# Physico-chemical and techno-functional quality of eggs of indigenous Holli hens of Benin kept under free range and confinement systems

**Ulbad TOUGAN[1], Issaka YOUSSAO ABDOU KARIM[2], André THEWIS[3]**

[1] *Department of Nutrition and Food Science, Faculty of Agronomy, University of Parakou, Benin*

[2] *Department of Animal Production and Health, Polytechnic School of Abomey-Calavi, Cotonou, Benin*

[3] *Nutrition and Animal Production Engineering Unit, Gembloux Agro-Bio Tech, University of Liege, Gembloux, Belgium*

*Corresponding author ulbad.tougan1@gmail.com*

*Received 20/09/2025*
*Accepted 25/10/2025*

## Abstract

Indigenous chicken populations of Benin serve as an important source of supplementary income and nutrition for rural households. The current study aimed to assess the influence of rearing system on the physical, rheological, and technological characteristics of eggs from Holli hens, an indigenous breed of Benin. Therefore, 30 new laid eggs from Holli hen reared under traditional free range and 30 new laid eggs from Holli hens kept in confinement system were sampled at 32 weeks old for the different analyses. The results showed that most external egg traits, including weight (47.3 g vs. 44.4 g), length (5.14 cm vs. 4.99 cm), and height (3.68 cm vs. 3.63 cm), did not differ significantly between confinement and free-range systems. However, shell-related parameters were significantly higher in confinement eggs, including shell weight (4.36 g vs. 3.67 g), shell proportion (9.20 % vs. 8.27%), and shell thickness (0.27 mm vs. 0.23 mm). For techno-functional properties, albumen thickness was greater in confinement eggs (6.26 mm vs. 5.26 mm), while yolk diameter and yolk index remained unchanged. The Haugh unit, indicating albumen freshness, was slightly higher in free-range eggs (77.1 vs. 76.0). Remarkable differences were observed in yolk color attributes, with free-range eggs showing higher color intensity (10.2 vs. 2.0), redness (a* = 3.78 vs. –6.30), yellowness (b* = 54.0 vs. 19.3), and chroma (54.2 vs. 20.4). Correlation analysis showed strong positive associations among egg weight, shell characteristics, and albumen traits, whereas negative correlations between egg volume and Haugh unit indicated potential trade-offs between size and freshness. Overall, confinement rearing improved shell integrity and albumen thickness, whereas free-range management enhanced yolk pigmentation, reflecting diet diversity and natural foraging.

**Keywords:** Benin, egg quality, Holli Ecotype, indigenous chicken, production system

## INTRODUCTION

Indigenous chicken breeds contribute significantly to the rural economy and food security in many developing and underdeveloped nations. They serve as an important source of supplementary income and nutrition for rural households, particularly among poor and marginalized populations, through the production of eggs and meat. These native breeds are well known for their adaptability and relatively high productivity under low-input management conditions (Tougan *et al*., 2021; Kumar *et al*., 2013).

In Benin, the indigenous chickens represent 81.3 % of the national poultry flock (FAO, 2022) and are an important source of animal protein supply for the population and income for producers and poultry sellers (Tougan, 2023). Despite the importance of this poultry flock, local poultry meat production remains below the consumer demand. This shortage created pressure on every form of food supply and lead on increase of meat imports, 2.5 times from 2012 to 2022 (FAO, 2022). Despite the low domestic production of local chickens (2,020 tons in 2010), local chicken meat is more appreciated by consumers in comparison with imported chicken meat because of its leanness and relatively lower price (Mankor, 2009). The lack of religious restriction against indigenous chicken consumption justifies the perenniality of its production in Benin (Tougan, 2023).

The local population of poultry of the species *Gallus gallus* of Benin is composed of various ecotypes among which are North, South, Holli, Fulani or Peuhl and Sahoue ecotypes (Tougan *et al*., 2016). These indigenous poultry have a remarkable heterogeneity in phenotypical traits (Youssao *et al*., 2013; 2009a; 2009b) and polymorphism trait (Youssao *et al*., 2010; 2011). Several studies were carried out on carcass traits of these local genetic types (Youssao *et al*., 2009; Youssao *et al*., 2013; Youssao *et al*., 2012; Tougan *et al*., 2013a). The recent studies carried out on the effect of rearing mode, type of muscle and slaughter age on technological meat quality of these local chickens of Benin (Tougan *et al*., 2013) on the one hand, and on nutritional quality of meat of local poultry population of *Gallus gallus* specie of Benin (Tougan *et al*., 2013) on the other hand, showed significant variation of technological and nutritional qualities.

Although the variability of meat quality of the five ecotypes of local chicken is well known, no data exist on the external and internal quality of their eggs.

For accuracy and better valuation of the eggs from these rustic local avian resources of Benin, the current study aimed to assess the physical traits and techno-functional quality of Holli hens in relation with the rearing mode. Specifically, it was to:

- Evaluate the effect of the rearing system (free-range vs confinement) on the physical and rheological characteristics of Holli hen eggs.


https://doi.org/10.5281/zenodo.17453575

• Analyze the influence of the rearing system on the technological and functional properties of Holli hen eggs.

• Determine the relationships between the physical, rheological, and techno-functional parameters of Holli hen eggs reared under free range and confinement system.

## MATERIALS AND METHODS

### Area of study

The current study was conducted jointly at the experimental farm of “Ecole Polytechnique d’Abomey-Calavi (EPAC)” and at the traditional poultry breeders located in Abomey-Calavi (latitude of 6 ° 27’ north and at a longitude of 2 ° 21’ east) in Atlantic Department (Figure 1) from April 2013 to September 2017. The commune of Abomey-Calavi, located in southern Benin, experiences a subequatorial climate characterized by warm temperatures and alternating wet and dry seasons throughout the year. The annual temperature generally ranges between 25°C and 32°C, with only slight variations between months. The commune is influenced by both maritime and continental air masses, resulting in high humidity levels, especially during the rainy periods. Rainfall is distributed across two main seasons: a long rainy season that extends from March to July and a shorter one from September to November. These periods are separated by a short dry spell in August and a more pronounced dry season from December to February, during which the harmattan, a dry and dusty wind from the Sahara, occasionally lowers humidity and visibility. Annual rainfall averages between 1,100 and 1,400 millimeters, which supports diverse agricultural and horticultural activities in the region.

