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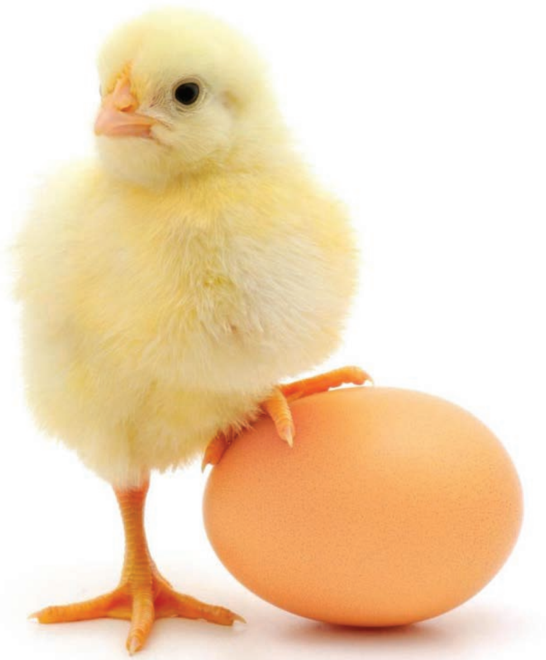

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Research Article
Feeding Strategies for Slow-Growing Broilers in the Tropics: Production Efficiency and Welfare Behavior

[1,2]KPOMASSE Cocou Claude, [3]NIDEOU Dassidi, [1,2]EDIKOU K.U. Spero, [1]HOUNDONOUGBO M. Frédéric, [2]TONA Kokou

[1]Faculty of Agronomic Sciences (FSA), University of Abomey-Calavi, Abomey-Calavi, Benin
[2]Regional Center of Excellence on Poultry Sciences (CERSA), University of Lome, P.O. Box 1515, Lome, Togo
[3]Institut national supérieur des sciences et techniques d'Abeché, Abéché, Tchad

Abstract
Background and Objective: Slow-growing broilers are well adapted to tropical climate but have poor growth performance and feed efficiency. This study aimed to evaluate the effect of feeding strategy on production efficiency and welfare behavior of slow-growing broilers in the tropics. **Materials and Methods:** A total of 390 Sasso broiler chickens of 14 days old were divided into three groups of five replicates with 26 chicken per replicate: birds in group A (as control) fed complete diet, birds in group B fed diets with variation in energy content and in group C birds fed diet with energy and protein contents. Feeding behavior at 10 weeks of age and carcass evaluation, abdominal fat and meat pH at 11 weeks of age were evaluated. **Results:** Results showed that feed intake, energy intake, growth rate and body weight were higher ($p<0.05$) in broiler chickens of group A compared to those of groups B and C. Protein intake, thigh weight, mortality, feed cost per chicken were similar among all treatment groups ($p>0.05$). However, birds fed sequentially showed lower abdominal fat, feed conversion ratio and higher economic feed efficiency ($p<0.05$). In addition, they showed positive welfare behavior under tropical condition. Moreover, carcass weight increased ($p<0.05$) in birds of groups A and B. The meat pH decreased more rapidly in groups A and C compared to group B. **Conclusion:** It was concluded that the variation of the energy level of diet can be used as a feeding strategy for slow growing broilers in the tropics.

Key words: Feeding behavior, hot climate, meat production, production efficiency, slow-growing broiler

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Corresponding Author: Kpomasse Cocou Claude, Faculty of Agronomic Sciences (FSA), University of Abomey-Calavi, Abomey-Calavi, Benin.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Fast growing broilers, genetically selected for production efficiency, are very sensitive to tropical climatic conditions and therefore less thermotolerant compared to slow growing strains[1,2]. Their rapid growth is associated with several metabolic disorders such as sudden death, lameness and myopathies. Also, enteric diseases and other troubles have been reported[3-5]. However, the benefits of using slow growing breeds are numerous: Thermotolerance, welfare and meat quality (less tender and less juicy meat compared to that of fast-growing breeds)[6,7]. Moreover, because they take longer time to mature, slow-growing broilers have fewer problems with muscle abnormalities and therefore can be used as free-range chicken in rural areas[8]. Despite this, they present lower growth performances and poor feed efficiency[9]. The poor feed efficiency of birds is a major challenge resulting in an increased feed intake[10]. This makes them less economical and profitable for farmers[8]. Improving these chickens' ability to convert feed intake into meat is a primary objective[11]. But, because of the negative correlation between thermotolerance and growth rate, feeding practices are the most appropriate way to address the problem[12]. Feeding is a key factor which must be controlled in order to improve feed efficiency and profitability[13]. According to Kpomasse *et al.*[14], intestinal length and carcass yield weight of Sasso chickens was improved by the distribution of diet with low energy and high protein contents in the morning followed by high energy and low protein contents diets in the afternoon under hot climate. Nevertheless, such feeding method did not improve feed efficiency of Sasso broiler and since then, very few studies have focused on improving feed efficiency of slow-growing broilers through the use of feeding strategies. The observations reported in the previous studies are extended in this study. It aimed to evaluate the effect of feeding strategy on production efficiency and welfare behavior of slow-growing broiler in the tropics.

