf meal and *Parkia biglobosa* pulp meal on nutrient intake of laying hens

Nutrients	Diets		
	CT	MLT	PPT
Dry matter (g/day)	73.25	79.00	76.73
Metabolizable energy (kcal/day)	236.60	258.10	248.60
Crude protein (g/day)	15.05	16.24	15.81
Crude fat (g/day)	2.69	2.96	2.77
Lysine (g/day)	0.80	0.86	0.84
Methionine (g/day)	0.40	0.44	0.42
Calcium (g/day)	3.01	3.29	3.17
Phosphorus (g/day)	0.28	0.31	0.28

CT: Control treatment without additive, MLT: Treatment with 2% incorporation of *M. oleifera* leaf meal and PPT: Treatment with 2% incorporation of dry *P. biglobosa* pulp meal

Effects of the inclusion of *M. oleifera* leaf meal and *P. biglobosa* pulp meal on the onset of lay and laying rate:

The first eggs were recorded in the *P. biglobosa* treatment at the end of the 19th week of age. The progression of laying rate according to dietary treatment is presented in Fig. 4. In the control group, laying rate increased from 7 to 50% between 20

and 27 weeks of age. During the same period, it increased from 6 to 73% in the MLT and from 5 to 54% in the PPT.

Overall, dietary supplementation with these plant-derived feed additives improved laying performance. From the 21st week of age onward, hens receiving the supplemented diets consistently achieved higher laying rates than those fed the control diet. This improvement was particularly evident in the *M. oleifera* treatment, which maintained the highest laying rate from 25 weeks of age onwards.

Effects of the inclusion of *M. oleifera* leaf meal and *P. biglobosa* pulp meal on egg physical characteristics

Egg weight and egg volume: The effects of the dietary treatments on egg weight and egg volume are presented in Table 4. Mean egg weight differed significantly among treatments. Hens fed the *M. oleifera* diet produced significantly heavier eggs (51.28 g) than those in the control (50.11 g) and *P. biglobosa* (50.18 g) groups, whereas no significant difference was observed between the latter two treatments ($p = 0.031$).

Table 4: Effects of dietary incorporation of *Moringa oleifera* leaf meal and *Parkia biglobosa* pulp meal on egg weight, egg volume, egg component weights and yolk colour index (mean±SD) (n = 372)

Parameters	Treatments			p-value
	CT	MLT	PPT	
Albumen weight (g)	31.48±2.57	31.63±2.88	31.11±3.12	0.072
Yolk weight (g)	14.7±1.09	15.13±1.15	14.93±1.42	0.061
Shell weight (g)	4.53±0.9	3.93±0.86	4.14±0.89	0.074
Egg weight (g)	50.11±3.31 ^b	51.28±3.82 ^a	50.18±3.99 ^b	0.031
Egg volume (cm ³)	46.61±4.27 ^b	47.7±2.84 ^a	46.68±2.67 ^b	0.045
Egg yolk colour index	4.59±0.6 ^b	7.06±1 ^a	5.12±0.9 ^b	0.028

Within the same row, means with different superscripts differ significantly (p<0.05)

Table 5: Effects of dietary treatments on feed cost per egg and per kg of egg mass

Parameters	Treatments		
	CT	MLT	PPT
Cost of layer feed (XOF/kg)	213.7	242.1	214.2
Total feed intake (kg/hen)	8.75	10.11	9.44
Total feed cost (XOF/hen)	1,870	2,448	2,022
Number of eggs produced (eggs/hen)	30	40	35
Feed cost per egg (XOF/egg)	62.33	61.20	57.77
Total egg mass (kg/hen)	1.50	2.05	1.75
Feed cost per kilogram of egg mass (XOF/kg)	1,240	1,190	1,150

1 USD: 557.5 XOF

Egg volume ranged from 46.6 to 47.7 cm³. The largest egg volume was recorded in the MLT, which differed significantly from the other treatments (p = 0.045). No significant difference in egg volume was observed between the PPT and control treatment.

Egg component weights: Albumen weight ranged from 31.1 to 31.6 g and was not significantly affected by dietary treatment. Similarly, yolk weight varied from 14.70 to 15.13 g and did not differ significantly among treatments (p = 0.061). Eggshell weight ranged from 3.9 to 4.5 g, with hens in the control group producing significantly heavier eggshells than those receiving the supplemented diets.

