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RESEARCH ARTICLE

Egg Quality and Nutritional Profiles of Four Turkey Varieties Reared under Tropical Conditions

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Abstract

Background and Objective: Characterizing the egg quality traits and nutritional composition of turkey varieties is essential for informed breeding decisions and the development of functional eggs. However, information on these characteristics under tropical production conditions remains limited. Therefore, this study investigated the egg quality traits, proximate composition and amino acid profiles of eggs from four turkey varieties (Black, Bronze, White and Bourbon Red) reared under tropical conditions in Bangladesh.
Materials and Methods: A total of 240 turkey layers, with 60 birds per variety, were reared on a corn-soya-based diet from 24 to 55 weeks of age in four separate floor pens under an intensive rearing system. At 55 weeks of age, a total of 120 eggs (30 eggs per variety) were randomly collected to evaluate external and internal egg quality, proximate composition and amino acid profiles. Data were analyzed using one-way ANOVA and treatment means were separated using Duncan's multiple range test at $p<0.05$.
Results: The White variety exhibited a higher shape index than the other varieties ($p<0.001$). Moisture, crude protein and ash contents differed among the varieties. Bourbon Red showed the highest moisture content ($p<0.001$), whereas Black and Bronze exhibited the highest crude protein content and Black had the highest ash content ($p<0.05$). The Black variety also showed the highest amino acid concentration, followed by the Bronze variety ($p<0.0001$).
Conclusion: Overall, the Black and Bronze turkey varieties produced eggs with superior crude protein and amino acid concentrations, providing valuable baseline nutritional information to support variety selection under tropical production conditions.

INTRODUCTION

Poultry eggs are considered one of the most complete and affordable animal-derived foods because they contain highly digestible protein, essential amino acids, lipids, vitamins and minerals required for human growth, health and development[1]. Egg quality traits and variety are important indicators in poultry breeding programs, human nutrition and the development of value-added functional eggs[2,3]. In Bangladesh, turkey farming has recently gained attention as an emerging alternative poultry enterprise due to the increasing demand for nutrient-rich poultry products and the adaptability of turkeys to local production systems[4,5]. Environmental conditions and genetic background are key determinants of poultry growth, reproductive performance and production efficiency, especially in developing countries where birds are predominantly reared under uncontrolled housing systems[6,7]. However, despite the growing interest in turkey farming, the combined effects of variety and tropical conditions on the egg quality and nutritional composition of turkeys in Bangladesh remain poorly understood.

Turkey eggs are larger than chicken eggs and are valued for their high protein, lipid and essential micronutrient contents, making them a promising source of high-quality animal protein for human consumption[8,9]. Egg quality is commonly assessed by external traits, such as egg weight, shape index and shell thickness and internal traits, such as albumen quality, yolk proportion and Haugh unit, all of which influence consumer acceptability, hatchability and chick performance[10,11]. Beyond these physical characteristics, the proximate composition and amino acid profile of eggs determine their nutritional value and their suitability for the development of functional eggs and successful breeding programs[12,13]. These egg quality traits and amino acid profiles vary among different poultry species[8]. Because variety reflects underlying genetic variation, both the physical and biochemical characteristics of eggs may differ considerably among turkey varieties, resulting in measurable differences in egg quality and nutrient composition.

Under tropical conditions, poultry variety plays a significant role in overall production performance and egg quality characteristics[7,14,15]. Chronic heat stress, caused by elevated ambient temperatures (above 25°C) and relative humidity (above 60%) in tropical regions, reduces feed intake, alters blood biochemistry and general health status and ultimately compromises egg quality, making it a major constraint to poultry production[7,16,17]. Nevertheless, certain varieties and breeds within a species are better adapted to tropical conditions and outperform others under uniform feeding and management systems[18]. Differences in the performance of varieties and breeds under tropical conditions also influence the proximate composition and amino acid profiles of eggs from laying hens[19]. The amount and composition of amino acids determine protein quality[20]. Inadequate nutrient and amino acid contents in eggs impair embryonic development, increase post-hatch chick mortality, reduce bird performance and decrease the nutritional value and taste of eggs[19,21]. Since proximate composition and amino acid profiles are important criteria for selecting varieties in breeding programs aimed at developing functional eggs for human nutrition, identifying the highest-quality eggs among available turkey varieties is of considerable importance.