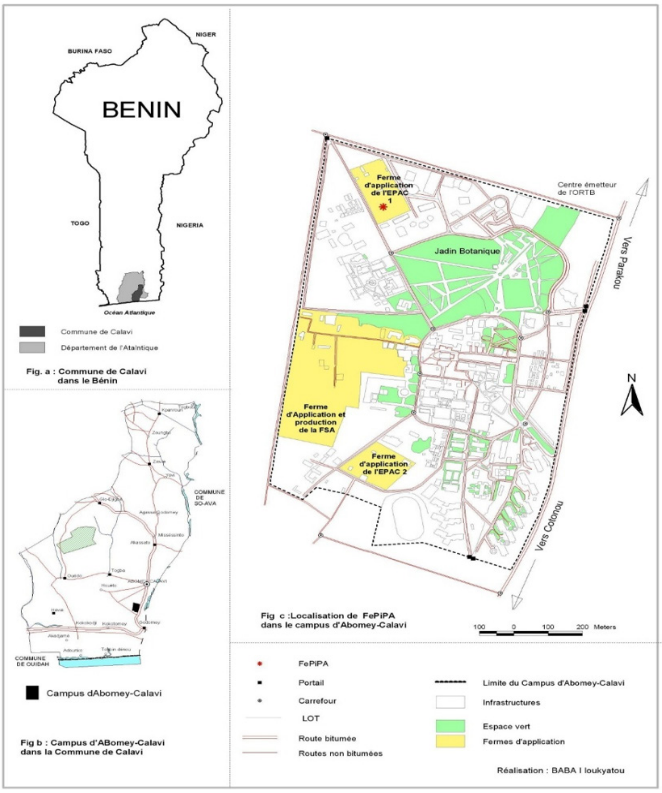



*Figure 1: Map of the study area*

### Egg production and characteristics of rearing modes

The chickens used in this trial were produced from breeding nuclei of 20 hens and 6 cocks of Holli ecotype of Benin, reared in confinement at the experimental farm of EPAC as described by Tougan *et al.* (2013). The new laid eggs from these breeding nuclei were incubated and the chicks were collected after hatching and reared in confinement until 8 weeks of age. The female chicks (42 young birds) were then selected, divided into 2 groups and reared respectively under traditional free range and improved confinement breeding modes until 32 weeks old. At 32 weeks, 30 new laid eggs from each rearing mode were sampled and analyzed.

In free range system, the birds were scavenge during the day but housed at night in traditional shelters (henhouse made of mud, straw or wicker), or kept outside on any support that could serve as a perch. The birds fed themselves by gleaning, but some grain supplement was occasionally distributed to birds. Their diet was composed of energetic elements (kitchen waste, bran ...), vitamins (green fodder, sprouted grains ...), minerals (salt and pounded shells) and protein from termites and leguminous plants. Water was distributed *ad libitum*. Various containers were often used by traditional chicken breeders as drinking materials. In this type of farming, no health follow-up nor prophylactic standard were applied.

Concerning improved breeding mode in confinement, the birds were bred on a fresh wood shavings litter in buildings of California type. The livestock equipment used were composed of brooders, feeders, drinkers. The number of these devices depended on the number of birds in the henhouse. All the animals were fed with the same diet (Table 1): starting (2880 ME Kcal/kg and 18% of crude protein), growing (2969 ME Kcal/kg and 18% crude protein) and laying (2800 ME Kcal/kg of feed and 20% of crude protein). The starter feed was used

**Table 1: Composition and nutrient content of the starting, growing and laying diets**

| Composition | Starting diet | Growing diet | Laying diet |
|---|---|---|---|
| Soy cakes (g/kg) | 12 | 7.5 | 15.5 |
| Wheat bran (g/kg) | 10 | 17.5 | 7 |
| Corn (g/kg) | 60 | 59 | 59 |
| Cotton cakes (g/kg) | 8 | 6.5 | 6 |
| Fish meal (g/kg) | 7 | 7 | 9 |
| Lysine (g/kg) | 0.2 | 0.2 | 0.2 |
| Methionine (g/kg) | 0.2 | 0.2 | 0.2 |
| Salt (g/kg) | 0.2 | 0.2 | 0.2 |
| Oyster shell (g/kg) | 2 | 1.5 | 2.5 |
| Premix 0.25 (g/kg) | 0.25 | 0.25 | 0.25 |
| Total (g/kg) | **100** | **100** | **100** |
| Metabolisable energy (kcal/kg) | 2880.5 | 2969.6 | 2800.0 |
| Crude protein (g/kg) | 18.6 | 17.2 | 20.1 |
| Lysine (g/kg) | 0.91 | 0.78 | 0.92 |
| Methionine + Cystine (g/kg) | 0.63 | 0.58 | 0.72 |
| Calcium (g/kg) | 1.11 | 0.91 | 1.35 |
| Digestible phosphate (g/kg) | 0.28 | 0.27 | 0.35 |

from hatching to the age of 2 months and the growth feed from 2-month-old to the point of laying (22 weeks). From the point of laying to the end of the experimentation, the laying feed was used. The animals were fed *ad-libitum* throughout the study. Feed transitions were done during three days between the different growth periods by gradual incorporation to the previous diet with the respective proportions of 25, 50 and 75% of the new diet. The composition and the nutrient contents of each diet are given in Table 1. Habitat, Health and medical prophylaxis used in confinement breeding system were described by Tougan *et al.* (2013).

### Evaluation of the physical traits of Holli hen eggs

The data collected in this study relate to the physical composition and the technological quality of eggs. The weight of the whole egg, the weight of the albumen, the weight of the yolk, and the weight of the shell were determined using a scale of 100 g capacity and 1 g precision. The length and width of the egg, the shell thickness, and the yolk diameter were measured using a digital caliper. The thickness of the albumen and the yolk was measured using a digital tripod (Figure 2). The shape index of the whole egg and the egg yolk shape index were calculated as the ratio of their respective width to length multiplied by 100. The percentages of the different components (yolk, albumen, shell) relative to the whole egg weight were also calculated.

The egg volume was determined using the formula described by Hoyt (1978):

$$\textbf{Egg volume (cm}^3\textbf{)} = 0.51 \times \text{egg length} \times (\text{egg width})^2$$

The specific gravity of the egg was calculated according to Tougan *et al.* (2021):

$$\textbf{Specific gravity (g/cm}^3\textbf{)} = \text{egg weight (g)} / \text{egg volume (cm}^3\text{)}$$

### Evaluation of the techno-functional quality of Holli hen eggs

Technological measurements included shell mechanical resistance, albumen pH, yolk pH, yolk intensity on the Roche scale, color (L*, a*, b*) of the shell and yolk, Haugh Unit (HU), and yolk hue.

pH measurements were performed by genetic type and by egg size using a Hanna pH meter equipped with a specialized probe. The instrument was calibrated with two pH standards: pH = 4.1 and pH = 7.1, following the manufacturer's instructions (Hanna Instruments®). Color was determined according to the International Commission on Illumination (CIE) standards using a CR-400 colorimeter in the Cielab L* a* b* trichromatic system after calibration. L* corresponds to lightness, a* to redness, and b* to yellowness. Six replicates were performed for each measurement.

