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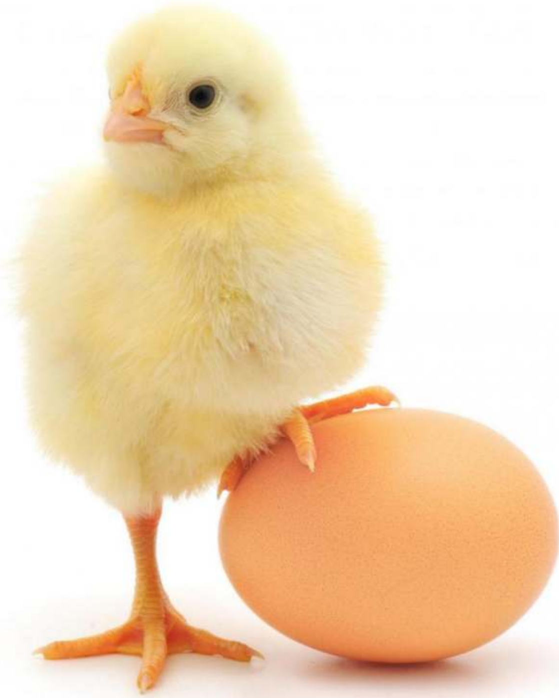

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Research Article
Evaluation of Egg Quality Traits of Three Indigenous Chicken Ecotypes Kept Under Farmers' Management Conditions

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Abstract
Background and Objective: Understanding egg quality traits of indigenous chicken ecotypes under farmers' management conditions is very important for designing and implementing environment friendly and community based holistic genetic and performance improvement strategies. This study was conducted to compare three ecotypes (lowland, midland and highland) in Tigray, Ethiopia in terms of their external and internal egg quality traits and to determine relationships among these traits. **Materials and Methods:** From each ecotype, 50 fresh eggs were used to measure external egg quality traits (egg weight, shell weight, shell ratio, egg length, egg width and egg shape index) and internal egg quality traits (albumen weight, albumen ratio, yolk weight, yolk ratio, albumen height, yolk height, yolk to albumen ratio, Haugh unit and yolk color). One-way ANOVA was used to compare the ecotypes and correlation analysis was used to determine relationships among the traits. **Results:** Three ecotypes were significantly different on all traits except shell ratio and yolk color. In all other external traits, highland ecotype had higher mean values than midland and lowland had the lowest mean values. Highland also had higher mean values in the internal traits other than albumen ratio whereas lowland had higher mean values than both highland and midland ecotypes. The strength of the significant correlations among the external traits, among internal traits and between external and internal traits varied with ecotype. **Conclusion:** The differences in the quality of local chicken eggs from the three ecotypes suggest that there is a need for customized genetic and performance improvement strategies.

Key words: Egg quality, yolk, albumen, Haugh unit, indigenous chicken, ecotype, farmers' management conditions, correlation

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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

Ethiopia has 60.51 million indigenous chickens of which 94.3% are non-descriptive breeds, 3.2% are hybrid chicken and 2.5% are exotic breeds[1]. This large number indicates the importance of indigenous chickens as potential Farm Animal Genetic Resources in the Country. Moreover, 97.3% of indigenous chickens have been distributed in different agro-ecological zones of Ethiopia[2] and their distribution indicates their adaptive potential to different environmental conditions, diseases and other stresses[3].

Village chickens play an important role in food security and income generation for poverty alleviation in Ethiopia. Generally, chickens are considered as movable poor man's bank because of ease of management of village chickens and their short reproductive cycles[4]. Consumers usually prefer products of local chicken to exotic ones because of their flavor, taste and nutrition. In spite of their significant roles, their low performances masked their potential to uplift the living standards of their owners and contribute to rural developments in Ethiopia. This has been attributed to their low genetic potential, prevalence of diseases and predators, limited feed resources, constraints related to institutional and socio-economic factors and limited skill management practices[5,6].