The objective of this study was therefore to assess and compare the external and internal egg quality characteristics, proximate composition and amino acid profiles of eggs produced by four turkey varieties, namely Black, Bronze, White and Bourbon Red, raised under tropical conditions in Bangladesh. We hypothesized that genetic differences among Turkey varieties would result in variations in egg quality traits and nutritional composition, including amino acid profiles, despite uniform feeding and management conditions.

MATERIALS AND METHODS

Animal material: This study was conducted at the Turkey Research Shed, Poultry Research Centre, Bangladesh Livestock Research Institute, Savar, Dhaka-1341, Bangladesh. All experimental procedures were approved by the Ethical Committee of the Bangladesh Livestock Research Institute and were conducted in accordance with the institute's ethical guidelines.

Birds, diets and experimental procedure: A total of 240 laying turkeys representing four varieties (60 birds per variety) were reared from 24 to 55 weeks of age on a corn-soya-based layer diet under an intensive rearing system in an environmentally uncontrolled house. Feed and water were provided *ad libitum* throughout the experimental period. Appropriate biosecurity measures, including foot baths and virocid spraying, as well as the recommended vaccination program, were maintained throughout the study. The turkeys were fed a conventional corn-soya-based layer diet during the entire experimental period (Table 1). A standard lighting program of 16 hrs light and 8 hrs dark (16L:8D) was maintained throughout the laying period. The study was conducted during the summer season (April to June) in Savar, Dhaka, Bangladesh, when the ambient temperature ranged from 28-36°C, with an average of approximately 32°C. During this period, the relative humidity typically ranged from 60 to 85%, providing the natural tropical climatic conditions for the laying birds.

Egg sampling: At 55 weeks of age, a total of 120 eggs (30 eggs per variety) were randomly collected to evaluate external and internal egg quality, proximate composition and amino acid profiles. Each egg was assigned a unique identification code according to its respective variety. Prior to analysis, all eggs were visually inspected and those with shell cracks, deformities, abnormal shape, or other visible defects were excluded from the study. Only clean, intact and normally shaped eggs were used for further analysis. The eggs were

Table 1: Ingredients and nutritional composition of Turkey layer diet

Ingredient		Inclusion (%)
Corn		49.90
Soybean meal		24.00
Rice polish		8.00
Wheat bran		3.00
Fish meal		3.00
Oil		2.00
Limestone		6.50
Dicalcium phosphate		1.00
Salt		0.30
Vitamin–mineral premix[1]		0.50
DL-Methionine		0.20
Nutrient composition	Calculated	Analyzed
Metabolizable energy (kcal/kg)	2800.00	2811.750
Crude protein (%)	18.00	17.500
Crude fat (ether extract) (%)	4.00	4.400
Crude fiber (%)	4.00	3.450
Ash (%)	-	
Lysine (%)	0.90	
Methionine (%)	0.44	
Calcium (%)	4.00	
Phosphorus (%)	0.70	
Serine[2]		1.101
Arginine[2]		1.343
Glycine[2]		1.049
Aspartic acid[2]		2.429
Glutamic acid[2]		4.690
Threonine[2]		0.871
Alanine[2]		1.237
Proline[2]		1.425
Lysine[2]		1.320
Tyrosine[2]		0.634
Valine[2]		1.150
Isoleucine[2]		0.974
Lucine[2]		2.054
Phenylalanine[2]		1.026

[1] Vitamin-mineral premix supplied per kg diet: vitamin A, D , E, K, B-complex vitamins, Cu, Fe, Zn, Mn, Se and I, according to layer requirements, [2]Amino acid concentrations are expressed as grams per 100 grams of crude protein (CP basis), *Crude protein, ether extract, crude fiber and ash were determined by standard AOAC methods, Amino acids and mineral contents were calculated based on ingredient composition

stored at 4°C under uniform conditions until analysis. Before measurement, the eggs were allowed to reach room temperature, when required, to minimize temperature-related variation. External and internal egg quality traits, together with nutritional composition analyses, were determined using standard laboratory procedures at the Poultry Research Centre, Bangladesh Livestock Research Institute, Savar, Dhaka, Bangladesh.