MATERIALS AND METHODS

This study was carried out in strict accordance with the recommendations of the Guide for the Care and Use of Experimental Animals of the University of Lome, Togo. The protocol was approved by the Ethics of Animal Experimentation Committee of the same University. All efforts were made to minimize discomfort to the birds (ref: 008/2021/BC-BPA/FDS-UL).

Experimental design: A total of 390 chickens (14 days of age) were allotted to three treatments of five replicates of twenty-six chicken. The treatments were: A: served as control (broiler chickens fed complete diet)' B: Birds fed sequentially low energy diet (E^- diet) in the morning and high energy diet (E^+ diet) in the afternoon] and C [birds fed sequentially low energy and high protein (E^-P^+) diet in the morning and high energy and low protein (E^+P^-) diet in the afternoon. All the chickens were reared on a deep litter with wood shavings having a density of 5 birds per m^2 during the experiment. Feed was provided twice a day: 07:00 and 13:00 (UTC). Birds of sequential group received alternated diets during the day (Table 1). Lighting program of 23 hrs of light and 1 hr of darkness was used and water was supplied *ad libitum*.

Management of chicken: Feed intake in the morning and afternoon was recorded weekly and the difference between the feed supplied and the left-over was used to calculate total

Table 1: Feed formulation used during the experiment

		Alternated diets 1		Alternated diets 2	
Ingredients	Control	Low energy diet	High energy diet	Low diet	High diet
Maize (kg)	59.3	56.3	59.4	60	52.5
Wheat bran (kg)	6.5	12.4	4.4	4	16.5
Soybean (kg)	19.5	17.5	22	21	19
Lysine (kg)	0.2	0.3	0.2	0.2	0.2
Methionine (kg)	0.2	0.2	0.2	0.2	0.2
Oyster shell (kg)	1	1	1	1	1
Salt (kg)	0.3	0.3	0.3	0.3	0.3
Concentrate 5% (kg)	6.5	8	5	5	5
Palm oil (kg)	1	0.5	2.5	3	0
Dried brewers grains (kg)	5.5	3.5	5	5.3	5.3
Total	100	100	100	100	100
Nutritional composition of dite					
ME (kcal kg^{-1})	3084.1	2953.56	3216.33	3278.80	2888.90
PB (%)	19.01	19.02	19.03	18.81	19.23

Alternated diets 1: Diets distributed alternately during the day for E group birds, Alternated diets 2: Diets distributed alternately during the day for EP group birds, ME: Metabolizable energy and PB: Crude protein feed intake. Mortality was recorded daily. Also, body weight and weight gain (difference between body weight at the end of the week and body weight at the beginning of the week) were evaluated weekly and feed conversion ratio was calculated as feed intake per weight gain. At 11 week of age, six broiler chickens per replication were slaughtered for the determination of carcass traits. Physiological organ weights, intestinal length and weight and carcass weight were determined.

Meat pH evaluation at different times: Meat pH measurements were carried out on pectoralis major muscle from slaughtered birds. The pHu values after 15 min and 24 hrs (pHu 15 min and pHu 24 hrs, respectively) were measured by inserting a glass electrode directly into the thickest part of the muscle using a pH meter OARTON pH 700 (with precision of 0.01). Muscles were stored in a cooler at 4°C during assessment[15-17].

Chicken behavior assessment through kinetics of feed and nutrients intake: During a short period in the morning and in the afternoon (2h30), feeding behavior of 10 week aged broiler chickens of different treatments were evaluated. A one-day adaptation period to human presence was performed before data collection on three consecutive days[18]. The chickens were deprived of feed for 8 hrs before the beginning of the observations which started from 7 am in the morning and at 1 pm in the afternoon[19,18]. The amount of feed remaining was weighed every 30 min during each observation period.