Yolk colour index: The mean yolk colour index differed significantly among treatments, ranging from 4.59 to 7.06 (Table 4). Hens receiving the *M. oleifera*-supplemented diet produced eggs with the highest yolk colour index (7.06), indicating superior yolk pigmentation. The *P. biglobosa* treatment resulted in an intermediate yolk colour index (5.12), whereas the control group produced the least intensely pigmented yolks (4.59). These differences were statistically significant (p = 0.028), demonstrating that dietary supplementation, particularly with *M. oleifera* leaf meal, enhanced yolk pigmentation.

Feed cost of egg production: The feed-related costs associated with egg production are presented in Table 5. The cost of the experimental diets ranged from 213 to 242 XOF/kg

and varied slightly according to the dietary additive. The diet supplemented with 2% *M. oleifera* leaf meal had the highest unit cost (242 XOF/kg), whereas the control and *P. biglobosa*-supplemented diets had comparable costs.

Despite higher feed intake observed in the supplemented groups, the feed cost per egg was lower than that in the control treatment. The lowest feed cost per egg was recorded in the PPT (57.77 XOF/egg), followed by the MLT (61.20 XOF/egg), whereas the control treatment recorded the highest per egg feed cost (62.33 XOF/egg). A similar trend was observed for feed cost per kilogram of egg produced, indicating improved economic efficiency in the supplemented diets, particularly in the diet containing *P. biglobosa* pulp meal.

DISCUSSION

Climatic context: Heat stress is widely recognized as one of the major constraints affecting poultry production systems because of its detrimental effects on bird welfare, productive performance, immune function and survival^{6,32,33}. Throughout the present study, ambient temperatures consistently exceeded the thermoneutral range recommended for commercial laying hens (18 to 22 °C), while the temperature-humidity index (THI) remained above the comfort threshold of 70 and occasionally exceeded the critical value of 81. According to the classification proposed by Zulovich and DeShazer³⁴, these environmental conditions correspond to moderate to severe heat stress situations.

Although, physiological stress indicators were not evaluated in the study, previous investigations have demonstrated that exposure to such thermal conditions induces oxidative stress, disrupts metabolic and immune functions and ultimately compromises productive performance in poultry^{7,35}.

Feed intake and feed efficiency: Hens receiving diets supplemented with *Moringa oleifera* leaf meal or *Parkia biglobosa* pulp meal exhibited higher daily feed intake and lower feed conversion ratios than those fed the control diet, with the greatest improvement observed in the *M. oleifera* treatment. These responses are particularly important under tropical production conditions, where elevated ambient temperatures generally reduce voluntary feed intake^{5,7}. The increased feed intake observed in the supplemented groups may be associated with improved diet palatability, enhanced antioxidant status and better gastrointestinal function under heat stress conditions. Moreover, hens fed the *M. oleifera* diet recorded the lowest feed conversion ratio, indicating greater feed utilization efficiency, which was likely associated with their higher laying rate (73% at 27 weeks of age). Similar improvements in feed efficiency following *M. oleifera* supplementation have been reported by several authors³⁶⁻³⁸.

The relatively high feed conversion ratios recorded across all treatments (>2) nevertheless suggest reduced nutrient utilization under the prevailing heat stress conditions. Elevated temperatures are known to impair digestive efficiency, nutrient metabolism and energy utilization in poultry^{6,35}.

Laying performance: Dietary supplementation influenced laying performance throughout the experimental period. Hens receiving the *P. biglobosa* pulp meal diet reached sexual maturity earlier, whereas those fed *M. oleifera* leaf meal achieved the highest laying rates between 20 and 27 weeks of age. These findings are consistent with those reported by Melesse *et al.*³⁹ and Abdel-Wareth and Lohakare³¹, who demonstrated that dietary inclusion of *M. oleifera* improved reproductive performance and alleviated the adverse effects of heat stress on reproductive function. Comparable improvements in egg production following supplementation with *M. oleifera* leaf meal have also been reported in studies conducted in India and Indonesia⁴⁰⁻⁴². Similarly, Kenneth-Obosi *et al.*⁴¹ observed enhanced egg production, reflected by an increased number of eggs and greater egg weight, following supplementation with 1% *P. biglobosa* pulp in the drinking water of laying hens.

The beneficial effects of these plant resources may be attributed to their high concentrations of antioxidants, vitamins and other bioactive compounds, which are known to support ovarian function and sustain reproductive activity under heat stress conditions^{38,43}. Nevertheless, the comparatively lower laying performance observed in hens receiving *P. biglobosa* pulp meal may be related to its higher fibre content and lower digestible nutrient value relative to *M. oleifera* leaf meal⁴⁴.