The Haugh Unit (HU), used to evaluate the internal quality of the egg, particularly the freshness of the albumen, was calculated as follows:

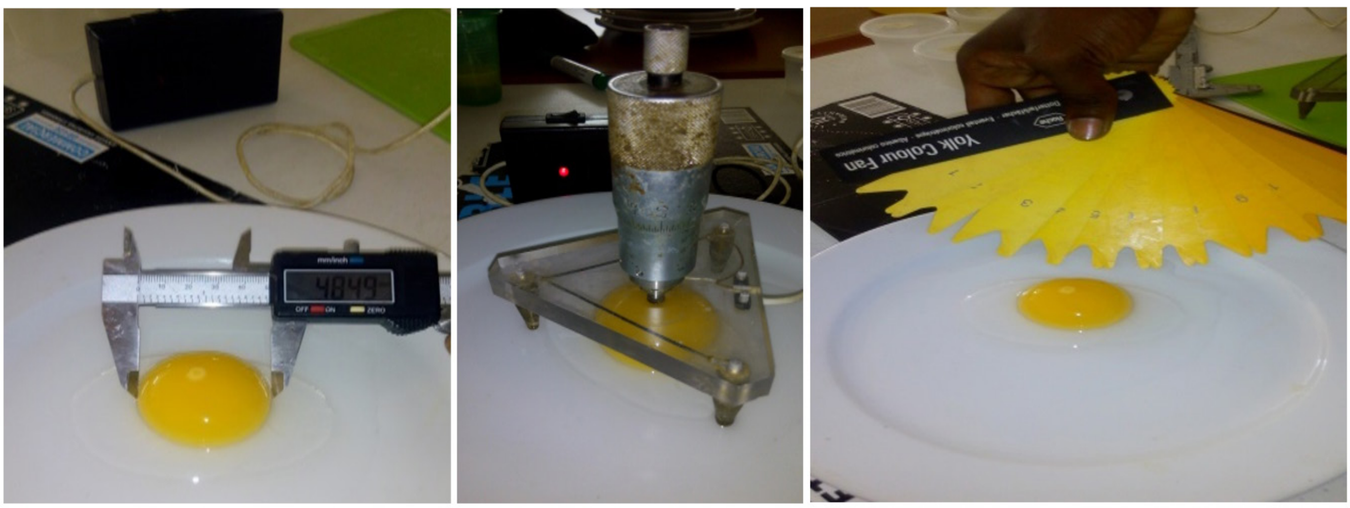
$$\mathbf{HU = 100 \times \log_{10} (H - 1.7W^{0.37} + 7.6)}$$

Where: HU = Haugh Unit; H = height of the thick albumen (mm); W = weight of the egg (g); $\log_{10}$ = base-10 logarithm.

Shell mechanical resistance was determined by compression using an LF Plus texturometer (Llyod Instruments).

### Statistical Analysis

The collected data were analyzed using an Statistical Analysis System (SAS 9.2, Copyright 2008). The General Linear Model (Proc GLM) procedure was used for analysis of variance. The rearing mode was used as the source of variation. The significance of the rearing mode effect was determined using the Student's t-test. Correlations between physical characteristics and technological quality of the eggs were determined using the Proc Corr procedure in SAS.




**Yolk diameter** **White and yolk height** **Yellowness intensity**

*Figure 2: Assessment of internal quality of Holli hen eggs*

# RESULTS

## Effect of rearing system on the physical and rheological traits of Holli hen eggs

The effects of rearing system on the physical traits of Holli hen eggs are presented in Table 2. The results showed that the egg weight, egg height and egg length of both rearing systems were similar. Nevertheless, eggs from hens reared under the improved confinement system tended to be slightly heavier (47.3 g) than those from the traditional free-range system (44.4 g). Similarly, egg length and height were slightly greater in the confinement system (5.14 cm and 3.68 cm, respectively) compared to free-range eggs (4.99 cm and 3.63 cm). The egg shape index also did not differ significantly between the two systems. Significant differences were observed for shell weight and shell proportion, which were higher in eggs from the confinement system (4.36 g and 9.20%, respectively) than in free-range eggs (3.67 g and 8.27%). Shell thickness was also greater in confinement eggs (0.27 mm vs 0.23 mm). Other parameters, including yolk weight, albumen weight, yolk and albumen proportions, shell resistance, shell color (L*, a*, b*, chroma, hue), egg volume, and specific gravity, did not differ significantly between rearing systems.

## Effect of rearing system on the technological properties of Holli hen eggs

The technological and functional characteristics of Holli hen eggs under different rearing systems are shown in Table 3. Albumen thickness was significantly higher in eggs from the confinement system (6.26 mm) than in free-range eggs (5.26 mm), whereas yolk thickness, yolk diameter, and yolk index did not differ significantly. Similarly, albumen and yolk pH values were comparable between the two systems.

Significant differences were observed in yolk color parameters. Eggs from free-range hens exhibited much higher yolk color intensity (10.2 vs 2.0), redness (a* = 3.78 vs -6.30), yellowness (b* = 54.0 vs 19.3), and chroma

**Table 2: Effect of rearing system on the physical and rheological traits of Holli hen eggs**

| Variable | Improved confinement system (Mean ± SE) | Traditional free range system (Mean ± SE) | P-value |
|---|---|---|---|
| Egg weight (g) | 47.3 ± 1.38 | 44.4 ± 0.61 | 0.116 |
| Egg length (cm) | 5.14 ± 0.06 | 4.99 ± 0.06 | 0.120 |
| Egg height (cm) | 3.68 ± 0.07 | 3.63 ± 0.03 | 0.500 |
| Shape index (%) | 71.7 ± 1.09 | 72.8 ± 1.09 | 0.507 |
| Shell weight (g) | 4.36 ± 0.20 | 3.67 ± 0.09 | **0.018** |
| Yolk weight (g) | 16.1 ± 0.46 | 15.7 ± 0.64 | 0.666 |
| Albumen weight (g) | 26.8 ± 0.91 | 25.1 ± 0.23 | 0.114 |
| Shell proportion (%) | 9.20 ± 0.19 | 8.27 ± 0.19 | **0.008** |
| Albumen proportion (%) | 56.8 ± 0.59 | 56.4 ± 0.92 | 0.736 |
| Yolk proportion (%) | 34.0 ± 0.73 | 35.3 ± 1.05 | 0.324 |
| Shell resistance (N) | 32.3 ± 3.11 | 31.4 ± 2.89 | 0.833 |
| Shell luminance (L*) | 88.6 ± 1.12 | 89.8 ± 1.00 | 0.447 |
| Shell redness (a*) | 1.12 ± 0.55 | -0.13 ± 0.58 | 0.155 |
| Shell yellowness (b*) | 13.5 ± 1.59 | 9.92 ± 1.66 | 0.158 |
| Shell Chroma | 13.6 ± 1.62 | 9.98 ± 1.68 | 0.160 |
| Shell Hue | 2.78 ± 3.75 | -0.97 ± 0.78 | 0.395 |
| Shell thickness (mm) | 0.27 ± 0.01 | 0.23 ± 0.01 | **0.018** |
| Volume ($cm^3$) | 35.6 ± 1.52 | 33.5 ± 0.51 | 0.257 |
| Specific gravity | 1.33 ± 0.02 | 1.33 ± 0.01 | 0.849 |