Evaluation of production efficiency: For different calculations, the values for each phase (starter and growing phase) were calculated and then summed. Feed cost per chicken per treatment and economic feed efficiency were calculated using the following equation as described by Houndonougbo *et al.*[20]:

Feed cost per chicken per treatment (€) = Starter diet cost + price per kg of feed × FCR × Body weight gain (kg) per chicken from 3-11 weeks of age

where, FCR is feed conversion ratio

For a given rearing phase, the economic feed efficiency was calculated using the following equation:

$$\text{EFE} = \frac{\text{BWG}\times\text{Pr}}{\text{Feed intake}\times\text{cost per kg of feed}}$$

where, BWG is body weight gain and feed cost is the amount invested in feeding.

Statistical analysis: The software Graph Pad Prism 8.0.2 (GraphPad Software, San Diego, CA, USA) was used for data analysis. One way analysis of variance was used to compare the sample means. The generalized linear regression model was used to analyze the effects of feeding strategy on feed consumption, growth rate, feed conversion ratio, carcass characteristics, abdominal fat weight, digestive organs weights, production efficiency and feed and nutrients consumption. When significant, further analyses were performed using Tukey' s test[21]. Mortality was analyzed with a χ^2 test. Tested parameters were considered as significantly different if p<0.05.

RESULTS

Effect of feeding strategy on feed and nutrients intake, weight gain, final body weight and mortality: Table 2 shows the effect of feeding strategy on feed, energy and protein consumed by Sasso chickens during the experimental period. In the morning, feed consumption of broiler chicken in group C was higher (p<0.05) than those of groups A and B while in the afternoon, feed intake of control group (group A) was higher (p<0.05) than those of groups B and C. Overall, broiler chickens of group A fed complete diet consumed daily more feed than those of group B and C (p<0.05) (Table 2). Similarly, these birds consumed more energy (p<0.05) than those of groups B and C. However, the amount of protein consumed did not differ (p>0.05) across all treatment groups (Table 2). As shown in Table 3, weight gain and final body weight of broiler

Table 2: Effect of feeding strategy on feed, energy and protein intake

	A groups	B groups	C groups	p-value
Feed intake in the morning (g)	40.17 ± 4.41^{b}	38.40 ± 4.77^{b}	44.17 ± 6.22^{a}	0.022
Feed intake in the afternoon (g)	41.70 ± 4.40^{a}	34.46 ± 4.04^{b}	33.91 ± 5.19^{b}	0.014
Total feed intake (g)	81.87 ± 8.77^{a}	72.85 ± 8.80^{c}	78.08 ± 3.72^{b}	0.017
Daily energy intake (kcal)	252.5 ± 27.05^{a}	224.7 ± 27.13^{b}	246.1 ± 33.82^{b}	0.020
Daily protein intake (g)	15.57±1.67	13.86±1.60	14.10±0.24	NS

Broiler chickens fed complete diet (A group), broiler chickens fed low energy diet in the morning followed by high energy diet in the afternoon (B group), Birds fed low energy high protein diet in the morning followed by high energy low protein diet in the afternoon (C group), ^{abc}Means within row values with different superscript differ significantly (p<0.05) and NS: Non significant

Table 3: Effect of feeding strategy on growth rate and mortality

	A groups	B groups	C groups	p-value
Final body weight (g)	1903.00±31.25[a]	1801.00±29.54[b]	1753.00±24.58[b]	0.019
Weight gain (g)	193.90±25.29[a]	182.50±17.17[b]	188.20±2.78[b]	0.021
Mortality (%)	0.75±0.01	0.80±0.02	1.04±0.42	NS

Broiler chickens fed complete diet (A group), broiler chickens fed low energy diet in the morning followed by high energy diet in the afternoon (B group), Birds fed low energy high protein diet in the morning followed by high energy low protein diet in the afternoon (C group), [ab]Means within row values with different superscript differ significantly ($p<0.05$) and NS: Non significant

