



## Research article

# Evaluation of fertility, hatchability and egg quality of indigenous chickens in different agro-ecologies of the Sidama Region, Ethiopia

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## Abstract

Poultry is one of the most important subsectors of livestock, supplying a cheap source of good quality animal protein in the form of meat and eggs. This study was conducted to assess egg fertility, hatchability and egg quality parameters of indigenous chickens in the Hulla, Aleta Wondo and Dale districts, representing highland, midland and lowland agroecologies, respectively. Six kebeles (two kebeles from each district) were purposively selected based on a lower distribution of exotic chickens. A total of 750 eggs of indigenous chicken were collected from three different agro-ecologies, 450 eggs were used for fertility and hatchability evaluation, and 300 eggs were used for internal and external quality analysis. The collected data were analyzed using Statistical Package for Social Science (SPSS) version 20 and Statistical Analysis Software (SAS) version 9.0 packages. The results indicated that agroecology has no significant effect on the fertility (78.17%) and hatchability on total egg basis (63.1%) and hatchability on fertile egg basis (84.1%) of indigenous chicken eggs. The values of egg weight ( $49.50 \pm 5.52$  (Mean $\pm$ SD)), egg length ( $53.25 \pm 2.80$ ), shell weight ( $4.38 \pm 0.66$ ), yolk weight ( $17.86 \pm 1.96$ ), and yolk diameter ( $41.40 \pm 2.09$ ) and albumen weight ( $25.47 \pm 3.39$ ) of eggs collected from midland were higher than those of eggs from highland and lowland areas. However, the highest values for albumen height ( $6.26 \pm 1.03$ ), yolk height ( $16.80 \pm 1.10$ ) and Haugh unit ( $84.23 \pm 6.73$ ) were observed on eggs collected from highland agroecology. In conclusion, agroecology has no effect on the fertility and hatchability of indigenous chicken eggs. However, agroecology significantly affects the internal and external egg quality of indigenous chicken eggs. Therefore, the storage condition and duration of storage need consideration to maintain the external and internal quality of eggs.

**Keywords:** Agro-ecology, Egg quality, Fertility, Hatchability, Indigenous chicken

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**Article history;** received manuscript: 18 July 2022,  
revised manuscript: 10 August 2022,  
accepted manuscript: 1 February 2023,  
published online: 10 February 2023

**Academic editor;** Korakot Nganvongpanit



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## INTRODUCTION

Livestock is an important subsector of agriculture, and poultry is one of the most important subsectors of livestock, supplying a cheap source of good-quality animal protein in the form of meat and eggs (Nure Hasin, 2018). In Ethiopia, the term poultry is almost synonymous with chicken. Other poultry species, such as guinea fowl, geese, turkeys, and ducks, are not common in the country. Poultry production offers considerable opportunities in terms of generating employment opportunities, improving family nutrition, empowering women (especially in rural areas), and ultimately ensuring household food security. Extensive scavenging poultry production is often the domain of poor women. Reasons include that it requires little initial investment and that it does not usually conflict with women's other household duties (FAO, 2019).

Fertility and hatchability are major parameters of reproductive performance that are most sensitive to environmental and genetic influences (Stromberg, 1975). Fertility refers to the percentage of incubated eggs that are fertile, while hatchability is the percentage of fertile eggs that hatch. Egg quality is a factor that contributes to the better economic price of fertile and table eggs (Kocevski et al., 2011). The overall quality of an egg can be discussed under two broad categories, namely, external and internal quality (Monira et al., 2003). The external quality of the egg is determined by features such as the egg weight and shape of the egg, shell thickness, and strength of the shell (Bain, 2005). From the point of view of consumers, egg weight is the most important quality trait (Adeogun and Amole, 2004; Dudusola, 2010). Shell strength is important not only for producers but also for consumers. Obtaining high eggshell quality is important for both table egg and hatching egg purposes. Consumers have come to expect uniform, strong shelled eggs, and for hatching purposes, eggs that have a strong shell will be more likely to produce a healthy chick (Grignon, 2016). The internal quality is measured based on the quality of the albumen as indicated by the Haugh units (HU), the relative size of the various internal components such as weight of yolk, yolk color and the integrity of the shell membrane. Several studies have examined egg quality in chickens (Ahmedin and Mangistu, 2016; Yonas et al., 2019; Aberra, 2019; Welelaw, 2018). In addition, the type of incubation influences the hatchability of eggs and the production of viable chicks. Most farmers in Ethiopia hatch their eggs by a natural incubation method using broody hens to incubate eggs and rear chicks (Meseret, 2010; Addisu et al., 2013).

Different studies have been performed on the egg quality, fertility and hatchability of local chickens. However, there is a lack of sufficient information on the effect of different agro-ecologies on the egg quality, fertility and hatchability of local chickens in the study areas. Thus, this study was conducted with the following objectives to fill the gap discussed. To evaluate the effect of agroecology on the fertility and hatchability of indigenous chickens in the Sidama region of Ethiopia

To determine internal and external quality parameters of indigenous chicken eggs collected from different agro-ecologies of the study area

## MATERIALS AND METHODS

### Description of study area

This study was conducted in three districts of the Sidama Regional State, namely, Hula, Aleta Wondo and Dale, representing high land, midland and lowland, respectively.