Measurement of egg quality: A total of 60 eggs (15 eggs per variety) were randomly selected from each variety to evaluate external and internal egg quality traits. The analyses were conducted at the Laboratory of Food Processing and Value Addition, Poultry Research Centre, Bangladesh Livestock Research Institute. Egg, albumen and yolk weights were measured using an electronic balance with a precision of 0.01 g. Egg length and breadth were measured to the nearest 0.1 mm using a digital vernier caliper (Model: INSIZE Electronic Digital Caliper, China). The eggs were then broken and the contents were transferred onto a glass plate to measure thick albumen height using a tripod micrometer (Model: Mitutoyo 293-240-30 Digimetric Micrometer, Tokyo, Japan). The yolk and albumen were carefully separated and weighed using an electronic balance. Eggshells were rinsed with water to remove any residual albumen, dried in a fume hood and subsequently weighed. Eggshell thickness was measured using an eggshell thickness gauge (Model: Mitutoyo Digital Micrometer, Tokyo, Japan). Yolk colour was determined using the Roche Yolk Color Fan (Switzerland). The following egg quality parameters were calculated for each egg: Egg weight ($x \pm 0.1$ g), shape index (%), yolk, albumen and shell percentages, shell thickness (mm), yolk index and albumen-to-yolk ratio (g/g).

Shape index: The shape index (%) was calculated using egg width and egg length measurements, recorded to an accuracy of $\pm$ 0.1 cm, according to the following formula:

$$\text{Shape index (\%)} = \frac{\text{Egg width (mm)}}{\text{Egg length (mm)}} \times 100\%$$

Yolk/albumin/shell (%): The percentages of the yolk, albumen and shell were calculated using the following formula:

$$\text{Yolk, albumen and shell (\%)} = \frac{\text{Yolk weight, albumen weight, shell weight (g)}}{\text{Egg weight (g)}} \times 100\%$$

Yolk index: Yolk height and yolk diameter were measured using a micrometer with an accuracy of $\pm$1 mm. The yolk index was calculated using the following formula:

$$\text{Yolk index} = \frac{\text{Yolk height (mm)}}{\text{Yolk diameter (mm)}}$$

Albumen index: Albumen height and albumin diameter were measured using a micrometre with an accuracy of $\pm$1 mm. Albumen index was calculated using the following formula:

$$\text{Albumen index} = \frac{\text{Albumen height (mm)}}{\text{Albumin diameter (mm)}}$$

Egg shell thickness: Average eggshell thickness ($\pm$0.001 mm) was calculated from measurements taken at the sharp (pointed) end, the blunt (rounded) end and the widest part of the eggshell (excluding the membrane), using a micrometer screw gauge.

Haugh unit: The Haugh Unit (HU) was determined using the following formula, as first described by Haugh[22] in 1937.

$$HU = 100\log(H-1.7W0.37+7.57)$$

Proximate analysis: The proximate composition of eggs was determined using five eggs per variety, following the AOAC method. Crude nitrogen was measured using the Kjeldahl method and crude protein concentration was calculated using the formula:

$$\text{Crude protein} = \text{Crude nitrogen}\times 6.25$$

Fat content was determined using the reflux Soxhlet ether extraction method.

Freeze-drying (lyophilization): A total of 40 eggs (10 eggs per variety) were selected for freeze-drying prior to amino acid analysis. The shells of the fresh eggs were cleaned, broken and the contents were emptied into clean, labelled glass beakers. The whole egg contents were then freeze-dried at -60°C for 2 days using a Freeze Dryer (Christ, Germany).