Table 4: Effect of feeding strategy on some digestive organ weights

	A groups	B groups	C groups	p-value
Gizzard (%)	2.09±0.11[b]	2.52±0.14[a]	2.12±0.09[b]	0.023
Liver (%)	1.49±0.09[c]	1.68±0.08[b]	2.49±0.13[a]	0.011
Heart (%)	0.39±0.03	0.42±0.03	0.44±0.02	NS
Small intestine weight (%)	2.07±0.13	2.23±0.11	2.25±0.32	NS
Small intestine length (cm)	158.30±6.52[a]	155.60±6.20[a]	128.60±5.24[b]	0.002

Broiler chickens fed complete diet (A group), broiler chickens fed low energy diet in the morning followed by high energy diet in the afternoon (B group), Birds fed low energy high protein diet in the morning followed by high energy low protein diet in the afternoon (C group), [a,b,c]Means within row values with different superscript differ significantly ($p<0.05$) and NS: Non significant

Table 5: Effect of feeding strategy on meat yield, abdominal fat and meat pH at different times

	A groups	B groups	C groups	p-value
Carcass yield (%)	76.31±0.88[a]	74.51±0.90[a]	69.06±1.15[b]	0.003
Breast yield (%)	14.16±0.87[b]	12.61±0.49[b]	17.24±0.56[a]	0.013
Thigh yield (%)	21.16±0.82	22.06±0.75	21.47±0.38	NS
Abdominal fat (%)	1.68±0.19[a]	0.99±0.13[b]	1.09±0.33[b]	0.022
pH 15 min	6.08±0.28[a]	5.79±0.34[b]	6.28±0.16[a]	0.003
pH 24 hrs	5.77±0.06[b]	5.69±0.05[b]	5.90±0.04[a]	0.044

Broiler chickens fed complete diet (A group), broiler chickens fed low energy diet in the morning followed by high energy diet in the afternoon (B group). Birds fed low energy high protein diet in the morning followed by high energy low protein diet in the afternoon (C group), [ab]Means within row values with different superscript differ significantly ($p<0.05$) and NS: Non-significant

Table 6: Effect of feeding strategy on some production efficiency traits

	A groups	B groups	C groups	p-value
Feed conversion ratio	3.62±0.71[a]	2.95±0.28[b]	3.36±0.18[b]	0.041
Feed cost per chicken (€)	0.32±0.02	0.25±0.01	0.30±0.01	NS
Economic feed efficiency (EFE)	0.68±0.01[b]	0.91±0.08[a]	0.80±0.04[a]	0.002

Broiler chickens fed complete diet (A group), broiler chickens fed low energy diet in the morning followed by high energy diet in the afternoon (B group), Birds fed low energy high protein diet in the morning followed by high energy low protein diet in the afternoon (C group), [ab]Means within row values with different superscript differ significantly ($p<0.05$) and NS: Non-significant and 1 € = 655.9 Fcfa

chicken of group A were higher ($p<0.05$) than those of groups B and C. Also, mortality was not significantly different in all treatment groups (Table 3).

Effect of feeding strategy on digestive organ weights: The effect of feeding method on gizzard, liver, heart weights, small intestine weight and length are presented in Table 4. Broiler chickens in group B [birds fed sequentially low energy diet (E^- diet) in the morning and high energy diet (E^+ diet) in the afternoon] had a heavier gizzard weight ($p<0.05$) than those of groups A (control group) and C [birds fed sequentially low energy and high protein (E^-P^+) diet in the morning and high energy and low protein (E^+P^-) diet in the afternoon]. However, birds in group C had a higher ($p<0.05$) liver weight compared to those of the other treatment groups. No significant difference was noticed in heart and small intestine weight ($p>0.05$) among all treatment groups. But an increase in the length of small intestine ($p<0.05$) was observed in birds of groups A and B (Table 4).

Effect of feeding strategy on meat yield, abdominal fat and meat pH at different times: As indicated in Table 5, broiler chickens of groups A and B showed higher carcass yield and lower breast yield compared to that of group C ($p<0.05$). Thigh weight was similar among all treatment groups ($p>0.05$). Also, birds in groups B and C showed a reduction in abdominal fat ($p<0.05$) (Table 5). Broiler chicken in groups A and C showed higher meat pH at 15 min while those of groups A and B showed a decrease in meat pH at 24 hrs ($p<0.05$) (Table 5).