Understanding the egg quality characteristics of local chicken ecotypes under their natural breeding tract has a paramount significance in designing and implementing environment friendly and community based holistic genetic and performance improvement strategies in order to ensure improved chicken productivity and, sustainable utilization and conservation of indigenous chicken genetic resources to respond to changes in climate and to meet the ever increasing demand of chicken products. Egg quality trait evaluation of some local ecotypes, exotic and crossbreeds have been conducted in some parts of Ethiopia[7-12] and Markos[13] classified the local chicken ecotypes of Western Tigray, where this study was conducted as lowland, midland and highland based on their morphological variations. Moreover, productive, reproductive[14] and carcass[15] performance evaluation of these local chicken ecotypes had been carried out under their natural breeding environments. Incubation and brooding practices of local chicken producers[16], marketing and price determinant factors of village chicken products[17], village chicken production constraints and opportunities[4] and village chicken breeding practices, objectives and farmers' trait preferences[18] had also been studied in the Western zone of Tigray. However, no research on evaluation of egg quality traits of these local chicken ecotypes kept under farmers' management conditions had been conducted in Tigray and in particular in Western zone of Tigray. This study, therefore, was designed to evaluate the egg quality traits of three local chicken ecotypes, that represent almost all of Ethiopia, kept under their natural breeding environment of Western zone of Tigray.

MATERIALS AND METHODS

Description of study area: The study was carried out in Western zone of Tigray regional state of Ethiopia in 2015. The geographical location of the zone is 13°42' to 14°28' North latitude and 36°23' to 37°31' East longitude[19]. The annual rainfall of the zone ranges from 600-1800 mm while the annual temperature ranges from 27-45°C in the lowland areas and 10-22°C in both midland and highland areas of the zone. The altitude of the zone ranges from 500-3008 m a.s.l. The ranges for the three ecotypes were: lowland from 500-1500 m a.s.l. midland from 1500-2200 m a.s.l. and highland from 2200-3000 m a.s.l. The zone shares borders with Tahtay Adibayo, Tselemti and Asgede Tsimbla of Ethiopia in the East, Sudan in the West, Amhara region of Ethiopia in the South and Eritrea in the North. The study area represents a remote, tropical climate where extensive agriculture is performed mainly manually.

Data collection: A total of 150 fresh eggs (50 eggs from each of highland, midland and lowland chicken ecotypes) laid with clutch ranging from 3rd to 4th clutches were purchased and transported to Humera Agricultural Research Center (HuARC) laboratory to evaluate egg quality traits of the chicken ecotypes. Soon after arrival, egg weight was measured using a 1.0 g sensitive digital scale. Length (mm) and width (mm) of the egg were measured with Electronic Digital Caliper (Mitutoyo Corporation, Kawasaki, Kanagawa, Japan) sensitive (±1 mm). Egg Shape Index (SI) was calculated using the following equation[20]:

$$\text{Shape index} = \frac{\text{Egg width}}{\text{Egg length}} \times 100 \qquad (1)$$

After taking the external measurements of the egg sizes, measurements of the internal components were obtained by carefully making an opening around the sharp end of the egg, large enough to allow passage of both the albumen and the yolk through it without mixing their contents together. The yolk was then carefully separated from the albumen and placed in a petri dish for weighing. Simultaneously, the associated albumen was also placed on another petri dish and weighed. Both petri dishes used in weighing the egg contents had been initially weighed and the difference in the weights of the petri dish after and before the egg component was taken as the weight of the egg components. After each weighing, the petri dishes were washed in clean water and wiped dry before next weighing. The yolk and albumin height measurements were taken using a Tripod Micrometer (Technical Services and Supplies Ltd., York, England).