#### Hula

Hula District is located at a distance of 91 km from Hawassa and 366 km away from Addis Ababa. The district is located at longitudes and latitudes of 6°.41'-6°.61'N and 38°.44'-38°.70'E, respectively, and 1201 to 3000 *masl* elevation. It received a mean annual rainfall of 700-1200 mm with an average annual temperature of 11-18°C. The total population of the district is 80,464 (Hula district administration office, 2015). The total livestock population of Hula district is 15,456 cattle, 2,215 sheep, 1,056 goats, 769 horses, 456 donkeys, and 3,422 poultry (Hula district livestock and fishery office, 2019). The main agricultural activities of the district are livestock production, enset plantation and cereal crop production.

#### Aleta Wondo

Aleta wondo district is one of 36 districts in the Sidama Regional State. It is located at a distance of approximately 64 km from Hawassa and 339 km from the capital city Addis Ababa. It is situated in the coordinates of 60° 35' to 60° 40' north latitude and 38° 25' to 38° 30' east longitudes. Mean annual temperature ranging from 10°C to 24°C. Elevation is ranging from 1700 to 2500 *m.a.s.l.* The average annual rainfall of the district ranges from 900 mm to 1400 mm (Aleta Wondo District report, 2013/14). Aleta wondo district borders Dare to the south, Chuko to the west, Dale and Wonsho to the west and Bursa and Hulla to the east. The livestock population is estimated to be 138,251 cattle, 39,211 sheep, 22,421 goats, 3918 horses, 8586 donkeys, 168 mules and 169,256 poultry (Aleta Wondo District Livestock and Fishery Report 2018). The main agricultural practices in the areas include coffee plantations, enset plantations, maize and cereal crop production, cattle fattening, apiculture, vegetable production and fruit production.

#### Dale

Dale District is one of the 36 districts of the Sidama Regional State. The district is located on Hawassa to Moyale main road at 45 km from Hawassa and 320 km from the capital city Addis Ababa, and situated with latitude of 6° 39' 20" - 6° 50' 28" North and longitude of 38° 18' 12" - 39° 31' 30" East. Its elevation ranges from 1200-3200 *masl*. The annual rainfall of the Dale district ranges from 1300-1900 mm, and the annual temperature varies from 18°C to 20°C (DWARD, 2015). The main agricultural activity of the district is livestock production, enset plantation, coffee plantation and cereal crop production.

## Protocol of the experiment

The experiment had two parts. The first part was fertility and hatchability evaluation. For this test, farmers who owned at least one cock of local chicken in his flock were selected during survey work. From those selected households, one hundred fifty eggs of local chickens were collected from each agroecology and transported to Hawassa University Agricultural College, School of Animal and Range Sciences. Eggs were individually cleaned using pieces of clothes treated with savlon before setting. Incubation was conducted according to the guidelines of the incubator's manufacturer. Then, candling was performed two times (day seven and day fourteen). Data on the number of eggs set, number of eggs that were fertile, total number of chicks hatched, and number of embryos that died was recorded.

$$\text{Fertility (\%)} = \frac{\text{No.of fertile eggs}}{\text{Total No.of eggs set}} * 100$$

$$\text{Hatchability percent from fertile eggs} = \frac{\text{No.of chicks Hatched}}{\text{Total No.of fertilized eggs}} * 100$$

$$\text{Hatchability percent from total eggs} = \frac{\text{No.of chicks Hatched}}{\text{Total No.of eggs set}} * 100$$

The second part was internal and external egg quality evaluation. This study was conducted at Hawassa University Agricultural College, School of Animal and Range Sciences, poultry laboratory. One hundred eggs were collected from each agroecology (a total of three hundred eggs were used for internal and external quality evaluation). Care has been given that eggs collected should be laid from local chicken breeds (eggs collected from farmers who own only local chickens). The eggs stored for less than five days were collected, and laboratory analysis was conducted as soon as the eggs reached the laboratory.

## External egg quality traits

Egg weight and shell weight were measured using a digital balance (SF-400) with the precision level of 0.01gm. Egg length, egg width and shell thickness were measured using a digital caliper (mm). Shell weight was measured after it was dried in an oven for 24 hours (Khatkar et al., 1994). The shell thickness was measured using digital calipers at different points (center, broad and narrow ends), and the calculated average value was used for analysis (Mohammed et al., 2005). In addition, the eggshell ratio and egg shape index were computed using the following formula.

$$\text{Shell weight (\%)} = \frac{\text{Dry shell Weight}}{\text{Egg Weight}} * 100$$

$$\text{Egg shape index (\%)} = \frac{\text{Width of egg}}{\text{Length of egg}} * 100 \text{ (Van den Brand et al., 2004).}$$

## Internal Egg Quality

For the internal quality traits, the eggs were broken into a flat surface. Thick albumen and yolk heights were measured using a tripod micrometer. The thick albumen height (AH) was measured at its widest part at a position half way between the yolk and the outer margin. Yolk height was measured at the center part of yolk. The yolk was carefully separated from the albumen. Albumen and yolk weights were determined by weighing with an electronic sensitive balance separately (gm). The yolk color was determined using the

Roche Color Fan (Roach scale), which contains 15 scales with a standard colorimetric system. Individual Haugh units (HU) were calculated from the two parameters height of albumen (AH) and egg weight (EW) (Haugh, 1937) using the formula.

$$HU = 100 \log (AH - 1.7 EW^{0.37} + 7.6)$$

Where HU = Haugh unit, AH= albumen height in millimeters, and EW= egg weight in grams.