Effect of feeding strategy on some production efficiency traits: Table 6 shows the effect of feeding strategy on feed conversion ratio, feed cost per chicken and economic feed

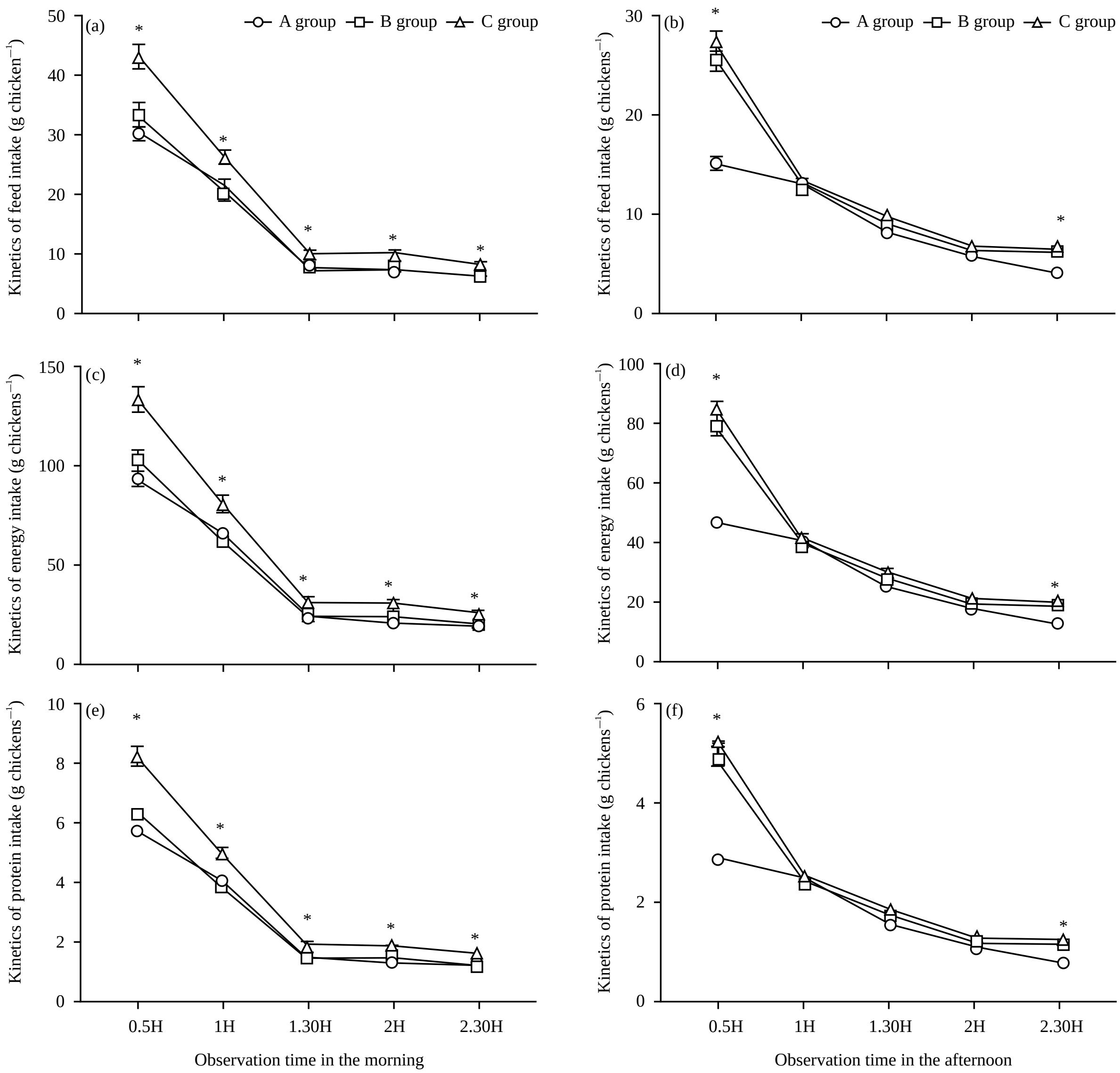

Fig. 1(a-f): Effect of sequential feeding on kinetic of (a) Feed intake in the morning, (b) Feed intake in the afternoon, (c) Energy intake in the morning (d) Energy intake in the afternoon, (e) Protein intake in the morning and (f) Protein intake in the afternoon

efficiency according to treatment. Feed conversion ratio was lower ($p<0.05$) in broiler chicken of groups B and C compared to that of control group. Similar feed cost per chicken ($p>0.05$) was recorded in all treatment groups. However, Economic Feed Efficiency (EFE) of birds in group B and C was higher ($p<0.05$) than that of control group.