The shell weight with membrane was obtained by carefully placing the opened part in the shell and weighing on the electronic scale. Egg yolk/albumin (Y/A) ratio was calculated by dividing the yolk weight by the albumen weight[21]. Egg shell color of each egg was identified by visual observation while yolk color was measured with a Roche yolk color fan scale (ranged 1-15) (Roche scale). The following internal egg quality traits were calculated according to Singh and Panda[22].

$$\text{Shell (\%)} = \frac{\text{Shell weight}}{\text{Egg weight}} \times 100 \tag{2}$$

$$\text{Yolk (\%)} = \frac{\text{Yolk weight}}{\text{Egg weight}} \times 100 \tag{3}$$

$$\text{Albumin (\%)} = \frac{\text{Albumin weight}}{\text{Egg weight}} \times 100 \tag{4}$$

Haugh[23] unit (albumen height corrected for egg weight) is a measure of the internal quality of an egg by relating the height of thick albumen and egg weight. The higher the Haugh unit, the better the quality of the egg (fresher, higher quality eggs have thicker whites) is and it was determined using the following formula developed by Haugh[23].

$$\text{HU} = 100 \log (\text{AH} + 7.57 - 1.7\ \text{EW}0.37)$$

where, HU is Haugh unit, AH is albumen height (mm) and EW is egg weight (g).

Statistical analysis: The effect of ecotype (3 levels: lowland, midland and highland) on external egg quality traits [egg weight (g), shell weight (g), shell ratio (%), egg length (mm), egg width (mm) and egg shape index] and internal egg quality traits [albumen weight (g), albumen ratio (%), yolk weight (g), yolk ratio (%), albumen height (mm), yolk height (mm), yolk to albumen ratio (%), Haugh unit and yolk color] were determined using a one-way analysis of variance. For each response, the validity of model assumptions was verified by examining the residuals as described in Montgomery[24]. Since the effect of ecotype was significant ($p<0.05$) on all external traits other than shell ratio and on all internal traits other than yolk color, multiple means comparison was completed using Duncan's multiple range test at the 5% level of significance and letter groupings were generated. The analysis was completed using the GLM Procedure of SAS[25].

The relationships among external traits, among internal traits and between external and internal traits were investigated using correlation analysis. The significance of the correlation coefficients was also determined using the CORR Procedure of SAS[25].

RESULTS

External egg quality traits: Significant difference was observed among three local chicken ecotypes in terms of egg weight, egg width, egg length, egg shape index and egg shell weight, however, there was no significant difference among the three chicken ecotypes in terms of egg shell ratio (egg shell content) and its overall mean was 11.58%. Significantly higher mean values of egg weight, shell weight, egg width and egg shape index were obtained from highland chicken ecotype followed by midland (Table 1). The average egg lengths from highland (56.4 mm) and midland (56.2 mm) ecotypes were not significantly different but higher than that of lowland (53.8 mm) ecotype. On the other hand, the mean egg shape index from midland and lowland ecotypes were not significantly different (Table 1).

Internal egg quality traits: Significant differences in albumen weight, yolk weight and yolk height were observed among the three local chicken ecotypes (Table 2), with highland giving the highest mean (22.2 g, 16.5 g and 17.2 mm, respectively), followed by midland (21.0 g, 15.6 g and 14.9 mm, respectively) and then by lowland (19.3 g, 13.1 g and 13.5 mm, respectively) ecotype. The mean yolk ratio, yolk to albumen ratio and Haugh unit values of highland and midland ecotypes were not significantly different but were significantly higher than those of lowland ecotype (Table 2). But the mean albumen ratio of lowland was significantly higher than those of highland and midland, which were not significantly different (Table 2). There was no significant difference among the three ecotypes in terms of yolk color (overall mean = 8.9). The significant variations in the internal egg quality traits of local chicken ecotypes suggest the presence of genetic dissimilarity, which implies that targeted egg quality improvement strategies can be applied to the different ecotypes.