*SE: Standard Error*

**Table 3: Effect of rearing system on the techno-functional properties of Holli hen eggs**

| Variable | Improved confinement system (Mean ± SE) | Traditional free range system (Mean ± SE) | Effect of Breeeding system (P-value) |
|---|---|---|---|
| Yolk thickness (mm) | 1.77 ± 0.03 | 1.71 ± 0.04 | 0.265 |
| Albumen thickness (mm) | 6.26 ± 0.37 | 5.26 ± 0.05 | **0.039** |
| Yolk diameter (cm) | 3.78 ± 0.11 | 3.76 ± 0.05 | 0.859 |
| Yolk index (%) | 46.9 ± 1.10 | 45.6 ± 1.47 | 0.480 |
| Albumen pH | 9.65 ± 0.15 | 9.74 ± 0.06 | 0.630 |
| Yolk pH | 6.23 ± 0.05 | 6.15 ± 0.15 | 0.593 |
| Yolk color intensity | 2.00 ± 0.37 | 10.2 ± 0.49 | **0.000** |
| Yolk luminance (L*) | 67.8 ± 1.62 | 67.3 ± 1.01 | 0.810 |
| Yolk redness (a*) | -6.30 ± 0.29 | 3.78 ± 1.77 | **0.000** |
| Yolk yellowness (b*) | 19.3 ± 1.32 | 54.0 ± 6.05 | **0.000** |
| Yolk Chroma | 20.4 ± 1.30 | 54.2 ± 6.18 | 0.000 |
| Yolk Hue | -1.11 ± 5.93 | -0.66 ± 0.56 | 0.947 |
| Haugh unit | 76.0 ± 0.58 | 77.15 ± 0.26 | 0.116 |

(54.2 vs 20.4) compared to confinement eggs, while yolk hue did not vary significantly. The Haugh unit, which indicates albumen quality, was slightly higher in free-range eggs (77.1) than in confinement eggs (76.0), although this difference was not significant.

In summary, while the rearing system had limited effects on egg physical size and weight, confinement eggs had heavier shells and thicker albumen, whereas free-range eggs exhibited much more intense yolk coloration.

### Relationships between physical, rheological and techno-functional parameters of eggs form Holli hen reared in confinement system

The relationships between physical, rheological and techno-functional parameters of eggs form Holli hen reared under traditional free-range system are given in table 4. The analysis of this table revealed close interrelationships among the various egg quality traits, reflecting the structural and compositional coherence of the egg. A strong and positive correlation was observed between egg weight and egg length (r = 0.83), egg height (r = 0.89), and shell weight (r = 0.94), indicating that heavier eggs tend to be larger in size and possess thicker shells. Egg weight also correlated positively with albumen weight (r = 0.95) and shell resistance (r = 0.84), suggesting that the increase in egg mass is accompanied by both improved shell strength and a greater contribution of albumen to the total egg composition.

Egg length was positively associated with shell weight (r = 0.88) and albumen weight (r = 0.86), supporting the idea that morphological traits such as egg size influence both the structural and internal components of the egg. The correlation between egg height and albumen pH (r = 0.99) and yolk weight (r = 0.88) further demonstrated that larger eggs tend to maintain better internal chemical balance.

Shell weight exhibited strong correlations with albumen weight (r = 0.97) and yolk luminance (r = 0.91), meaning that eggs with heavier shells generally contain more albumen and have brighter yolk coloration. Yolk weight also correlated positively with albumen pH (r = 0.94) and negatively with egg specific gravity (r = -0.92), showing that eggs rich in yolk are less dense, probably because of the higher lipid content of the yolk. Similarly, albumen weight was strongly related to yolk luminance (r = 0.84) and to shell weight (r = 0.97), but negatively correlated with Haugh unit (r = -0.95), indicating that higher albumen mass might be associated with a decline in albumen quality due to dilution effects.

Shell resistance was positively correlated with albumen pH (r = 0.81) and yolk pH (r = 0.90), suggesting that stronger shells are often associated with stable internal chemical properties. In contrast, shell thickness did not show any significant relationship with most of the measured traits, implying that shell quality depends more on mineral composition and microstructure than on mere thickness.

Regarding color traits, yolk luminance correlated positively with yolk redness (r = 0.84) and yolk yellowness (r = 0.91), which means that more intensely colored yolks are also brighter and more yellow. However, these pigmentation traits showed weak or negative relationships with Haugh unit and shell traits, indicating that yolk color depends more on dietary pigment availability than on the structural characteristics of the egg.

The Haugh unit was negatively correlated with egg volume (r = -0.97) and with egg height (r = -0.90), suggesting that eggs with larger volume or dimensions may have lower albumen quality, possibly due to age or storage effects. Likewise, egg volume and egg specific gravity were inversely related (r = -0.89), showing that larger eggs tend to have lower density.

Overall, these results illustrate a strong physiological linkage between external and internal egg parameters. Size-related traits such as egg weight, length, and height are tightly associated with shell and albumen characteristics, while internal quality indicators such as pH, Haugh unit, and yolk color exhibit more complex interactions. The significant positive correlations among weight, shell, and albumen traits make them reliable indicators of overall egg quality, whereas the negative correlations involving the Haugh unit and volume reveal potential trade-offs between egg size and freshness-related quality attributes.

**Table 4: Relationships between physical, rheological and techno-functional parameters of eggs form Holli hen reared in confinement system**

| Variables | EGW | EGL | EGH | SHW | YOW | ALW | SHR | APH | YPH | YOL | YOR | YOY | SHT | HU | Volume | ESG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Egg weight (EGW)** | 1 | 0.83* | 0.89* | 0.94** | 0.71 | 0.95*** | 0.84* | 0.87* | 0.61 | 0.75 | 0.44 | 0.28 | 0.05 | -0.99 | 0.97** | -0.75 |
| **Egg length (EGL)** | | 1 | 0.55 | 0.88* | 0.42 | 0.86* | 0.62 | 0.54 | 0.32 | 0.67 | 0.41 | 0.13 | -0.02 | -0.83* | 0.74 | -0.42 |
| **Egg height (EGH)** | | | 1 | 0.74 | 0.88* | 0.74 | 0.78 | 0.99*** | 0.60 | 0.57 | 0.36 | 0.11 | -0.10 | -0.90* | 0.97* | -0.95* |
| **Shell weight (SHW)** | | | | 1 | 0.47 | 0.97*** | 0.79 | 0.70 | 0.48 | 0.91* | 0.65 | 0.17 | -0.07 | -0.94* | 0.86* | -0.58 |
| **Yolk weight (YOW)** | | | | | 1 | 0.46 | 0.70 | 0.94** | 0.65 | 0.20 | -0.06 | 0.08 | -0.13 | -0.71 | 0.83* | -0.92* |
| **Albumen weight (ALW** | | | | | | 1 | 0.75 | 0.69 | 0.48 | 0.84* | 0.56 | 0.34 | 0.16 | -0.95* | 0.86* | -0.54 |
| **Shell resistance (SHR)** | | | | | | | 1 | 0.81* | 0.90* | 0.68 | 0.22 | 0.39 | 0.02 | -0.84* | 0.81* | -0.64 |
| **Albumen pH (APH)** | | | | | | | | 1 | 0.66 | 0.51 | 0.26 | 0.10 | -0.14 | -0.87* | 0.96** | -0.96** |
| **Yolk pH (YPH)** | | | | | | | | | 1 | 0.35 | -0.17 | 0.62 | 0.26 | -0.61 | 0.58 | -0.47 |
| **Yolk luminance (YOL)** | | | | | | | | | | 1 | 0.84* | 0.04 | -0.21 | -0.75 | 0.66 | -0.40 |
| **Yolk redness (YOR)** | | | | | | | | | | | 1 | -0.38 | -0.46 | -0.44 | 0.41 | -0.28 |
| **Yolk yellowness (YOY)** | | | | | | | | | | | | 1 | 0.91* | -0.28 | 0.13 | 0.13 |
| **Shell thickness (SHT)** | | | | | | | | | | | | | 1 | -0.05 | -0.09 | 0.30 |
| **Haugh unit (HU)** | | | | | | | | | | | | | | 1 | -0.97** | 0.75 |
| **Volume** | | | | | | | | | | | | | | | 1 | -0.89* |
| **Egg specific gravity (ESG)** | | | | | | | | | | | | | | | | 1 |