Amino acid analysis by ultra performance liquid chromatography: The amino acid profile of turkey egg samples was determined according to the methods described by Moore *et al.*[23] and Domínguez *et al.*[24]. A freeze-dried egg sample (200 mg) was weighed and transferred into a glass bottle (GL45, Max 180°C, Duncan, Germany) for hydrolysis. A 25 mL volume of 6 N hydrochloric acid was added to the samples and the glass bottle was sealed and incubated at 110°C for 24 hrs in a drying oven (Fison Instruments Ltd., United Kingdom). After protein hydrolysis was completed, the hydrolysate was diluted with DDW water to a final volume of 100 mL and filtered through Whatman No. 1 filter paper (125 mm). The filtrate was then evaporated at 60°C and concentrated to a final volume of 1 mL. The dried residue was dissolved in 2 mL of DDW water and filtered through a 0.22 µm syringe filter. Pre-column derivatization was subsequently performed and the amino acids were finally analysed using an Ultra Performance Liquid Chromatography system (UPLC H-Class, Waters, Milford, MA, USA) equipped with a scanning PDA detector (Waters). Quantification was performed using the external standard technique with an amino acid standard (Amino Acid Standard H, Waters, Milford, MA, USA) and the results were expressed as g/100 g protein.

Statistical analysis: All statistical analyses were performed using RStudio (version 4.5.1). One-way analysis of variance (ANOVA) was used to determine the effects of variety (Black, Bronze, White and Bourbon Red) on egg quality characteristics, proximate composition and amino acid profiles. When significant differences among means were observed, mean comparisons were performed using Duncan's Multiple Range Test (DMRT). Data are presented as Mean±SEM and differences were considered statistically significant at $p<0.05$.

RESULTS AND DISCUSSION

External and internal quality of egg: In the present study, no significant differences were observed in the external and internal egg quality parameters among the four turkey varieties, with the exception of shape index ($p<0.001$) (Table 2). Egg weight ranged from 62.6 g to 70.4 g across the varieties and did not differ significantly. Previous studies conducted under tropical conditions have reported reductions in egg weight, internal quality and shell quality across different laying hen varieties as a consequence of heat stress[7,17]. The shape index differed significantly among the four varieties, with the White variety exhibiting the highest value (77.10) and the Black variety the lowest (70.01). According to

Table 2: External and internal quality of Turkey eggs

	Variety					
Parameters	Black	Bronze	White	Red	SEM	p-value
Egg weight (g)	62.64	67.32	70.38	64.89	2.25	0.131
Shape Index	70.01^{c}	71.28^{bc}	77.10^{a}	73.93^{b}	0.99	0.001
Albumin Index	0.11	0.10	0.11	0.10	0.01	0.953
Yolk colour	6.20	7.40	6.00	7.20	0.40	0.057
Yolk index	0.44	0.43	0.41	0.40	0.01	0.223
Albumin (%)	57.93	61.22	56.92	60.61	1.37	0.118
Yolk (%)	30.18	26.73	31.49	28.15	1.32	0.092
Shell (%)	11.89	12.05	11.59	11.25	1.49	0.076
Shell thickness (mm)	0.46	0.47	0.48	0.45	0.02	0.862
Haugh unit	85.79	81.59	83.93	83.76	4.66	0.937
Grade	AA	AA	AA	AA		

$^{a-d}$Means within a column with no common superscript differ ($p<0.05$)

Table 3: Proximate component of different varieties of Turkey egg

Proximate components	Variety					
	Black	Bronze	White	Red	SEM	p-value
MO	66.300[c]	69.217[b]	67.317[bc]	73.367[a]	0.790	0.001
CP	12.923[a]	12.800[a]	12.250[ab]	11.760[b]	0.250	0.038
CF	0.800	1.750	0.683	1.783	0.203	0.212
EE	5.800	5.800	4.667	4.200	1.231	0.734
Ash	3.217[a]	2.200[b]	2.133[b]	1.450[b]	0.307	0.023

[a-d]Means within a column with no common superscript differ (p<0.05), MO: Moisture, CP: Crude protein, CF: Crude fiber and EE: Ether extract

the proposed classification, eggs from the White variety were categorized as rounded (SI>76), those from the Bourbon Red variety as standard (72≤SI≤76) and those from the Black and Bronze varieties as sharp (SI<72)[25]. Previous studies have reported both positive and negative correlations between shape index and egg quality traits, indicating that these relationships are strongly influenced by poultry species and genotype[26,27]. All four turkey varieties produced Grade AA eggs, with Haugh unit values ranging from 81.59 to 85.79, reflecting consistently high albumen quality irrespective of variety. The absence of significant varietal differences in most egg quality traits agrees with previous reports indicating that yolk, albumen and shell proportions in turkey eggs are largely species specific and are minimally affected by varietal differences when nutritional inputs are standardized[28]. Nevertheless, the significant variation observed in shape index suggests that variety specific differences in egg morphology should be considered in breeding and selection programmes aimed at improving egg uniformity under tropical production conditions.