Phenotypic correlations between external egg quality traits of three local chicken ecotypes: Egg weight was positively and strongly ($p<0.01$, highly significant) correlated

Table 1: External egg quality traits obtained from three ecotypes

Ecotypes	Egg weight (g)	Shell weight (g)	Egg length (mm)	Egg width (mm)	Egg shape index
Highland	43.7a	5.05a	56.4a	40.1a	71.3a
Midland	41.2b	4.72b	56.2a	38.3b	68.2b
Lowland	36.8c	4.30c	53.8b	35.7c	66.5b

Within each column, means sharing the same letter are not significantly different at the 5% level

Table 2: Internal egg quality traits obtained from three ecotypes

Ecotypes	Albumen weight (g)	Albumen ratio (%)	Yolk weight (g)	Yolk ratio (%)	Albumen height (mm)	Yolk height (mm)	Yolk to albumen ratio (%)	Haugh unit
Highland	22.2a	50.7b	16.5a	37.7a	5.66a	17.2a	0.746a	79.1a
Midland	21.0b	50.7b	15.6b	37.9a	5.65a	14.9b	0.749a	79.0a
Lowland	19.3c	52.5a	13.1c	35.7b	5.05b	13.5c	0.681b	78.8b

Within each column, means sharing the same letter are not significantly different at the 5% level

Table 3: Phenotypic correlations among external egg quality traits for lowland, midland and highland ecotypes

	Shell weight (g)	Shell ratio (%)	Egg length (mm)	Egg width (mm)	Egg shape index
Lowland					
Egg weight	0.62**	-0.08	0.39**	0.53**	0.17
Shell weight		0.73**	0.08	0.12	0.06
Shell ratio			-0.23	-0.30*	-0.09
Egg length				0.86**	-0.47**
Egg width					0.05
Midland					
Egg weight	0.72**	-0.26	0.08	0.62**	0.63**
Shell weight		0.48**	0.28	0.69**	0.55**
Shell ratio			0.26	0.17	-0.02
Egg length				0.50**	-0.23
Egg width					0.73**
Highland					
Egg weight	0.07	-0.45**	0.30*	0.32*	0.08
Shell weight		0.86**	0.15	0.06	-0.02
Shell ratio			-0.02	-0.10	-0.05
Egg length				0.34*	-0.42**
Egg width					0.71**

*Significant (0.01<p<0.05), **Highly significant (p<0.01)

with shell weight (r = 0.62), egg length (r = 0.39) and egg width (r = 0.53) in lowland ecotype but positively and strongly correlated with shell weight (r = 0.72), egg width (r = 0.62) and egg shell index (r = 0.63) in midland ecotype and negatively and strongly correlated with shell ratio (r = -0.45) and weakly (0.05<p<0.01, significant) positively correlated with egg length (r = 0.30) and egg width (r = 0.32) in highland ecotype (Table 3).

For lowland and highland ecotypes, shell weight was strongly correlated with shell ratio (r = 0.73 and r = 0.86, respectively) only but for midland ecotype, shell ratio is strongly correlated with shell weight (r = 0.48), egg width (r = 0.69) and egg shape index (r = 0.55) (Table 3). Egg length was positively correlated with egg width in all three ecotypes (Table 3) but strongly negatively correlated with egg shape index only for lowland and highland ecotypes (Table 3). Egg width was strongly positively correlated with egg shape index only in midland (r = 0.73) and highland (r = 0.71) ecotypes, but not in lowland ecotype. All other pairs of external traits were not significantly correlated.

Phenotypic correlations between internal egg quality traits of three local chicken ecotypes: The correlation between albumen weight and albumen ratio was weak in lowland (r = 0.29) but strong in midland (r = 0.72) and highland (r = 0.86) chicken ecotypes (Table 4). The direction of the correlation (positive or negative) between albumen weight and the other internal egg quality traits were consistent across the ecotypes but the strength of the relationships was not consistent (Table 4). A strong positive correlation was observed between albumen weight and yolk weight (r = 0.69) in lowland chicken ecotype but this correlation was either weak (r = 0.30) in midland or non-significant in highland ecotype.