### Relationships between physical, rheological and techno-functional parameters of eggs form Holli hen reared under traditional free-range system

The relationships between physical, rheological and techno-functional parameters of eggs form Holli hen reared under traditional free-range system are given in table 5. This table reveals that egg weight showed a positive and significant correlation with yolk weight (r = 0.89), yolk pH (r = 0.88), and egg volume (r = 0.96), indicating that heavier eggs tend to have larger yolks, higher internal pH values, and greater overall volume. In contrast, a strong negative relationship was found between egg weight and Haugh unit (r = -0.99), suggesting that as eggs become heavier and older, their albumen quality, reflected by the Haugh unit, tends to decline.

Egg length was positively correlated with yolk yellowness (r = 0.97) and yolk redness (r = 0.81), suggesting that elongated eggs may be associated with richer yolk pigmentation. It also correlated moderately with albumen weight (r = 0.80) and shell resistance (r = 0.69), implying that larger eggs may have proportionally stronger shells and greater albumen content.

Egg height was strongly and positively related to yolk weight (r = 0.90) and yolk pH (r = 0.87), showing that taller eggs tend to have larger and more alkaline yolks. On the contrary, it was negatively correlated with albumen weight (r = -0.73) and Haugh unit (r = -0.62), which might reflect a trade-off between egg shape and internal albumen quality.

Shell weight correlated positively with shell resistance (r = 0.91) and moderately with yolk luminance (r = 0.64), suggesting that eggs with heavier shells generally have better mechanical strength and lighter-colored yolks. However, its relationship with yolk weight (r = -0.10) and yolk pH (r = -0.05) was negligible, showing that shell mass does not directly affect internal composition.

Yolk weight was one of the most influential traits, correlating significantly with yolk pH (r = 0.98) and egg volume (r = 0.93), highlighting that yolk development is a key determinant of egg size and internal chemical balance. The negative association between yolk weight and Haugh unit (r = -0.89) suggests that larger yolks may contribute to reduced albumen quality or freshness.

Albumen weight exhibited a moderate positive correlation with yolk luminance (r = 0.48) and yolk redness (r = 0.56), implying a possible compositional linkage between albumen mass and yolk coloration, possibly influenced by nutritional or physiological factors.

Shell resistance showed strong positive correlations with yolk luminance (r = 0.85) and moderate ones with yolk yellowness (r = 0.51), reinforcing the idea that higher shell integrity may coincide with improved yolk color quality, while its correlation with Haugh unit (r = -0.63) was negative, indicating that thicker shells are not necessarily associated with better internal quality.

Albumen pH correlated negatively with yolk redness (r = -0.89) and Haugh unit (r = -0.89), suggesting that higher albumen alkalinity might correspond to lower pigment intensity and poorer albumen consistency.

Yolk pH showed a strong positive relationship with yolk luminance (r = 0.43) and volume (r = 0.91), indicating that eggs with more alkaline yolks are generally larger and brighter.

The color parameters were strongly interrelated, with yolk redness and yolk yellowness showing a significant positive correlation (r = 0.93), and both traits being positively related to shell thickness (r = 0.79), reflecting a coordinated expression of yolk pigmentation traits.

The Haugh unit exhibited a strong negative correlation with egg volume (r = -0.96), confirming that larger eggs generally have lower albumen height and thus lower freshness indicators.

Overall, the correlation pattern demonstrates that egg size traits (egg weight, length, height, and volume) are closely linked with yolk characteristics, while shell and albumen properties exhibit more complex relationships. The negative correlations of Haugh unit with egg weight, pH, and volume highlight the delicate balance between physical growth and internal quality attributes, which are key for assessing egg freshness and consumer acceptability.

**Table 5: Relationships between physical, rheological and techno-functional parameters of eggs form Holli hen reared under traditional free-range system**

| Variables | EGW | EGL | EGH | SHW | YOW | ALW | SHR | APH | YPH | YOL | YOR | YOY | SHT | HU | Volume | ESG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Egg weight (EGW)** | 1,00 | 0,53 | 0,62 | 0,29 | 0,89* | 0,06 | 0,63 | 0,20 | 0,88* | 0,61 | 0,20 | 0,42 | 0,05 | -0,99 | 0,96* | -0,26 |
| **Egg length (EGL)** | | 1,00 | -0,29 | 0,47 | 0,15 | 0,80 | 0,69 | -0,66 | 0,16 | 0,75 | 0,81 | 0,97* | 0,63 | -0,53 | 0,49 | -0,06 |
| **Egg height (EGH)** | | | 1,00 | -0,36 | 0,90* | -0,73 | -0,11 | 0,68 | 0,87* | -0,07 | -0,32 | -0,31 | -0,29 | -0,62 | 0,70 | -0,52 |
| **Shell weight (SHW)** | | | | 1,00 | -0,10 | 0,66 | 0,91* | -0,01 | -0,05 | 0,64 | -0,08 | 0,27 | -0,23 | -0,29 | 0,03 | 0,81 |
| **Yolk weight (YOW)** | | | | | 1,00 | -0,39 | 0,25 | 0,43 | 0,98** | 0,32 | -0,00 | 0,09 | -0,05 | -0,89* | 0,93* | -0,50 |
| **Albumen weight (ALW** | | | | | | 1,00 | 0,62 | -0,65 | -0,40 | 0,48 | 0,56 | 0,74 | 0,35 | -0,06 | -0,06 | 0,42 |
| **Shell resistance (SHR)** | | | | | | | 1,00 | -0,08 | 0,31 | 0,85 | 0,16 | 0,51 | 0,00 | -0,63 | 0,42 | 0,49 |
| **Albumen pH (APH)** | | | | | | | | 1,00 | 0,38 | -0,36 | -0,89* | -0,79 | -0,89* | -0,20 | 0,13 | 0,17 |
| **Yolk Ph (YPH)** | | | | | | | | | 1,00 | 0,43 | 0,01 | 0,11 | 0,01 | -0,88 | 0,91* | -0,46 |
| **Yolk luminance (YOL)** | | | | | | | | | | 1,00 | 0,44 | 0,66 | 0,43 | -0,61 | 0,49 | 0,15 |
| **Yolk redness (YOR)** | | | | | | | | | | | 1,00 | 0,93* | 0,94* | -0,20 | 0,31 | -0,47 |
| **Yolk yellowness (YOY)** | | | | | | | | | | | | 1,00 | 0,79 | -0,42 | 0,44 | -0,23 |
| **Shell thickness (SHT)** | | | | | | | | | | | | | 1,00 | -0,05 | 0,20 | -0,53 |
| **Haugh unit (HU)** | | | | | | | | | | | | | | 1,00 | -0,96** | 0,26 |
| **Volume** | | | | | | | | | | | | | | | 1,00 | -0,51 |
| **Egg specific gravity (ESG)** | | | | | | | | | | | | | | | | 1,00 |