Egg characteristics: Dietary supplementation also influenced several egg quality characteristics. Hens fed the *M. oleifera* leaf meal diet produced significantly heavier eggs with greater egg volume than those in the control and *P. biglobosa* treatment groups. These findings agree with previous studies demonstrating the positive effects of *M. oleifera* leaf meal on egg weight and yolk quality^{31,38}. The observed improvements are likely attributable to the high concentrations of essential amino acids, vitamins, minerals and antioxidant compounds present in *M. oleifera* leaves^{11,31,45}.

In contrast, supplementation with *P. biglobosa* pulp meal did not improve egg volume. This response may be associated with its relatively lower protein quality and less balanced amino acid profile, as reported by Jacob *et al.*⁴⁶ in Nigeria, factors that may limit egg development under stressful environmental conditions^{47,48}. Eggshell weight was slightly reduced in the supplemented groups, which may reflect lower mineral availability, resulting from the presence of dietary fibre and antinutritional compounds that interfere with calcium absorption^{46,49}. Heat stress itself may further impair calcium metabolism and eggshell formation³².

Yolk pigmentation was markedly enhanced by dietary supplementation with *M. oleifera* leaf meal and, to a lesser extent, with *P. biglobosa* pulp meal. This response is most likely attributable to the high carotenoid concentration of *M. oleifera* leaves, particularly lutein and β -carotene, which are efficiently deposited in the egg yolk^{22,50}. Similar improvements in yolk pigmentation have been reported by Madkour *et al.*⁵¹ following the use of carotenoid-rich diets under heat stress conditions in Egypt. The β -carotene naturally present in *P. biglobosa* pulp may likewise explain the greater yolk pigmentation observed, relative to the control treatment²³.

Feed economic efficiency: From an economic perspective, feed cost varied according to the dietary additive incorporated. The diet supplemented with *M. oleifera* leaf meal had the highest cost per kilogram. Despite this higher formulation cost, both supplemented treatments improved

the economic efficiency of egg production. Hens receiving *P. biglobosa* pulp meal diet exhibited the lowest feed cost per egg and per kilogram of egg produced, indicating superior economic efficiency. This advantage may be attributed to the relatively low purchase cost of the fruit pulp together with its high energy content, may help compensate for the increased energy demands associated with heat stress^{52,53}.

Although, the *M. oleifera* leaf meal diet was more expensive, its economic efficiency was comparable to that of the *P. biglobosa* treatment and superior to that of the control diet. This improvement is likely associated with the lower feed conversion ratio observed in hens receiving *M. oleifera* leaf meal supplementation. Furthermore, the high concentrations of minerals, vitamins, antioxidants and other bioactive compounds present in *M. oleifera* may have contributed to improved nutrient utilization and enhanced resilience to heat stress, as reported previously^{45,54}. Because feed cost represents one of the principal determinants of profitability in commercial poultry production, these improvements are of considerable practical and economic importance^{55,56}.

While the findings of this study are encouraging, several limitations should be acknowledged. First, the absence of physiological and biochemical biomarkers precluded a direct assessment of the birds' responses to heat stress. Second, only a single dietary inclusion level (2%) of *M. oleifera* leaf meal and *P. biglobosa* pulp meal was evaluated, preventing the determination of optimal supplementation levels and potential dose-response relationships. Finally, the relatively short experimental period may not have been sufficient to fully evaluate the long-term effects of these dietary interventions on laying performance, egg quality traits and the economic efficiency of egg production.

CONCLUSION

In tropical regions, where laying hens are frequently exposed to severe heat stress, particularly during the hot season from May to June, as indicated by elevated temperature humidity index values, dietary supplementation with *Moringa oleifera* leaf meal or *Parkia biglobosa* pulp meal at a 2% inclusion level improved both productive performance and the economic efficiency of feed utilization. Compared with the control diet, both dietary supplements increased feed intake and enhanced overall laying performance. However, *M. oleifera* leaf meal consistently produced superior responses, including higher laying rate, greater egg weight and egg volume and more intense yolk pigmentation. However, supplementation with *P. biglobosa* pulp meal provided the greatest economic benefit, resulting in the lowest feed cost

per egg and per kilogram of eggs produced. Overall, these findings demonstrate the potential of locally available plant resources as sustainable feed additives for improving the resilience and productivity of laying hens under hot climatic conditions. In particular, *M. oleifera* leaf meal appears to represent a more effective nutritional strategy for enhancing laying performance and egg quality under heat stress. Nevertheless, further research is warranted to determine the optimal dietary inclusion levels of these feed resources and to evaluate their long-term effects on laying performance, egg quality and the economic sustainability of table eggs production.

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