Strong negative correlations were observed between albumen ratio and yolk weight in lowland and midland chickens (r = -0.45 and r = -0.42, respectively) but this correlation was not significant in highland chicken ecotype (Table 4). The strong negative correlations between albumen ratio and yolk ratio in the three chicken ecotypes

Table 4: Phenotypic correlations among internal egg quality traits for lowland, midland and highland ecotypes

	Albumen ratio (%)	Yolk weight (g)	Yolk ratio (%)	Albumen height (mm)	Yolk height (mm)	Yolk to albumen ratio (%)	Haugh unit
Lowland							
Albumen weight	0.29*	0.69**	-0.31*	0.87**	0.96**	-0.31*	0.76**
Albumen ratio		-0.45**	-0.86**	0.40**	0.21	-0.95**	0.44**
Yolk weight			0.46**	0.47**	0.68**	0.47**	0.40**
Yolk ratio				-0.29*	-0.30*	0.97**	-0.33*
Albumen height					0.82**	-0.35*	0.99**
Yolk height						-0.27	0.77**
Yolk to albumen ratio							-0.39**
Midland							
Albumen weight	0.72**	0.30*	-0.62**	0.11	0.55**	-0.69**	0.04
Albumen ratio		-0.42**	-0.93**	0.35*	0.30*	-0.98**	0.14
Yolk weight			0.49**	-0.30*	0.16	0.48**	-0.30*
Yolk ratio				-0.30*	0.41**	0.99**	-0.13
Albumen height					-0.22	-0.31*	0.98**
Yolk height						-0.37**	-0.17
Yolk to albumen ratio							-0.15
Highland							
Albumen weight	0.86**	0.19	-0.69**	0.70**	0.22	-0.80**	0.64**
Albumen ratio		-0.28	-0.87**	0.54**	0.08	-0.96**	0.53**
Yolk weight			0.56**	0.30*	0.30*	0.44**	0.22
Yolk ratio				-0.36**	0.03	0.97**	-0.36*
Albumen height					0.41**	-0.47**	0.97**
Yolk height						-0.04	0.39**
Yolk to albumen ratio							-0.47**

*Significant ($0.01<p<0.05$), **Highly significant ($p<0.01$)

suggest that direct selection for albumen ratio improvement may result in decrease in the yolk ratio of these chicken ecotypes. Similarly, positive correlations between albumen ratio and albumen height were obtained in all three chicken ecotypes (Table 4). All in all, yolk height has the most non-significant correlations with the other traits across ecotypes and Haugh unit has the most significant correlations with the other traits in lowland and highland ecotypes but not in midland ecotype (Table 4).

Phenotypic correlations between external and internal egg quality traits for three local chicken ecotypes: Egg weight was positively and significantly correlated with albumen weight (r = 0.93, r = 0.91, r = 0.90, respectively), with yolk weight (r = 0.89, r = 0.57, r = 0.54, respectively) and with yolk height (r = 0.92, r = 0.55, r = 0.29, respectively) in all three local chicken ecotypes. These results imply that selecting these local chicken ecotypes for increased egg weight will result in eggs with higher albumen weight, yolk weight and yolk height. Moreover, there were significant positive correlations between egg weight and albumen ratio in both midland (r = 0.37) and highland (r = 0.56) chicken ecotypes but not in lowland chicken ecotype (Table 5). On the other hand, egg weight was strongly positively correlated with albumen height and Haugh unit in lowland (r = 0.68 and r = 0.61) and in highland (r = 0.67 and r = 0.58) but not in midland (Table 5).

Shell weight was positively correlated with albumen weight, yolk weight and albumen height and yolk height and negatively correlated with albumen ratio in lowland but positively correlated with albumen weight and albumen height and negatively correlated with yolk ratio and yolk to albumen ratio in lowland ecotype (Table 5). Shell weight was not correlated with any of the internal egg quality traits in highland ecotype (Table 5).