## DISCUSSION

### Effect of rearing system on the physical and rheological traits of Holli hen eggs

The present study demonstrated that the rearing system had limited influence on most of the physical and rheological characteristics of Holli hen eggs, although some shell parameters were significantly affected. The absence of significant differences in egg weight, length, height, and shape index between the traditional free-range and improved confinement systems indicates that the genetic background of Holli hens may exert a stronger influence on egg morphometry than the production environment. Similar findings were reported by Adeyemo *et al.* (2018) in Nigerian indigenous chickens and by Sapkota *et al.* (2020) in Sakini hens, who both observed comparable egg dimensions across production systems or selection generations.

However, the slightly higher egg weight recorded in the confinement system (47.3 g vs. 44.4 g) suggests that controlled feeding and reduced energy expenditure under confinement could enhance nutrient allocation toward egg formation. Kumar *et al.* (2022) and Maddheshiya *et al.* (2020) similarly reported heavier eggs in improved backyard or semi-intensive systems compared to scavenging systems. Gongolo and Tanganyika (2018) also attributed improved egg size under confinement to better feed conversion efficiency and stable microclimatic conditions.

Shell characteristics, particularly shell weight, proportion, and thickness, were significantly higher in eggs from the improved confinement system. This suggests that hens under confinement had higher mineral intake and lower physical stress, enhancing calcium deposition during shell formation. According to Kiczorowska *et al.* (2015) and Lordelo *et al.* (2020), mineral content and shell quality tend to be superior in eggs from managed systems with balanced diets compared to free-range systems, where nutrient variability is higher. Rajkumar *et al.* (2014) and Sohail *et al.* (2013) also observed that shell thickness and shell weight were positively correlated with dietary mineral balance and egg weight.

The similarity observed in yolk and albumen traits between the two rearing systems aligns with findings by Akhilesh *et al.* (2023) and Balamurugan *et al.* (2024), who noted that internal egg composition of indigenous breeds such as Siruvidai and Aseel is more genetically determined than environmentally influenced. Indigenous chickens have evolved adaptive physiological mechanisms that maintain internal egg consistency across variable environmental conditions (Isidahomen *et al.*, 2013; Sreenivas *et al.*, 2013).

Furthermore, the lack of difference in shell color and resistance between the rearing systems suggests that pigment synthesis and shell structural integrity are more genotype-dependent than diet-dependent in Holli hens. Whiting *et al.* (2019) and Wang *et al.* (2017) showed that although dietary composition can modify shell pigmentation or strength in commercial layers, such effects are less pronounced in indigenous chickens due to their robust adaptive physiology. Similar findings were also reported by Tougan *et al.* (2021), who observed that allowing Bonaparte guinea fowls outdoor access in Benin influenced certain egg physical and technological traits, with eggs from confined birds exhibiting thicker shells and higher shell proportion, while free-range systems enhanced yolk pigmentation due to diverse natural feed resources.

Overall, these results indicate that while the rearing environment marginally influences external egg parameters such as shell thickness and weight, the intrinsic qualities of Holli hen eggs remain stable across systems. This resilience underscores the adaptability of indigenous breeds, which can sustain acceptable egg quality under low-input rural systems. This finding supports previous observations that indigenous chickens play a crucial role in food and nutritional security in developing countries due to their robustness and consistent productivity even under suboptimal management (Kumar *et al.*, 2013a; Adeyemo *et al.*, 2018; Lordelo *et al.*, 2020).

### Effect of rearing system on the technological properties of Holli hen eggs

The technological quality of eggs reflects the combined influence of genotype, nutrition, and environmental conditions on albumen structure, yolk composition, and pigmentation. In the present study, the rearing system exerted a marked influence on certain technological traits of Holli hen eggs, notably albumen thickness and yolk pigmentation.

The significantly higher albumen thickness observed in the confinement system (6.26 mm *vs.* 5.26 mm; $P = 0.039$) suggests that hens maintained under controlled housing conditions benefit from reduced physical stress and a more balanced nutrient intake, promoting albumen integrity. Similar trends were reported by Maddheshiya *et al.* (2020) and Kumar *et al.* (2022), who found that improved feeding and management systems enhanced albumen height and Haugh unit in indigenous chicken breeds. Sreenivas *et al.* (2013) also highlighted that albumen quality is positively correlated with protein nutrition and the physiological condition of the hen. The non-significant difference in Haugh units between systems in the present study (77.1 *vs.* 76.0) is consistent with findings by Akhilesh *et al.* (2023) and Gandhimathi *et al.* (2024), who reported that genetic factors play a more dominant role in determining albumen quality than environmental management in local breeds.

In contrast, yolk color characteristics were strongly affected by the rearing system. Free-range eggs exhibited markedly higher color intensity, redness ($a^*$), and yellowness ($b^*$), resulting in a higher chroma value. This difference can be attributed to the ingestion of natural pigments such as xanthophylls and carotenoids from grasses, seeds, and insects available to scavenging hens. Lordelo *et al.* (2020) and Kiczorowska *et al.* (2015) similarly reported that free-range and organic systems enhance yolk pigmentation due to greater access to pigment-rich feed sources compared with confinement systems relying on commercial diets. Rajkumar *et al.* (2014) and Sapkota *et al.* (2020) also observed intense yolk coloration in native hens allowed to forage, emphasizing the nutritional and aesthetic advantage of free-range production systems.

The similarity in yolk diameter, yolk index, and pH between rearing systems indicates that the structural and biochemical stability of yolk components in Holli hens is largely genetically determined and resilient to environmental variation. These findings align with Isidahomen *et al.* (2013) and Adeyemo *et al.* (2018), who observed comparable internal egg quality traits across genotypes and production systems among indigenous chickens.