Estimate YR and AR were used the following formula:

$$YR = \frac{\text{Yolk weight}}{\text{egg weight}} * 100$$

$$AR = \frac{\text{Albumen weight}}{\text{Egg weight}} * 100$$

$$\text{Yolk index} = \frac{\text{Yolk Height (mm)}}{\text{Yolk Diameter (mm)}} * 100$$

## Statistical analysis

The laboratory data for fertility and hatchability were analyzed by crosstabs among agro-ecologies in descriptive statistics of SPSS V.20.0. Other parameters, such as external and internal egg quality and correlations among egg quality parameters, were analyzed using the general linear model (GLM) procedure of SAS (Version 9.0). Mean comparisons were conducted using Duncan's multiple range test. Values were considered significant at the 5% level of significance.

## RESULTS

### Fertility and hatchability

The fertility and hatchability results of scavenging indigenous chickens are shown in Table 1. Result of this study indicates that there was no significant variation among agro-ecologies in the egg fertility percentage of indigenous chickens ( $p > 0.05$ ). There was no significant difference in hatchability on the total egg basis of indigenous chicken eggs among all studied agro-ecologies ( $p > 0.05$ ). The results of the current study revealed that agroecology has no impact on hatchability on the fertile egg basis of indigenous chicken eggs ( $p > 0.05$ ).

**Table 1** Effect of agroecology on the fertility and hatchability of scavenging indigenous chickens

Parameters	Agro-ecology			Overall	Chi-square	P value
	Highland	Midland	Lowland			
Fertility (%)	76.0	78.7	79.9	78.17	0.645	0.724
Hatchability on total egg basis (%)	61.0	63.0	65.4	63.1	7.217	0.125
Hatchability on fertile egg basis (%)	89.2	80.9	82.2	84.1	3.321	0.190

### External egg quality traits

The external egg quality traits in different agro-ecologies are presented in Table 2. The results indicated that values for egg weight and egg length in midland were significantly higher than lowland and highland, whereas values of egg weight and length in highland is lower than values lowland agro-ecology ( $p < 0.0001$ ). The results indicated that agroecology in the study areas had no effect on the shape index of indigenous chicken eggs ( $p > 0.05$ ). The study indicated that agroecology has a significant effect on the shell weight of indigenous chicken eggs ( $p < 0.0001$ ). Agroecology had no significant effect on the shell thickness of indigenous chicken eggs ( $p > 0.05$ ). There was a significant effect of agroecology on the shell percent of indigenous chicken eggs ( $p < 0.0001$ ).

**Table 2** External egg quality traits

Traits	Agro-ecologies			p value
	Highland	Midland	Lowland	
Egg weight (gm)	42.89±4.25 <sup>c</sup>	49.50±5.52 <sup>a</sup>	44.93±4.49 <sup>b</sup>	<0.0001
Egg length (mm)	51.23±1.81 <sup>c</sup>	53.25±2.80 <sup>a</sup>	52.42±2.86 <sup>b</sup>	<0.0001
Egg width (mm)	37.36±1.53 <sup>b</sup>	38.65±1.78 <sup>a</sup>	38.62±1.50 <sup>a</sup>	<0.0001
Shell weight (gm)	3.70±0.61 <sup>c</sup>	4.38±0.66 <sup>a</sup>	4.12±0.60 <sup>b</sup>	<0.0001
Shell thickness (mm)	0.286±0.08 <sup>a</sup>	0.234±0.03 <sup>b</sup>	0.298±0.07 <sup>a</sup>	<0.0001
Shape index	72.96±2.86	72.78±3.10	73.76±4.90	<0.1422
Shell percent (%)	8.68±1.48 <sup>b</sup>	8.92±1.64 <sup>ab</sup>	9.26±1.46 <sup>a</sup>	<0.0001

<sup>a-c</sup> Means within the row with different superscripts are significantly different ( $p < 0.05$ ).

### Internal egg quality traits

Internal egg quality traits at different agro-ecologies are presented in Table 3. There was a significant difference in the yolk height of indigenous chickens in different agroecology systems ( $p < 0.0001$ ). Yolk height is the highest in highland agroecology, but it is the lowest in lowland agroecology. Albumen height shows higher value in highland than in midland and lowland agro-ecologies ( $p < 0.0001$ ), but there is no significant difference in albumen height of eggs between midland and lowland agro-ecologies. Significantly higher yolk weight was recorded in midland agroecology than in highland and lowland agroecology ( $p < 0.0001$ ), but yolk weight was statistically the same in both highland and lowland agroecology of the region. Albumen weight shows significantly different values between all agro-ecologies ( $p < 0.0001$ ). The highest albumen weight was measured midland, followed by lowland, and the lowest albumen weight was recorded in highland agroecology. There was no significant difference in yolk color, albumen ratio or yolk ratio among the different agro-ecologies of the region ( $p > 0.05$ ). The Haugh unit and yolk index are significantly highest in the highland agroecology and lowest in the midland agroecology ( $p < 0.0001$ ). There were differences in the yolk diameter of indigenous chickens among all agro-ecologies of the Sidama region ( $p < 0.0001$ ). Yolk diameter is highest in midland followed by lowland and lowest in highland agroecology.