Effect of feeding strategy on feeding behavior during a short-term feeding: Overall, significant differences in feed, energy and protein intake were noticed during the short-term observation test (Fig. 1 a-f). Feed, energy and protein consumption varied significantly according to treatment. Also, based on the data collected, birds did not show the same feeding behavior. Feed ingested by the birds decreased ($p<0.05$) as observation time increased. In addition, the average amount of feed, energy and protein consumption was lower ($p<0.05$) in the afternoon compared to that in the morning. Feed, energy and protein intake in the morning was similar ($p>0.05$) between groups A and B compared to group C where it increased ($p<0.05$). A rapid increase was observed in feed, energy and protein intake from 30 min to 1 hr 30 min (p<0.05) of observation and became similar (p>0.05) until the end of the trial in the morning (2 hr 30 min). In the afternoon, 30 min after the start of the trial, broiler chicken of group A consumed significantly less feed (p<0.05) compared to those of groups B and C. After 1 hr, this trend rapidly improved and all groups consumed similar amount of feed, energy and protein (p>0.05) across all treatment groups. After this time, variations in feed, energy and protein consumption was observed in broiler chicken of control group (p<0.05) compared to those of broiler chickens fed sequentially.

DISCUSSION

This study aimed to evaluate the effect of feeding strategy on production efficiency of slow-growing Sasso broiler and to understand the behavior of chicken in relation to short-term adaptation to a new diet. Feed consumption varied by time of day (morning or evening) in broilers fed sequentially (groups B and C). Broiler chickens fed complete diet (control group) had a similar feed intake regardless of the time of day while those fed sequentially showed a slight variation (group B) or a large variation (group C) in feed intake. Similar findings were reported by Kpomasse *et al.*[14]. In fact, under hot and humid climate, the mornings are cool while the afternoons are hot. This could be linked to the fact that chicken fed sequentially consumed less feed in warmer time compared to cooler time[1]. Therefore, birds of group A did not seem to regulate their feed consumption according to the time of the day. This is in agreement with the findings of Bouvarel *et al.*[22]. Overall, total feed consumption was higher in group A (birds fed complete diet) compared to those of groups B and C. Consequently, body weight gain and body weight of these birds were significantly increased compared to those of groups B and C fed diets with variation in energy and protein contents (Table 3). Also, this increase in body weight and weight gain is related to higher energy consumption compared to chickens of the other groups. Feed intake has been shown to be correlated with the energy level of diet in broilers[23]. In sequential feeding method, Bouvarel *et al.*[22] suggested that low energy diets be distributed first, followed by high energy diets. Further, Kpomasse *et al.*[14] reported that varying energy and protein content of alternated diets improved carcass weight without affecting abdominal fat in Sasso broiler. The decrease in weight gain and body weight might result in a decrease in nutrients intake[24]. On the other hand, the increase in abdominal fat noticed in chickens fed complete diet might explained the improvement of body weight of broiler chicken of group A. These observations support the assertion that broilers get fatter when they are fed complete diet under hot and humid climate[1]. Indeed, besides the low consumers' acceptance of fatty meat, an increase in abdominal fat also leads to a degradation of feed efficiency[25,26]. In the same vein, feed conversion ratio of birds in the control group was higher than those of chickens in the other groups. This confirms the aforementioned assertion.

The similarity in the mortality recorded among all treatment groups suggested that such feeding strategy did not degrade the health of the chickens. This is in agreement with the findings of Bouvarel *et al.*[22] and Kpomasse *et al.*[14].

Sequential feeding strategy had no significant effect on heart and weight of small intestine among all treatment groups. However, broiler chicken in group B presented heavy gizzard compared to those of groups A and C. Also, carcass weight and length of small intestine were higher in birds in groups A and B compared to that of group C. In practice, the gizzard plays an important role in feed grinding, which begins with the contraction of fine muscles[27]. Through gastroduodenal reflux, acidic gizzard contents are mixed with bile and pancreatic juices[28]. Greater grinding activity in the gizzard might improve the size of the gizzard muscles[29-31]. The efficiency of the utilization of dietary protein in poultry depends partly on the features of the gastrointestinal tract[32]. Improved intestinal length is associated with improved digestion and nutrient absorption through an increased number of crypts and villi[33]. Moreover, the increase in feed grinding activities results in a heavier gizzard, which improves gastrointestinal tract motility and nutrient utilization in general[34,35]. Higher grinding activities result in higher secretion of the bile leading to liver hyperactivity and consequently, a reduction in liver weight. But the reduction in liver weight in birds of group A, which is not consistent with this hypothesis, could be linked to higher abdominal fat. In practice, the mechanisms related to body fat deposits takes place in the liver and such activity might have induced liver hyperactivity contributing to lower liver weight in birds of group A[26]. Thigh weight was similar across all treatment groups. Since breast weight was higher in birds of group C, the effect of feeding strategy on breast weight deserves a further investigation.