Strong correlations were observed between egg length and albumen ratio (r = -0.55), egg length and yolk weight (r = 0.66), egg length and yolk ratio (r = 0.71) and egg length and yolk to albumen ratio (r = 0.66) in lowland and a weak relationship between egg length and albumen weight (r = 0.27) and strong relationships between egg length and albumen height (r = 0.45) and between egg length and Haugh unit (r = 0.50) in highland. However, there was no significant correlation between egg length and any of the internal quality traits for midland ecotype (Table 5).

On the other hand, egg width was correlated with all internal quality traits other than albumen height and Haugh unit in lowland ecotype but egg width was correlated only with albumen weight, yolk height and Haugh unit in midland ecotype. However, egg width was not correlated with any of the internal quality traits in highland ecotype (Table 5).

Egg shell index was positively and significantly correlated with albumen weight, albumen ratio and yolk height and negatively and significantly correlated with yolk ration and

Table 5: Phenotypic correlations between internal (columns) and external (rows) egg quality traits for lowland, midland and highland ecotypes

	Albumen weight (g)	Albumen ratio (%)	Yolk weight (g)	Yolk ratio (%)	Albumen height (mm)	Yolk height (mm)	Yolk to albumen ratio (%)	Haugh unit
Lowland								
Egg weight	0. 93**	-0.07	0.89**	0.00	0.68**	0.92**	0.03	0.61**
Shell weight	0.48**	-0.32*	0.53**	-0.05	0.28*	0. 57**	0.11	0.23
Shell ratio	-0.20	-0.35*	-0.10	-0.06	-0.23	-0.08	0.12	-0.25
Egg length	0.17	-0.55**	0.66**	0.71**	-0.02	0.11	0.66**	-0.08
Egg width	0.40**	-0.30*	0.67**	0.44**	0.17	0.37**	0.39**	0.20
Egg shell index	0. 37**	0.57**	-0.13	-0.63**	0.38**	0.42**	-0.63**	0.40**
Midland								
Egg weight	0.91**	0.37**	0.57**	-0.29*	-0.01	0.55**	-0.34*	-0.17
Shell weight	0.64**	0.23	0.28	-0.33*	-0.09	0.63**	-0.31*	-0.22
Shell ratio	-0.26	-0.15	-0.33*	-0.09	-0.12	0.20	0.01	-0.11
Egg length	0.05	-0.07	0.11	0.06	-0.19	0.26	0.05	-0.14
Egg width	0.57**	0.22	0.28	-0.28	-0.29	0.71**	-0.26	-0.30*
Egg shell index	0.60**	0.29*	0.23	-0.34*	-0.17	0.59**	-0.31*	-0.23
Highland								
Egg weight	0.90**	0.56**	0.54**	-0.39**	0.67**	0.29*	-0.49**	0.58**
Shell weight	-0.09	-0.23	-0.17	-0.22	-0.12	-0.05	0.01	-0.15
Shell ratio	-0.55**	-0.50**	-0.42**	0.01	-0.46**	-0.19	0.26	-0.44**
Egg length	0.27*	0.20	0.05	-0.23	0.45**	0.20	-0.23	0.50**
Egg width	0.21	0.05	0.27	0.00	0.27	-0.05	-0.03	0.27
Egg shell index	-0.03	-0.13	0.21	0.18	-0.11	-0.21	0.16	-0.14

*Significant (0.01<p<0.05), **Highly significant (p<0.01)

yolk to albumen ratio in both lowland and midland chicken ecotypes and but was not correlated with any of the internal quality traits in the highland chicken ecotype (Table 5).

DISCUSSION

Significant variations were observed among the local chicken ecotypes in all studied egg quality traits except yolk color and egg shell ratio. Highland chicken ecotype produced eggs with significantly higher mean values than either of the rest two chicken ecotypes in all considered egg quality traits except albumen ratio where lowland chicken ecotype produced eggs with significantly higher albumen ratio than the lowland and midland chicken ecotypes. The significant variations in egg quality traits among the three local chicken ecotypes indicate their genetic variations with respect to egg quality traits.