**Table 3** Internal egg quality traits

Traits	Agro-ecology			p value
	Highland (Mean±SD)	Midland (Mean±SD)	Lowland (Mean±SD)	
Yolk height (mm)	16.80±1.10 <sup>a</sup>	15.70±1.31 <sup>c</sup>	16.17±2.24 <sup>b</sup>	<0.0001
Albumen height (mm)	6.26±1.03 <sup>a</sup>	4.96±1.20 <sup>b</sup>	4.96±0.94 <sup>b</sup>	<0.0001
Yolk weight (gm)	16.02±2.32 <sup>b</sup>	17.86±1.96 <sup>a</sup>	16.52±2.04 <sup>b</sup>	<0.0001
Albumen weight (gm)	21.78±3.16 <sup>c</sup>	25.47±3.39 <sup>a</sup>	23.49±4.25 <sup>b</sup>	<0.0001
Yolk color (R/Scale)	9.35±1.49	9.46±1.78	8.96±1.80	0.1006
Yolk ratio	37.68±6.72	36.17±3.92	37.30±6.28	0.1697
Albumen ratio	51.35±9.75	51.48±6.19	52.94±10.66	0.4033
Haugh unit	84.23±6.73 <sup>a</sup>	71.86±9.79 <sup>c</sup>	74.44±7.29 <sup>b</sup>	<0.0001
Yolk index	43.84±3.99 <sup>a</sup>	37.67±5.18 <sup>c</sup>	40.76±3.56 <sup>b</sup>	<0.0001
Yolk diameter	38.47±2.49 <sup>c</sup>	41.40±2.09 <sup>a</sup>	39.75±1.79 <sup>b</sup>	<0.0001

<sup>a-c</sup> The means in rows with different superscript letters are significantly different (p<0.05)

### Phenotypic correlation among external egg quality traits

The phenotypic correlation of the external egg quality traits of indigenous chicken eggs is presented in Table 4. The results indicated that there was a positive and strong correlation between egg weight and egg length, egg weight and egg width, egg weight and shell weight, egg weight and surface area of the egg. Egg weight is negatively correlated with shell thickness and shell percentage. There was a positive and strong correlation between egg length and egg width. Both egg length and egg width were positively and strongly correlated with shell weight and surface area. Egg length is highly negatively correlated with the shape index, but egg width and shape index are strongly positively correlated with each other. Shell weight has a strong positive correlation with shell percentage and egg surface area. Shell percentage has a strong negative correlation with egg weight and surface area.

**Table 4** Phenotypic correlation among external egg quality parameters

	Egg weight	Egg length	Egg width	Shell weight	Shell thickness	Shape index	Shell percentage
Egg weight	1						
Egg length	0.645**	1					
Egg width	0.692**	0.443**	1				
Shell weight	0.326**	0.272**	0.315**	1			
Shell thickness	-0.187**	-0.148**	-0.024	0.036	1		
Shape index	-0.021	-0.606**	0.439**	0.015	0.128	1	
Shell percentage	-0.367**	-0.181**	-0.172**	0.752**	0.164**	0.029	1
Surface area	0.999**	0.646**	0.693**	0.327**	-0.188	-0.021	-0.368**

\*, p<0.05, \*\*, p<0.01

### Phenotypic correlation among internal egg quality traits

The phenotypic correlations among internal egg quality traits are shown in Table 5. The results indicated that there was a strong and positive correlation between albumen weight and yolk weight and between albumen weight and yolk diameter. Albumen height is strongly positively correlated with the Haugh unit. Yolk weight was positively correlated with yolk diameter and strongly negatively correlated with the yolk index. There was a strong positive correlation between yolk height and Haugh units. Yolk diameter is strongly negatively correlated with the yolk index and Haugh unit. The yolk index and Haugh unit are strongly positively correlated with each other.

**Table 5** Phenotypic correlation among internal egg quality traits

	A/weight	A/height	Y/weight	Y/height	Y/diameter	Y/index	Haugh unit
A/weight	1						
A/height	-0.04249	1					
Yolk weight	0.37739**	-0.14792*	1				
Yolk height	0.07297	0.51757**	0.09330	1			
Yolk diameter	0.34960**	-0.23178**	0.57340**	-0.11301	1		
Yolk index	-0.09492	0.48481**	-0.25472**	0.78193**	-0.60384**	1	
Haugh unit	-0.12347*	0.96261**	-0.18928**	0.52967**	-0.28406**	0.51693**	1

\*:  $p < 0.05$ , \*\*:  $p < 0.01$

### Phenotypic correlations between some internal and external egg quality traits

Phenotypic correlations between external and internal egg quality traits are presented in Table 6. The results of the current study show that albumen height has a statistically significant negative correlation with egg weight, egg length, egg width and shell weight ( $p < 0.01$ ). There was a slight positive correlation between albumen height and shell thickness ( $p > 0.05$ ). The correlation of albumen weight with egg weight, egg length, egg width and shell weight was positive and statistically significant ( $p < 0.01$ ). Albumen weight was significantly and negatively correlated with shell thickness ( $p > 0.05$ ). There was a statistically no significant positive correlation between albumen weight and shape index ( $p > 0.05$ ). Haugh unit had a strong negative correlation with egg weight, egg length, egg width and shell weight ( $p < 0.01$ ). Yolk height had a negative but no significant correlation with external egg quality parameters that were observed in this study ( $p > 0.05$ ). Yolk diameter had a strong positive correlation with egg weight, egg length, egg width and shell weight ( $p < 0.01$ ). However, there was a slight negative correlation of yolk diameter with shell thickness and shape index ( $p > 0.05$ ). Yolk weight had a strong positive correlation with egg weight, egg length and egg width ( $p < 0.01$ ). The yolk index had a significant negative correlation with egg weight, egg length, egg width and shell weight ( $p < 0.01$ ). There was a slight positive correlation between the yolk index and shell thickness and the shape index ( $p > 0.05$ ).