Overall, pH values decreased from 15 min to 24 hrs among all treatment groups. In fact, pH values measure the acidity of the meat. After the death of the animal, through the process of glycolysis, the muscle, in particular, the skeletal muscle, converts glycogen into ATP, lactate and H+ ions. This leads to a drop in pH, which is initially around 7.2 in a normal living muscle[36]. The pH value of chicken meat decreased rapidly (according to a great variation) in groups A and C compared to group B. This might be due to a rapid conversion of glycogen into lactate and energy after slaughter[37,38]. Further, this rapid breakdown of glycogen into lactic acid can lead to a degradation of the quality of the meat[39]. Thus, feeding strategies had impacted meat pH. Nevertheless, despite the fact that there were significant variation in the ultimate pH, the values recorded in the present study ranged from 5.69-5.90 which is an indication of the overall good quality of the slow-growing broiler's meat regardless of the feeding treatment. These results, therefore, confirm the fact that meat of slow-growing broilers is of good quality, since for higher quality, ultimate meat pH or Ph 24 hrs ranges from 5.7-6[40-43].

There were no significant differences in feed cost per chicken among all treatment groups. Nevertheless, Economic Feed Efficiency was higher in broiler chicken fed sequentially compared to those fed complete diet. This suggested that the use of sequential feeding strategy led to a higher income earned per unit of money invested in feed[20,44].

In short term trial, feed intake decreased with increasing time probably due to the filling of the crop of birds in relation to the kinetics of feed, energy and protein intake. There might be differences in feed, energy and protein intake behavior within the treatment groups based on memory and habit. Indeed, chickens identify feed based on their own mechanisms. Feeding behavior is actually divided into two phases: The appetite phase corresponding to the feed demand phase and the actual feed consumption phase[45]. Result showed that from the first minute until each feeder was withdrawn, the rate of energy and protein consumption varied across all the experimental groups both in the morning and in the evening. The identification of a diet is associated by its sensory characteristics with its nutritional post-ingestive effects which are memorized. Chicken appreciates the energy and protein content of the diet for this reason[46]. Similarly, the learning behavior associated with memorization may differ depending on the feeding strategy. In warmer time (afternoon), a reduction in the amount of feed, energy and protein consumption was observed. In the afternoon, heat stress affected the consumption of birds[1]. Adapting to climatic variations was clearly difficult for birds in group A (fed complete diet) since their feed, energy and protein intake had varied enormously in the afternoon. Therefore, in humid tropical areas there is often a shortage of some ingredients, which leads to permanent substitutions of feedstuffs and sometimes causes a decrease in the quality of the feed. Consequently, sequential feeding, through the alternation of feed during the day, prepares the chickens to better adapt to aforementioned situations. Bird consumes diet according to its energy content[22]. During present trial, in the hot period, the well-adapted behavior of the broiler chickens of group C is a positive indicator for the use of sequential feeding strategy in the tropics. This is in agreement with the findings of Kpomasse *et al.*[14] and Bouvarel *et al.*[19].

CONCLUSION

Considering the popularity of slow-growing broilers today, it is important to improve their production efficiency and increase income from their production. Firstly, the present study showed clearly the usefulness of feeding strategies and then suggested a feeding model for slow-growing broilers rearing under hot and humid climate. Indeed, the model of feeding low energy diet in the morning followed by high energy diet in the afternoon resulted in a significant reduction in abdominal fat, an improvement of carcass yield and production efficiency of birds. Also, it contributes to chicken's positive welfare behavior under hot condition. Finally, such feeding strategy can improve production efficiency and help birds to have a positive welfare attitude in hot and humid conditions. These results pave the way for the formulation of cheaper low-energy diets by valorizing locally available by-products. For farmers in rural areas, the model could even be modified with energy pre-feed (using only energy ingredients) and protein-mineral-vitamin premixes.

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