Moreover, significant correlations between almost all studied egg quality traits were found in the three chicken ecotypes. The type (whether positive or negative) as well as the strength of the relationships between the traits varied with ecotype. Most of the relationships were similar and some were dissimilar to the relationships in other indigenous chickens reported in the literature.

These significant variations in the external egg quality traits of the chickens imply the existence of genetic and environmental variations in the chickens as previously documented[26]. Comparable results were also reported in Ethiopian scavenging indigenous chickens[7] and three genotypes (local key, F1 Fayoumi crosses and F1 RIR-crosses)[8] under extensive rearing system. The mean egg length, egg width and egg shell ratio values obtained in this study are similar to values reported for three strains of Tswana chickens while the egg weight and egg shape index values of the current study are lower than those reported for three strains of Tswana chickens (Naked neck, normal and dwarf) under intensive rearing system[27].

Significant variations were also observed in the internal egg quality traits. The average albumen weight found in the current study for the three chicken ecotypes (Table 2) were comparable to the values reported for extensively managed Ethiopian local chickens in Southwest Ethiopia (Gomma wereda; 22.6 g)[11] and in Central Ethiopia (Fogera district; 22.1 g)[9]. However, these results were higher (17.8 g) than local chickens and lower (34.5 g) than Koekoek hens kept under farmers' management practices in Tanqua Abergelle district of Tigray regional state of Ethiopia[28]. The average albumen weight in this study was also lower than that reported for three exotic chickens (Isa Brown, Bovan Brown and Potchefstroom Koekoek) kept under backyard management in Ada'a and Lume districts, Central Ethiopia[10]. Similarly, the mean values for albumen ratio in this study were lower than those reported for intensively managed Tswana chicken strains[27] and for Oravka and Rhode Island Red laying hens in Slovak Republic[29].

The average yolk weight observed in this study (Table 2) was in close agreement with values reported for extensively managed Ethiopian local chickens (15.0 g)[11] but lower than the values reported for local scavenging chicken eggs in Fogera district, Central Ethiopia (16.3 g)[9] and higher than the values reported for Fayoumi chicken breed under backyard management (14.54 g)[12]. Under intensive management, yolk weight reported for Tswana chicken strains was 12.2-14.3 g [27], which is lower than that observed in the current study. Likewise, the yolk ratio obtained in this study was higher than the values reported for Tswana chicken strains[27] and for Oravka and Rhode Island Red laying hens under intensive management in Slovak Republic[29].

The average albumen height found in the current study was comparable with values reported for extensively managed local key chicken in Ethiopia (5.8 mm)[8] but higher than the values reported for local scavenging Ethiopian chickens[7, 30] and lower than the values (6.0-6.4 mm) reported for intensively managed Tswana chicken strains[27]. Similarly, the average yolk height in this study was lower than values reported for local scavenging chickens[7,8,30] and for intensively managed Tswana chicken strains[27].

The average Haugh unit obtained in this study was in close agreement with values reported for extensively managed Isa brown and Potchefstroom Koekoek chickens in both Ada'a and Lume districts[10] but higher than the values reported for local scavenging chickens in Ethiopia[7,30,31] and lower than the values reported for local key chickens under farmers' management conditions of Ethiopia[8]. Yolk color values of the three chicken ecotypes were in close agreement to the value found in local scavenging chickens[8] and in Fayoumi chickens under backyard management conditions of Ethiopia[12]. However, it was lower than the values reported for local scavenging Ethiopian chickens[7,30,31]. Similarly, yolk to albumen ratio value in this study was higher than the values reported for white Leghorn (45.21$\pm$0.11%)[32].