**Table 6** Phenotypic correlation between external and internal egg quality traits

	Egg weight	Egg length	Egg width	Shell weight	Shell thickness	Shape index
Albumen height	-0.172**	-0.138**	-0.209**	-0.237**	0.028	-0.053
Albumen weight	0.365**	0.279**	0.223**	0.161**	-0.134*	0.012
Haugh unit	-0.248**	-0.183**	-0.245**	-0.285**	0.074	-0.063
Yolk height	-0.081	-0.056	-0.091	-0.157	-0.033	-0.043
Yolk diameter	0.441**	0.291**	0.318**	0.296**	-0.177**	0.051
Yolk weight	0.341**	0.377**	0.232**	0.190**	-0.136*	0.037
Yolk index	-0.284**	-0.284**	-0.214**	-0.286**	0.088	0.002

\*:  $p < 0.05$ , \*\*:  $p < 0.01$ 

## DISCUSSION

### Fertility and hatchability

There was no significant variation among agro-ecologies in the egg fertility percentage of indigenous chickens. This implies that agroecology has no influence on the fertility of scavenging indigenous chicken eggs. The result in the current study (Table 1) was in line with the study by [Ahmedin and Mangistu \(2016\)](#), who reported a fertility of 74.45% on rural chickens in the Gorogutu district of Eastern Hararge. A higher value of fertility (81.1%-100%) was reported by [Halima \(2007\)](#) in different agro-ecologies of Northwest Ethiopia, and 95.6% and 98.9% was reported by [Getnet et al. \(2020\)](#) on eggs of Tilil and unimproved Horro chickens reared under intensive management. The highest value obtained might be observed due to the variation in the production system. The fertility percentage of indigenous chicken eggs in the current study was higher than the values reported by [Meseret \(2010\)](#) in the Gomma district of the Jimma Zone. The result on hatchability percentage in the current study is in agreement with the report by [Mbuthia et al. \(2007\)](#), who reported that 82.8% hatchability was recorded for indigenous chickens in Kenya.

The result on hatchability percentage (63.1%) in the current study was in agreement with the findings of [Tadelle \(2003\)](#) and [Ahmedin and Mangistu \(2016\)](#), who reported 68.8% and 64.45%, respectively, with no significant difference in hatchability percentage of Ethiopian indigenous chicken in different agro-ecologies. The finding of the current study was in agreement with the range given by [Halima \(2007\)](#), who reported hatchability of indigenous chickens between 46.2% and 73.3%. The finding of the present study was lower than the result of [Gebreegziabher \(2016\)](#), who reported total egg basis hatchability of 83.6% in the highlands and 74.1% in the midland agroecology of the Wolaita Zone.

In agreement with current findings, [Getnet et al. \(2020\)](#) reported 81.0% and 88.9% hatchability on fertile egg basis for Horro and Tilil local chickens, respectively. Additionally, the findings of the current study are in line with the results reported by [Ahmedin and Mangistu \(2016\)](#), who reported hatchability values on a fertile egg basis of 81.91%, 81.99% and 93.93% for highland, midland and lowland agroecologies, respectively ( $p > 0.05$ ). [Fisseha et al.](#)

(2010) reported average hatchability values of indigenous chickens of 82.6%, 78.9% and 89.1% at Bure, Fogera and Dale, respectively, which is also in good agreement with the present study.

### External egg quality traits

Egg weight is highly influenced by hereditary and environmental factors (Sekeroglu & Altuntas 2009). Environmental factors in terms of the age of hens, body size, diet, water intake, temperature, humidity and management practices may contribute to the variability observed in the results (Isidahomen et al., 2013). The result on egg weight and length in the current study (in Table 2) was in agreement with the finding of Aberra (2018), who reported an average egg weight of 43.9 grams on indigenous chickens. Similarly, the results of Markos et al. (2017) and Getnet et al. (2020) are in line with the findings of the present study. In their results, they reported an average egg weight of 40.56 g for different indigenous ecotypes, 43.5 g for Horro chickens and 42.3 g for Tilil chickens. However, Halima (2007) and Ahmedin and Mangistu (2016) reported lower values than the current study egg weights (37.38 g and 45.75 g, respectively) for indigenous chicken ecotypes of Ethiopia. Average egg weights of 49.79 g, 48.21 g and 41.32 g were reported on naked neck, normal and dwarf strains of Tswana indigenous chickens (Kgwatalala et al. 2016), which is in agreement with the present study. Inconsistently higher egg weight was given by Madalena et al. (2019) on different indigenous chicken breeds of Portugal.

In agreement with the current study, Aberra (2018) revealed a shape index value of 72.7 for indigenous chickens reared under a traditional management system in the Benchi Maji zone of southern Ethiopia. Similarly, the values in agreement with the current study were given by Veena et al. (2015), who reported shape index values of 72.10 during winter and 71.99 during summer on indigenous chickens of Andhra Pradesh. Hussain et al. (2013) reported an average shape index value of 80.40 on indigenous chickens of Pakistan, which is much higher than the result of current findings. Nedeljka and Kocevski (2006) suggested that the shape index is influenced by season, genetic factors and age group of birds. Eggs are categorized into three shape groups: Sharp (<72), normal (72-76) and round (>76). As this classification, the results of the current study show that eggs of indigenous chickens are classified as normal eggs regardless of other factors. The shape index is an important factor for characterizing species of birds (Song et al., 2000), as well as an indicator of egg quality (Mueller, et al., 1960) and is very important for chick survival (Lundberg and Vaisanen, 1979). Egg shape is an important parameter in commercial systems. Sharp eggs and round eggs do not fit well in egg cartons; therefore, they are much more likely to be broken during shipment than eggs of normal shape (Sarica and Erensayin, 2009).

In the current study, shell weight was the highest (4.38 gm) in midland agroecology, and it the lowest (3.70 gm) in highland agroecology. In agreement with the present study, shell weights within the range between 4.02 gm and 4.88 gm were recorded by Halima (2007) in different indigenous ecotypes of Ethiopian chickens. In a study conducted on unimproved Horro chickens, Demissu (2020) observed the lowest shell weight in highland agroecology compared to the rest of the agroecology systems, which is in line with the findings of the current study.