Overall, all four turkey varieties produced Grade AA eggs with comparable external and internal quality characteristics under tropical production conditions, with shape index being the only parameter that differed significantly among the varieties.

Proximate composition: Moisture, crude protein and ash contents differed significantly among the four turkey varieties (Table 3). The greatest variation was observed in moisture content (p<0.001), which was significantly higher in eggs from the Bourbon Red variety, whereas eggs from the Black variety exhibited the lowest moisture content. Differences in egg moisture have been attributed to genetic background, albumen proportion and the water binding capacity of egg proteins, all of which can influence egg freshness, processing characteristics and shelf life[29]. Crude protein content also differed significantly among the varieties (p = 0.038), with eggs from the Black and Bronze varieties containing higher crude protein levels than those from the Bourbon Red variety. Egg protein concentration is closely associated with the yolk to albumen ratio and the efficiency of amino acid deposition during egg formation[30]. Genetic variation among poultry types has also been shown to influence egg protein content, even under similar feeding and management conditions[8]. Ash content, which represents the total mineral fraction of the egg, reflects differences in shell mineralization, yolk mineral deposition and maternal nutrient utilization[29]. Variations in ash content among poultry species and breeds have been widely reported and are generally attributed to genetic differences affecting calcium and phosphorus metabolism[31].

In contrast, crude fat and crude fibre contents did not differ significantly among eggs from the four turkey varieties. Egg lipid content is primarily determined by yolk proportion and lipid transport mechanisms rather than minor genetic differences, which may account for the limited variation observed in the present study[30]. The present findings are consistent with previous reports describing comparable crude protein and ash contents in turkey eggs, although earlier studies reported higher crude fat concentrations than those observed in the current investigation[32]. A similar pattern has also been documented, with comparable protein and moisture contents but higher crude fat levels[9]. Differences among studies may be attributable to variation in bird age, diet composition, production system and analytical methodology[33]. However, Sun *et al.*[8] reported lower ash and higher moisture contents in turkey eggs than those observed in the present study, which may be explained by differences in egg structure and sampling conditions.

Collectively, these findings demonstrate that moisture, crude protein and ash are the principal proximate components distinguishing Turkey egg varieties under tropical production conditions. Eggs from the Black variety exhibited comparatively higher crude protein and ash contents, indicating superior nutritional composition for these parameters, whereas crude fat and crude fibre contents remained largely consistent across the four varieties.

Amino acid composition of Turkey eggs: Significant differences in amino acid concentrations were observed among the four Turkey varieties (Table 4). Most essential

Table 4: Amino acid profile (g/100g protein) of different varieties of Turkey eggs

	Variety					
Amino acids	Black	Bronze	White	Red	SEM	p-value
Essential						
Arginine	9.25^{a}	8.570^{b}	8.73^{b}	8.12^{c}	0.001	<0.0001
Histidine	4.07^{a}	3.70^{b}	3.62^{c}	2.54^{d}	0.001	<0.0001
Leucine	23.46^{a}	19.95^{b}	12.40^{c}	16.22^{d}	0.690	0.059
Lysine	11.94^{a}	9.95^{b}	11.29^{a}	10.42^{b}	0.017	<0.0001
Methionine	5.16^{a}	4.26^{b}	3.88^{c}	3.98^{c}	0.016	<0.0001
Phenylalanine	8.89^{a}	7.51^{b}	6.76^{c}	6.97^{c}	0.016	<0.0001
Threonine	8.61^{a}	7.67^{b}	7.96^{b}	7.46^{c}	0.022	<0.0001
Valine	10.30^{a}	8.74^{b}	9.28^{b}	8.57^{c}	0.003	<0.0001
Non-essential						
Alanine	8.14^{a}	6.79^{b}	7.42^{b}	7.14^{c}	0.029	<0.0001
Aspartic acid	16.02^{a}	13.18^{b}	15.28^{a}	13.55^{b}	0.047	<0.0001
Glutamic acid	22.23^{a}	18.62^{b}	20.72^{a}	18.75^{b}	0.281	0.0007
Glycine	5.70^{a}	4.91^{b}	4.49^{c}	4.56^{c}	0.002	<0.0001
Proline	6.11^{a}	5.20^{b}	5.43^{b}	5.34^{c}	0.017	<0.0001
Serine	12.16^{a}	10.74^{b}	12.16^{a}	10.78^{c}	0.008	<0.0001
Tyrosine	6.75^{a}	5.89^{b}	5.61^{b}	5.79^{c}	0.004	<0.0001
Cysteine	1.47^{a}	1.28^{b}	1.31^{b}	1.27^{c}	0.002	<0.0001