Taken together, these results demonstrate that confinement conditions improve albumen consistency and shell robustness, while free-range systems significantly enhance yolk pigmentation, an important attribute of consumer preference and market value. Similar complementary effects were documented by Whiting *et al.* (2019) and Wang *et al.* (2017), who suggested that diet formulation and rearing conditions jointly determine the functional and sensory attributes of eggs. Similar observations were also made by Tougan *et al.* (2021), who observed that allowing Bonaparte guinea fowls outdoor access in Benin influenced internal quality traits due to diverse natural feed resources. Therefore, optimizing the rearing system for Holli hens should aim to balance nutritional control with opportunities for natural foraging. Such integration could sustain albumen quality while enhancing yolk coloration, thereby improving both technological functionality and consumer appeal.

The different pH values of egg white and yolk recorded in the current study are higher than those reported by Haugh (1937) and Tùmová *et al.* (2007) for eggs collected the day after laying, but comparable to the values recorded by Aydin (2006) in White Leghorn laying hens at 28 weeks of age. According to Aydin (2006), the lightness of the yolk in White Leghorn eggs ranges from 59 to 71, the red index ranges between -4 and -3, and the yellow index fluctuates between 37 and 60. These values differ from those recorded in the present study, and this discrepancy may be associated with the composition of the feed used.

### Relationships between physical, rheological, and techno-functional parameters of eggs from Holli hens

Overall, the present findings highlight a close physiological interdependence between the external and internal quality traits of Holli hen eggs. Morphometric parameters such as egg weight, length, and height exhibited strong positive associations with shell and albumen characteristics, suggesting that larger eggs tend to develop thicker and heavier shells and a greater albumen mass. These correlations are consistent with previous observations by Gandhimathi *et al.* (2024) and Balamurugan *et al.* (2024), who reported similar patterns in indigenous chicken breeds, indicating that physical size traits can serve as reliable predictors of overall egg integrity.

Conversely, internal quality indicators such as pH, Haugh unit, and yolk color displayed more complex and sometimes inverse relationships with egg size. The observed negative correlations between the Haugh unit and size-related variables suggest that larger eggs may experience a faster decline in albumen quality during storage, as reported by Lordelo *et al.* (2020) and Kumar *et al.* (2022). This trade-off between egg size and freshness-related parameters reflects underlying physiological constraints in albumen synthesis and stabilization.

In addition, yolk color intensity showed weak or inconsistent correlations with other physical parameters, implying that pigmentation is more strongly influenced by dietary and environmental factors than by egg morphology. This observation aligns with findings from Kiczorowska *et al.* (2015) and Rajkumar *et al.* (2014), emphasizing the influence of carotenoid intake and rearing system on yolk coloration rather than egg structure itself.

Taken together, these relationships indicate that while size and shell traits provide robust indicators of structural quality, functional parameters such as Haugh unit and yolk color are governed by dynamic biochemical processes linked to nutrition, physiology, and storage stability. Understanding these interrelationships is essential for developing breeding and management strategies that optimize both the technological functionality and consumer appeal of indigenous Holli hen eggs.

## CONCLUSION

The present study demonstrates that the rearing system exerts a measurable influence on the physical, rheological, and techno-functional qualities of Holli hen eggs, an indigenous genetic resource of high local importance. While most size-related parameters such as egg weight, length, and height were not significantly affected by the production system, eggs from hens raised under improved confinement exhibited slightly greater shell weight, thickness, and albumen height, indicating superior structural integrity and protection. In contrast, free-range eggs displayed markedly enhanced yolk pigmentation, reflecting the effect of natural foraging and carotenoid-rich feed sources on yolk color development.

Correlations among the measured traits revealed strong physiological linkages between egg morphology, shell properties, and internal composition, confirming that external physical indicators can reliably predict internal quality. However, negative associations between egg size and freshness-related indicators such as the Haugh unit underscore potential trade-offs between productivity and storage stability.

Overall, the findings suggest that both rearing systems possess distinct advantages: confinement improves shell quality and consistency, while free-range management enhances yolk coloration and possibly consumer appeal. These insights support the need for balanced production strategies that integrate animal welfare, nutritional management, and technological quality improvement to optimize the performance and market value of indigenous Holli hen eggs.

## REFERENCES


Adeyemo G.O., Bolarinwa M.O., Ehiabhi O. (2018). Hematology and external egg quality parameters of three Nigerian indigenous chicken genotypes. *International Journal of Molecular Biology*, 3: 197–201.

Akhilesh P., Satya R., Sagar Gandhimathi D., Churchil R.R. (2023). External and internal egg qualities of fresh and stored eggs of indigenous Siruvidai, TANUVAS Aseel and White Leghorn breeds of chicken. Paper presented at the VI Convention of the AMST and National Seminar on "One Health – A New Paradigm to Augment Livestock Productivity and Food Security," *Madras Veterinary College*, Chennai, India.

Aydin R. (2006). Effect of storage temperature on the quality of eggs from conjugated linoleic acid-fed laying hens. *South African Journal of Animal Science,* 36: 13–20.

Balamurugan P., Sangilimadan K., Ezhil Valavan S., Manivannan C., Venkataramanan R. (2024). Assessment of external and internal egg quality traits of indigenous Siruvidai chicken of Tamil Nadu. *Forum – An International Journal*, 16: 293–298.

FAO (2022). CountryStat/Benin.

Gandhimathi D., Muthusamy P., Richard Churchil R., Thilak Pon Jawahar K. (2024). External and internal egg quality characteristics of indigenous Siruvidai, Aseel and White Leghorn chickens. *Indian Journal of Veterinary and Animal Sciences Research*, 53: 55–64.

Gongolo J., Tanganyika J. (2018). Evaluation of physical egg quality characteristics of free-range indigenous Malawian normal feathered and frizzled chickens. *International Journal of Avian and Wildlife Biology*, 3: 00046.

Haugh R.R. (1937). The Haugh unit for measuring egg quality. *U.S. Egg and Poultry Magazine,* 43: 552–555 and 572.

Isidahomen C.E., Njidda A.A., Olatunji E.A. (2013). Egg quality traits of indigenous and exotic chickens as influenced by specific genes. *Journal of Biology, Agriculture and Healthcare*, 3: 53–60.

Kiczorowska B., Samolińska W., Kwiecień M., Winiarska-Mieczan A., Rusinek-Prystupa E., Al-Yasiry A.R.M. (2015). Nutritional value and the content of minerals in eggs produced in large-scale, courtyard and organic systems. *Journal of Elementology*, 20: 887–895.

Kumar S.P.M., Dahiya Y., Ratwan P., Sheoran N., Kumar N. (2022). Assessment of egg quality and biochemical parameters of Aseel and Kadaknath indigenous chicken breeds of India under backyard poultry farming. *Poultry Science*, 101: 101589.