In line with the present study, Fereja et al. (2016) reported the value of shell thickness  $0.28 \pm 0.02$  mm and  $0.27 \pm 0.02$  mm (mean $\pm$ SD) in highlands and midlands, respectively, and Serkalem (2019) reported  $0.279 \pm 0.03$  mm and  $0.281 \pm 0.02$  mm in lowlands and midlands, respectively, in different areas of Ethiopian indigenous chicken eggs. However, the result of Demissu (2020) ( $0.35 \pm 0.06$  mm,  $0.36 \pm 0.06$  mm and  $0.37 \pm 0.07$  mm in the highlands, midlands and lowlands, respectively) was higher than the result of the current study. However, Yonas et al. (2019) reported a lower value ( $0.19 \pm 0.06$  mm) than the present study on indigenous chickens in the Yirgalem district. Kgwatalala et al. (2016), Saroj et al. (2020), and Hussain (2013) recorded higher shell thickness values than those in the present study on indigenous chickens of Botswana, Nepal and Pakistan, respectively. In their study, they reported average shell thickness values of 0.39 mm and 0.39 mm and 0.53 mm. Shell thickness is an important parameter that determines the internal quality of an egg. Internal egg contamination by microorganisms might be affected by the ability of eggshells to prevent the entrance of those microorganisms into the egg. Thick shells and firm interior parts (albumen and yolk) are accepted as being better in more successful hatching of embryos, especially from larger eggs (Narushin and Romanov, 2002).

Shell percentage is defined as shell weight over egg weight multiplied by hundred. Demissu (2020) reported a higher shell percent on unimproved Horro chickens in all agro-ecologies than the results of the current study.

### Internal egg quality traits

Yolk height indicates how the egg quality was influenced due to different storage factors. Higher the yolk height means better the egg quality is. The results of the current study (in Table 3) were in agreement with the findings of Yonas et al. (2019), who reported a mean yolk height value of 15.77 mm in Hawassa town and 15.90 mm in Yirgalem town. In line with the present study, average yolk heights of 15.9 mm and 15.2 mm were recorded for heavy ecotype and light ecotype Nigerian local chickens, respectively (Momoh, et al., 2010). Fisseha et al. (2010) reported a  $15.1 \pm 1.3$  mm mean value from local hens of Bure district, Ethiopia. His result is in good agreement with the findings of the current study. The result reported by Aberra (2018) is lower than the result of the current study. In his study, he reported average yolk height ( $14.0 \pm 1.7$  mm) on local scavenging chickens in three districts of the Bench Maji Zone in southwestern Ethiopia. Similarly, Getnet et al. (2020) reported lower values (14.8 mm and 13.8 mm) than the present study in local Horro and Tilil chicken ecotypes.

In agreement with present result, Halima (2007) reported a mean albumen height value between 4.23 and 4.95 mm in different local chicken ecotypes. A lower value ( $3.4 \pm 0.7$  mm) was found in a study conducted on indigenous chickens reared under extensive management conditions in different districts of the Bench maji Zone of southern Ethiopia (Welelaw, 2018). This might occur due to the longer storage period and storage conditions of the eggs before analysis was conducted. Thus, albumen height is an indication of the freshness of eggs (Zeidler, 2002).

Regarding yolk weight, Halima (2007) and Demissu (2020) reported lower results, but Meseret (2010), Welelaw et al. (2018), and Ahmedin and

Mangistu (2016) reported nearly similar results to those of the current study. The mean yolk weight value of 15.13 grams was recorded from a study conducted on Indigenous Sakini Chicken of Nepal (Saroj et al., 2020). A much lower yolk weight value of 9.667 grams was reported by the study of Nuhu et al. (2018) conducted on Nigerian indigenous chicken ecotypes. This difference may occur due to differences in genes and the environment.

In line with current study, Halima (2007) recorded 23.52 g and 23.60 g of average egg weight for Tilil and Mecha indigenous chicken populations, respectively. Albumen weighing  $22.30 \pm 0.25$  grams was reported in unimproved Horro chicken ecotypes, and this result is in agreement with the value of the current study (Demissu, 2020).

The yolk color results in the current study are in agreement with the reports of Meseret (2010) and Yonas (2019). However, a lower result was revealed by Halima (2007), who reported Roch fan results between 3.00 and 4.00 for different indigenous chicken ecotypes under intensive management conditions. This implies that the difference in the production system has a high impact on the yolk color of eggs from indigenous chickens. The color of the egg yolk is mainly dependent on the type of ration and the management systems of the chickens. The eggs collected from scavenging birds have a higher yolk color count because scavenging birds have free access to green plants and other feed sources rich in xanthophylls (Zaman et al., 2004). According to a study conducted in Boricha District, the sidama regional state breed and agroecology showed significant differences in yolk color (Aberra et al., 2019). The value of yolk color is higher for indigenous chickens than for exotic chicken breeds. This might be due to indigenous chickens having a better scavenging ability to obtain greenish scavengeable feed resources that contain high amounts of xanthophylls. In agreement with the current study, Demissu (2020) reported 54.71% and 34.99% average albumin ratio and yolk ratio, respectively. A higher albumen ratio (75.373) and lower yolk ratio (26.747) were recorded in Nigerian indigenous chickens (Nuhu et al., 2018).