$^{a-d}$Means within a column with no common superscript differ (p<0.05)

amino acids, including arginine, histidine, lysine, methionine, phenylalanine, threonine and valine, varied significantly among the varieties (p<0.0001). The Black variety exhibited higher concentrations of these essential amino acids than the other varieties, whereas the Bourbon Red variety consistently exhibited the lowest concentrations. On a crude protein basis, lysine (11.94 g/100 g), leucine (23.46 g/100 g), methionine (5.16 g/100 g), valine (10.30 g/100 g) and arginine (9.25 g/100 g) were present at the highest concentrations in eggs from the Black variety.

Similarly, the concentrations of all nonessential amino acids, including alanine, aspartic acid, glutamic acid, glycine, proline, serine, tyrosine and cysteine, also differed significantly among the varieties (p<0.001). The Black variety exhibited the highest concentrations of nonessential amino acids, whereas the Bourbon Red variety consistently showed the lowest concentrations. On a crude protein basis, glutamic acid (22.23 g/100 g), aspartic acid (16.02 g/100 g), serine (12.16 g/100 g), alanine (8.14 g/100 g) and glycine (5.70 g/100 g) were the most abundant nonessential amino acids in eggs from the Black variety. These findings indicate that the Black variety consistently produced eggs with higher total amino acid concentrations, which may enhance nutritional quality and protein value for both human nutrition and embryonic development[8,9].

Although, studies investigating the influence of turkey varieties on egg amino acid composition remain limited, evidence from chickens indicates that amino acid deposition in eggs is strongly genotype dependent[19]. Goto *et al.*[19] reported distinct differences in yolk and albumen amino acid concentrations among chicken breeds, supporting the interpretation that the elevated amino acid concentrations observed in eggs from the Black turkey variety are primarily attributable to variety specific genetic differences. In addition, breed by nutrition interactions have been shown to influence egg yolk amino acid composition, with significant effects of breed and breed by feed interactions on yolk amino acid concentrations in chickens[34]. These findings suggest that the genetic potential for amino acid enrichment can be expressed differently among varieties, even under standardized feeding conditions, as observed in the present study. Furthermore, the combined influence of genetic and environmental factors on egg quality traits highlights the central role of breed specific metabolic regulation in determining the amino acid profile of poultry eggs[35]. Eggs with higher concentrations of essential amino acids, such as those produced by the Black variety, provide superior protein quality for human nutrition and may also support improved embryonic development. Although, nonessential amino acids are not classified as dietary essentials, they play critical roles in metabolism, biosynthesis and protein function, thereby further enhancing the nutritional value of eggs from the Black variety[9].

Overall, turkey variety significantly influenced egg amino acid composition under tropical production conditions, with the Black variety exhibiting the highest concentrations of both essential and nonessential amino acids, followed by the Bronze variety. These findings provide valuable information for variety selection and support the potential development of nutritionally enhanced and functional turkey eggs.

CONCLUSION

This study demonstrated that Turkey variety significantly influences the nutritional composition of eggs under tropical production conditions in Bangladesh. Although, the White variety produced eggs with the highest shape index, all four varieties achieved Grade AA egg quality, indicating consistently high external and internal egg quality. The Black variety consistently exhibited the highest concentrations of crude protein, ash and amino acids, followed by the Bronze variety, whereas the Bourbon Red variety exhibited the lowest values for these nutritional components. These findings indicate that the Black and Bronze turkey varieties possess superior nutritional characteristics and provide valuable baseline information to support variety selection and the development of functional eggs under tropical production conditions.

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