The significant positive correlations between egg weight and egg width observed in these three local chicken ecotypes are consistent with previous reports[27,33,34]. Significant and positive correlation coefficients between egg weight and other external egg quality traits, such as egg width, indicate that selection for higher egg weight in these local chicken ecotypes could result in simultaneous positive improvements of the other traits but might be negatively affect the shell ratio of highland ecotype that is negatively correlated with egg weight. The strong positive correlation between egg length and egg width observed in all three ecotypes is in line with previous reports for free range naked neck and normal-feathered Nigerian indigenous chickens[33], for pearl grey[35] and for royal purple varieties of helmeted Guinea fowl and frizzle feathered and naked neck Nigerian chickens[36]. A significant positive correlation between egg length and egg width in the dwarf, naked neck and normal-feathered strains of Tswana chickens was also reported[27]. These results imply that improvements on any of the two traits through appropriate breeding program (selection or crossbreeding) could result in simultaneous improvement of both traits.

The significant negative correlation between egg length and egg shape index observed in this study is in agreement with the results in Nigerian frizzle feathered chickens[36]. Similarly, the strongly positive correlations were reported between egg width and egg shape index obtained from midland and highland chicken ecotypes corroborate the significant positive correlations between egg width and egg shape index in quail, chickens, pearl grey and royal purple varieties of helmeted Guinea fowl and three strains of Tswana chickens[27,35,37,38].

The positive correlations between albumen weight and yolk weight ($r = 0.69$) in lowland chicken ecotypes is in close agreement with previous reports that showed positive correlation between albumen weight and yolk weight in the Sudanese native dwarf chickens[34] and three strains of Tswana chickens[27]. This implies that selection for improvement in albumen weight might lead to improvement in yolk weight and this is in agreement with Kgwatalala *et al.*[27] who reported that improvement in albumen weight could lead to improvement in total edible portion of the egg.

The present study showed strong negative correlations between albumen ratio and yolk weight in lowland and midland chickens but non–significant correlation between the two traits in highland chicken ecotype, which are in agreement with previous reports[39-41] but in disagreement with Olawumi and Ogunlade[42] who reported significant positive correlation between yolk weight and albumen ratio. Strong positive correlations between albumen height and Haugh unit were reported in three Nigerian chickens (frizzle, nacked neck and smooth feathered)[36].

Results of the present study are in agreement with previous reports that showed positive correlations between egg weight and albumen height and between egg weight and yolk weight in the dwarf and nacked neck Sudanese chickens[34], pearl grey and black varieties of helmeted Guinea fowl[35] and three strains of Tswana chickens[27]. Also, similar correlations between egg weight and albumen height ($r = 0.67$) and between egg weight and Haugh unit ($r = 0.73$) were reported for nacked neck Nigerian chickens[36].

Weak and significant positive correlation between shell weight and albumen weight in dwarf strain and non-significant positive correlation between the two traits in the naked neck and normal strains of Tswana chickens was reported by Kgwatalala *et al*.[27], which is somewhat similar to the results of the present study. But results of the present study somewhat disagree with those of Bobbo *et al*.[36] who reported strong and significant correlations between shell weight and albumen height (r = 0.71) and shell weight and Haugh unit (r = 0.68) in the nacked neck Nigerian chickens, which highlights the dissimilarity between the Nigerian and the Ethiopian indigenous chicken. Non-significant correlation coefficients between egg shape index and albumen weight, between egg were also reported by Kgwatalala *et al*.[27] in all the three strains of Tswana chickens.

CONCLUSION

In conclusion, the variations in egg quality traits among the three local chicken ecotypes and the correlations among the internal and external egg quality traits found in this study indicate the presence of genetic and environmental variations with respect to egg quality traits and the potential for improving the performance of these local chicken by customizing genetic as well as environmental factors.

SIGNIFICANCE STATEMENTS

This study discovered the variations in internal and external egg quality traits of lowland, midland and highland indigenous chicken ecotypes of Northern Ethiopia. The average values of most of the external egg quality traits reduced as altitude decreased from high to low but this was not entirely the case for the internal egg quality traits. Relationships among the internal traits, among the external traits and between internal and external traits also varied substantially with ecotype. This study also documented similarities and differences between Northern Ethiopian ecotypes and other countries in terms of the studied egg quality traits and relationships among them. The findings of this study can guide the development of performance improvement strategies and new research topics.

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