Both Haugh unit and yolk index are the best indicators of the level of the deterioration of the quality of eggs. Higher the values of Haugh unit and yolk index the more the freshness of the eggs. The result of the current study showed that eggs maintain their freshness for the longer time in the highland agro-ecology, because higher temperature in the lowland agro-ecology deteriorates the quality of eggs in short period of time and vice versa. A lower value of the Haugh unit was given by Welelaw et al. (2018), Halima (2007) and Meseret (2010), but a nearly similar result was reported by Yonas (2019) on Ethiopian indigenous chickens and Momoh et al. (2010) on Nigerian indigenous chicken ecotypes. Saroj et al. (2020) reported 74.46 Haugh unit value for indigenous chickens of Nepal. A higher value of the Haugh unit (100.533) was recorded in a study performed on indigenous chickens of Nigerian savanna (Nuhu et al., 2018).

Regarding yolk diameter, Demissu (2020) reported yolk diameter values of unimproved Horro chickens of 36.6 mm, 41.1 mm and 39.7 mm ( $p$  value  $< 0.001$ ) in highland, midland and lowland agroecologies, respectively, and which was in agreement with current study. These differences on the yolk diameter may be attributed due to the variation of temperature between agro-ecologies.



### Phenotypic correlation among external egg quality traits

In line with the present study (Table 4), Markos et al. (2017) reported that egg weight has a strong positive correlation with shell weight, egg length and egg width in indigenous chicken ecotypes of Tigray. Similarly, Kgwatalala et al. (2016), on dwarf, normal and necked neck strains of Tswanan chickens, and Sezai et al. (2014), on Partridge (*Alectoris Chukar*), reported that there was a high positive correlation of egg weight with egg width, egg length and shell weight of different poultry species.

Regarding the correlation between egg weight and shell thickness, Udoh et al. (2012), Kgwatalala et al. (2016), Sezai et al. (2015) and Okon et al. (2020) reported negative correlation between both parameters, and this report agrees the finding of the current study. However, disagreement was reported by Cahyadi et al. (2019) and Zhang et al. (2005) on Japan's Quills and brown egg dwarf layers, respectively.

In line with present study, Bobbo et al. (2013) reported a strong positive correlation between egg length and egg width on frizzle and necked neck indigenous chickens of Yola. In agreement with current study Sezai et al. (2015) and Bobbo et al. (2013) reported strong positive correlation on egg length and egg width with shell weight and surface area on different poultry species. Non significant positive correlation was reported between egg length and shell weight or between egg width and shell weight in three different strains of Tswanan chickens (Kgwatalala et al., 2016). Egg length was highly negatively correlated with the shape index, but egg width and shape index are strongly positively correlated with each other. This indicates that when the egg becomes wider, its shape index will be larger, and it will possess a round shape that makes it difficult to handle and package. Similarly, a strong negative correlation between egg length and shape index and a strong positive correlation between egg width and shape index were shown in dwarf, normal and necked neck indigenous chickens of Tswana (Kgwatalala et al., 2016).

In line with current study, Sezai et al. (2015), Markos et al. (2017) and Islam and Dutta (2011) reported a significant positive correlation between shell weight and shell ratio in different poultry species. Shell percentage is defined as the ratio of shell weight to total egg weight, so that the amount of shell weight increases then higher will be shell percentage.

In agreement with the current study, Bertha (2013) reported a significant negative correlation between shell ratio and egg weight on Cobb 500 broiler hatching eggs. However, the report of Olawumi and Ogunlade (2008) is the reverse of the current study; they reported a nonsignificant positive correlation between shell ratio and egg weight in exotic Isa brown layer breeders. Additionally, there was a nonsignificant negative correlation between shell percentage and egg length and between shell percentage and egg width. This result is in agreement with the results of Sezai et al. (2015) and Markos et al. (2017).

### Phenotypic correlation among internal egg quality traits

The contradicting result was reported by Bertha (2013), who reported that there is a negative correlation on albumen weight with yolk weight and yolk diameter. Markos et al. (2017) reported a strong positive correlation between albumen weight and yolk weight in highland midland and lowland ecotypes

of Tigray chickens. A strong positive correlation between albumen weight and yolk weight was reported in dwarf, normal and necked neck indigenous chickens of Tswana (Kgwatalala et al., 2016). This result is in agreement with the findings of the current study.

In agreement with the current study, Bobbo et al. (2013) reported correlation values between albumen height and Haugh units of 0.98, 0.91 and 0.90 for frizzle, necked neck and smooth feathered indigenous chickens, respectively, in Adamawa state of Yola. Additionally, this result was in agreement with the findings of Alipanah et al. (2013), Olawumi and Ogunlade (2008), Bertha (2013), Markos et al. (2017). This value is an indication that the Haugh unit of egg is highly dependent on the albumen height. Albumen height is higher for fresh eggs and deteriorates with increasing storage period and storage temperature. At the same time, the Haugh unit of eggs decreased.

The result of current finding was in agreement with the results of Bertha (2013) and Olawumi and Ogunlade (2008), who reported strong positive correlation between albumen height and yolk height. However, a non-significant negative correlation was reported between albumen height and yolk height for local barred hens of Cameroon (Mube et al., 2014).

In opposition with current study, Bobbo et al. (2013) reported a strong positive correlation between albumen height and yolk height for necked neck indigenous chickens, but in a similar study, he reported a negative non-significant correlation between albumen weight and yolk weight for frizzle and smooth feathered indigenous chickens of Yola. These differences in egg qualities might occur due to different factors, such as storage, strain and age of hens, induced molt, nutrition and disease (Roberts. 2004).