Lordelo M., Cid J., Cordovil C.M.D.S., Alves S.P., Bessa R.J.B., Carolino I. (2020). A comparison between the quality of eggs from indigenous chicken breeds and that from commercial layers. *Poultry Science*, 99: 1768–1776.

Maddheshiya P.K., Ali N., Fahim A., Bharti M.K., Kumar R., Roy, D., Sahu D.S. (2020). Study of egg traits among improved varieties of chicken reared under backyard poultry production system. *Indian Journal of Animal Science*, 90: 898–902.

Mankor A. (2009). Evolution du secteur de l'élevage Ouest africain, consommation urbaine de viande en Afrique de l'Ouest: l'exemple de Dakar. *Grain de Sel*, 46–47: 16–17.

Rajkumar U., Raju M.V.L.N., Niranjan M., Haunshi S., Padhi M. K., Rao S.V.R. (2014). Evaluation of egg quality traits in native Aseel chicken. *Indian Journal of Poultry Science*, 49: 324–327.

Sapkota S., Kolakshyapati M.R., Devkota N.R., Gorkhali N., Bhattarai N.M. (2020). Evaluation of external and internal egg quality traits of indigenous Sakini chicken in different generations of selection. *International Journal of Agriculture and Forestry*, 10: 41–48.

Sohail A., Muhammad A., Hussain J., Iqbal A., Usman M., Rehman A., Hussnain F. (2013). Comparative study on productive performance, egg quality, egg geometry and hatching traits of three age groups of indigenous Peshawari Aseel chickens. *Journal of Veterinary Advances*, 2: 21–25.

Sreenivas D., Prakash M.G., Mahendra M., Chatterjee R.N. (2013). Genetic analysis of egg quality traits in White Leghorn chicken. *Veterinary World*, 6: 263–266.

Tougan P.U., Bonou A.G., Gbaguidi T., Koutinhouin G.B., Ahounou S., Salifou C.F.A., Zannou M.S., Mensah G.A., Beckers Y., Everaert N., Théwis A., Youssao A.K.I. (2016). Influence of feed withdrawal length on carcass traits and technological quality of indigenous chicken meat reared under traditional system in Benin. *Journal of World's Poultry Research*, 6: 37–47.

Tougan P.U., Dahouda M., Salifou C.F.A., Ahounou G.S., Kpodekon M.T., Mensah G.A., Kossou D.N.F., Amenou C., Kogbeto C.E., Lognay G., Théwis A., Youssao I.A.K. (2013b). Assessment of nutritional quality of meat of local poultry populations of *Gallus gallus* species of Benin. *Journal of Animal and Plant Sciences*, 19: 2908–2922.

Tougan P.U., Domingo I.A., Pomalegni B.C., Pitala W., Osseyi G.E., Théwis A. (2021). Caractéristiques physiques, qualité technologique et composition proximale des œufs de pintades Bonaparte du Bénin élevées avec ou sans accès au parcours extérieur. *International Journal of Innovation and Applied Studies*, 30: 885–891.

Tougan P.U., Youssao A.K.I., Dahouda M., Salifou C.F.A., Ahounou G.S., Kpodekon M., Mensah G.A., Kossou D.N., Amenou C., Kogbeto C., Théwis A. (2013a). Variability of carcass traits of local poultry populations of *Gallus gallus* species of Benin by genetic type, breeding mode and slaughter age. *International Journal of Poultry Science*, 12: 473–483.

Tougan P.U., Zannou M.S., Dedjiho A., Domingo I.A., Osseyi G. E., Théwis A. (2023). Influence of the slaughtering process and the post-mortem maturation time on carcass and meat quality of Sahoue chicken ecotype of Benin. *International Journal of Innovation and Scientific Research*, 67: 104–118.

Tůmová E., Zita L., Hubený M., Skřivan M., Ledvinka Z. (2007). The effect of oviposition time and genotype on egg quality characteristics in egg type hens. *Czech Journal of Animal Science,* 52: 26–30.

Wang X., Zhang H., Wang H., Wang J., Wu S., Qi G. (2017). Effect of dietary protein sources on production performance, egg quality, and plasma parameters of laying hens. *Asian-Australasian Journal of Animal Sciences*, 30: 400–409.

Whiting I.M., Rose S.P., Mackenzie A.M., Amerah A.M., Pirgozliev V.R. (2019). Effect of wheat distillers dried grains with solubles and exogenous xylanase on laying hen performance and egg quality. *Poultry Science*, 98: 3756–3762.

Youssao A.K.I., Assogba N.M., Alkoiret T.I., Dahouda M., Idrissou N.-D., Kayang B.B., Yapi-Gnaoré V., Assogba H.M., Houinsou A.S., Ahounou S., Tougan U.P., Rognon X., Tixier-Boichard M. (2012). Comparison of growth performance, carcass characteristics and sensory characters of Benin indigenous chickens and Label Rouge (T55×SA51). *African Journal of Biotechnology*, 11: 15569–15579.

Youssao A.K.I., Rognon X., Yapi-Gnaore V., Kpodekon T.M., Idrissou N.-D., Kayang B., Houinsou S.A., Ahounou S., Tougan P.U., Tixier-Boichard M. (2009b). Growth performances and laying abilities of the indigenous chickens of Benin and Label Rouge (T55×SA51). Paper presented at the 5th World Poultry Conference, Taba, Egypt, 10–13 March 2009.

Youssao A.K.I., Senou M., Dahouda M., Amoussou-Sydol E., Tougan U.P., Ahounou S., Yapi-Gnaoré V., Kayang B., Rognon X., Tixier-Boichard M.T.K. (2011). Laying performances and egg quality characteristics of F1 crossbred hens resulting from Label Rouge (T55×SA51) and two local ecotypes as parental lines. *International Journal of Livestock Production*, 2: 69–78.

Youssao A.K.I., Senou M., Dahouda M., Kpodekon T.M., Jenontin J., Idrissou N.-D., Bonou A.G., Tougan P.U., Assogba H.M., Ankole E., Rognon X., Tixier-Boichard M. (2009a). Genetic improvement of local chickens by crossing with the Label Rouge (T55×SA51): Growth performances and heterosis effects. *International Journal of Poultry Science*, 8: 536–544.

Youssao A.K.I., Tobada P.C., Koutinhoun B.G., Dahouda M., Idrissou N.-D., Bonou G.A., Tougan U.P., Ahounou S., Yapi-Gnaoré V., Kayang B., Rognon K., Tixier-Boichard M. (2010). Phenotypic characterization and molecular polymorphism of indigenous poultry populations of the species *Gallus gallus* of Savannah and Forest ecotypes of Benin. *African Journal of Biotechnology*, 9: 369–381.

Youssao A.K.I., Tougan U.P., Ahounou S.G., Houessionon B.F. J., Koutinhouin B. (2013). Typology of local poultry breeding of *Gallus gallus* species in family poultry in Benin. *International Journal of Agronomy and Agricultural Research*, 3: 1–13.