The result of present study was in consistent with the report of Markos et al. (2017), who reported that yolk weight was positively correlated with yolk diameter and strongly negatively correlated with the yolk index. This implies that as yolk weight increases, yolk diameter also increases. However, the results of the current study disagree with the findings of Okon et al. (2020), who reported a value of -0.296 between yolk weight and yolk diameter

Similar findings with the current study on the correlation between yolk height and Haugh unit were reported by Markos et al., (2017), Olawumi and Ogunlade (2008) and Bertha (2013), who reported strong positive correlation between yolk height and Haugh unit of different chicken breeds. This implies that yolk height and albumen height go in the parallel direction. When we opened the egg during our study, the first indications of its quality were both albumen height and yolk height. If the egg was stored for a long time, albumen and yolk expanded suddenly as the egg was opened, then measurements of both albumen height and yolk height decreased.

In line with current study, Sezai et al. (2015) reported that yolk diameter has a strong negative correlation with the yolk index and a non-significant negative correlation with the Haugh unit. This might occur because when yolk height decreases due to different factors, yolk expands, and its diameter increases. In agreement with current study, strongly positive correlation between yolk index and Haugh unit were reported by Ojedapo (2013) and Bobbo et al. (2013). These two parameters are related to yolk height and albumen height. As discussed above, when albumen height decreases due to different factors, yolk height also decreases, and the same is true for the yolk index and Haugh unit.



## Phenotypic correlations between some internal and external egg quality traits

In agreement with the current study (Table 6), Bertha (2013) reported a significant negative correlation of albumen height with egg weight, egg length, egg width and shell weight. In agreement with present study, Godson et al. (2020) found a positive correlation between albumen height and shell thickness. This implies that albumen height can be affected by shell strength because a thicker shell has better resistance to temperature and can control the entry of microorganisms inside the egg. Then, albumen height remained high for a longer time than eggs with thinner shells.

The result of present finding were supported by Olawumi and Ogunlade (2008), Bertha (2013), Kul and Seker (2004), and Markos et al. (2017), who reported strong positive correlation on albumen weight with egg weight, egg length, egg width and shell weight. In agreement with the findings of current study, Kul and Seker (2004), reported strong negative correlation between Albumen weight and shell thickness.

In agreement with the current study, the findings of Alipanah et al. (2013) and Godson et al. (2020) revealed that there is a strong negative correlation between the Haugh unit and shell weight of eggs. This happened due to the strong negative correlation of albumen height with shell weight. This result disagrees the findings of Kul and Seker (2004) and (Bertha 2013).

In line with current study, Godson et al. (2020) reported a positive correlation of yolk height with egg weight, egg length and egg width. In a similar study, he reported a negative correlation of yolk height with shell weight, shell thickness and shape index, which is in parallel with the findings of the current study. In contrast to the findings of the current study, Bertha (2013) found a strong positive correlation of yolk height with egg weight, egg length, egg width and shell weight of Cobb500 broiler hatching eggs.

This result was supported by. In line with current study, Kul and Seker (2004), Markos et al. (2017), and Liswaniso et al. (2020), reported that Yolk weight had a strong positive correlation with egg weight, egg length and egg width. According to these findings, including the current study, yolk weight increases with increasing external parameters. Egg weight, length and width increase with different factors, such as the age of the hen, breed and strain, nutrition and other environmental factors. At the same time, the weight of the egg increased.

In line with the present study, Godson et al. (2020) showed a slight positive correlation between the yolk index and shell thickness. The finding of Liswaniso et al. (2020) agrees with the results of the current study on the correlation between the yolk index and shape index.

## CONCLUSIONS

The results show that agroecology has no effect on the fertility and hatchability of indigenous chickens. Eggs collected from midland agroecology had the highest egg weight, egg length, egg width and shell weight, followed by those collected from lowland agroecology. However, agroecology has no effect on the shape index of indigenous chicken eggs. Eggs collected from midland showed superior yolk weight, albumen weight and yolk diameter. However,

eggs collected from highlands showed the highest yolk height, albumen height, yolk index and Haugh unit values. Agroecology has no effect on the yolk color of indigenous chicken eggs. Therefore, it can be concluded that midland agroecology is more favorable for external and internal egg quality of indigenous chickens when stored for a short period of time, but eggs remain fresh for a longer time in highland agroecology.

## ACKNOWLEDGEMENTS

First and above all my soul give thanks to Almighty GOD for he has been my shepherd, his love and assistance on my lifelong journey. Next, my heartfelt thanks and appreciation goes to my advisor Dr. Kefyalew Berhun (PhD), this all success is due to his close mentoring and guidance. I appreciate him to his friendship approach to his advisee. I am highly indebted to my friends Sidrak Sintayehu, Birhanu Bekele and others who helped me during laboratory work and survey data collection. All farmers and experts of districts and kebeles, who participated during survey work of present study, are in my heart. SARI (Southern Agricultural Research Institute) is highly acknowledged for financial support and their counseling during this work. Finally, I am highly grateful to my choir team (YIDIDYA) and all persons who helped me with prayers and counseling to achieve this program.

## AUTHOR CONTRIBUTIONS

Corresponding author of this study contributed to the study by proposal writing, data collection, data analysis and interpretation, and write up of this manuscript. Co-author of the study was contributed to the study by guiding and editing of the article.

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#### How to cite this article;

Legesse Yotona Tunsisa and Kefyalew Berihun Reda. Evaluation of fertility, hatchability and egg quality of indigenous chickens in different agro-ecologies of Sidama Region, Ethiopia. *Veterinary Integrative Sciences.* 2023; 21(1): 201 - 219.

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