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RESEARCH ARTICLE

Analysis of quality and prediction of external and internal egg traits in Mexican native turkey hens

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ABSTRACT

This study aimed to evaluate external and internal quality traits and determine prediction equations for some of these traits in eggs of Mexican native turkey hens. A total of 72 eggs from native turkey hens in the laying stage raised in rural municipality of Villaflores, Chiapas were measured. The external traits evaluated were: egg weight (EW), polar diameter (PD), equatorial diameter (ED), egg shape index (SI), shell weight (SW), shell percentage (SP), egg surface area (ESA) and shell weight per unit surface area (SSA). The internal traits were: albumen height (AH), yolk height (YH), albumen weight (AW), yolk weight (YW), Haugh units (HU), albumen percentage (AP), yolk percentage (YP) and yolk color (YC). The data were analyzed with descriptive statistics and Pearson correlation coefficients (r) and linear regression using the SAS program, ver. 9.4. The values obtained for the external egg quality traits showed greater variability. Pearson's correlation coefficients between external and internal traits were positive and moderately significant ($P < 0.05$), as well as highly significant ($P < 0.0001$), and ranged from $r = 0.31$ (EW vs PD) to $r = 0.99$ (ED vs ESA). All linear regression equations to predict EW, SW, AW and YW were found to be significant (<.0001). The best predictors of EW were PD, SI, SW and ESA ($R^2 = 76\%$). SW and YW traits can be adequately predicted using the EW and SI values together ($R^2 = 59\%$ and $R^2 = 74\%$, respectively), while the AW can be predicted from the EW ($R^2 = 33\%$). Based on the results obtained, it is suggested to implement selection programs to improve the quality parameters of the native turkey hen egg in Mexico.

Keywords: Egg quality; Egg weight; *Meleagris gallopavo;* Native turkey hen; Prediction equations

INTRODUCTION

Egg is an important food in the human diet due to its high protein content, easy preparation and wide availability in the market, low price compared to other sources of protein of animal origin such as meat and milk (Mendoza-Rodríguez et al., 2016). Mexico is the largest consumer *per capita* of eggs in the world, only in 2012 consumption reached a record 20.8 kg (Cruz-Jiménez et al., 2016). The main egg production system in Mexico is intensive and is based on the use of poultry species with specialized genetic lines, mainly laying hens (Hernández and Padilla, 2015). However, in the rural and sub-urban areas of the country, there is another type of egg production system that is carried out extensively and non-specialized poultry species are used (Centeno-Bautista et al., 2007), but in this type of egg production system, studies on egg quality are limited (Juárez-Caratachea et al., 2010).

Egg quality is a general term that refers to various standards that define both external and internal quality and affect the degree of acceptance by consumers. The external quality focuses on the weight, size, shape and cleanliness of the egg, as well as the texture of the shell, while the internal quality refers to traits related to the yolk and albumen of the egg (Fajemilehin, 2008). Various authors suggest evaluating the relationships between some external and internal traits for a better understanding of the egg quality parameters (Khurshid et al., 2003; Abanikannda and Leigh, 2007; Alkan et al., 2015; Baykalir and Aslan, 2020). For example, the traits of weight, length and width of the egg, shape index and shell weight are highly correlated, and in turn, can be

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used as predictors of internal egg traits such as the weight of yolk and albumen, to facilitate their evaluation without the need to break the egg (Fajemilehin, 2008; Çiftsüren and Akkol, 2018).

In Mexico, the egg quality of native turkey hens has been scantly evaluated. In a first study, Juárez and Gutiérrez (2009) determined that the values of the weight and polar and equatorial diameters of the native turkey egg presented a greater variation, even when the birds were of the same age and of the same laying cycle. However, the values of the traits evaluated were within the acceptance ranges given by the Official Mexican Standard on the physical characteristics that the fresh egg produced and/or marketed within the national territory must meet (NMX-FF-079-2004). Later, Juárez-Caratachea et al. (2011) reported that the internal quality egg traits of the native turkey hen showed greater variability than the external quality traits. Additionally, they suggest that the correlations found among quality egg traits suggest the possibility of implementing selection programs to genetically improve some of these traits. Recently, Camacho-Escobar et al. (2019) reported that native turkey hen eggs have a greater weight, polar diameter and equatorial diameter, compared to the Creole hen eggs; likewise, they determined that the larger the egg, the better the fertility percentage is obtained.

Despite the information available on the external and internal quality egg of the native turkey hens, it is necessary to carry out more studies for a more reliable characterization, which will allow to define national standard values of this important poultry product, even more considering that this poultry species is distributed practically throughout the mexican territory.

Therefore, this study aimed to evaluate external and internal quality traits and determine prediction equations for some of these traits in eggs of native turkey hens raised under tropical conditions in Mexico.

MATERIALS AND METHODS

Egg collection site

A total of 72 eggs were collected from native turkey hen flocks, raised in backyards in the rural municipality of Villaflores, Chiapas located at 16 °09', 16° 36' north latitude and 93° 02', 93 47' west longitude, at an altitude between 200 and 2,300 meters above sea level. The region has a subhumid warm climate with rains in the summer; Aw2 (García, 2004). The average annual temperature and total annual precipitation vary between 14-26 °C and 1000-3500 mm, respectively (INEGI, 2017).

To obtain the eggs, two turkey hens were selected per backyard belonging to six rural communities, obtaining a total of 12 turkey hens. For the selection of the birds, a rectal palpation procedure was performed to confirm that they were in the laying stage. Later they were identified with a metal ring placed in the tarsus. The birds were kept in the backyard under natural environmental conditions using a traditional or extensive management.

The eggs were collected in the early hours of the day during six weeks, placed in special egg containers, previously disinfected, and stored at room temperature until parameters were measured.

Evaluation of external and internal egg quality traits

Egg weight (EW) and shell weight (SW) were taken using an electronic scale (Medidata®) with an accuracy of 0.01 g. Polar (PD) and equatorial diameter (ED) of the egg were measured with a digital caliper (Mitutoyo®, Mizonokuchi, Japan) with an accuracy of 0.01 mm. Egg shape index (SI) was calculated considering the mathematical formula described by Hegab and Hanafy (2019). Shell percentage (SP) was estimated through the SW and EW relationship SW / EW x 100 ratio (Juárez-Caratachea et al., 2011). Egg surface area (ESA) was estimated using the mathematical expression suggested by Narushin (2005Shell weight per unit surface area (SSA) was determined considering the SW and ESA relationship (Alkan et al., 2015).

Albumen (AH) and yolk height (YH) were measured with a depth digital caliper bar. Yolk weight (YW) was obtained using the electronic scale. Subsequently, albumen weight (AW) was estimated from the following mathematical formula: AW = EW - (YW + SW). The Haugh units (HU) were calculated considering the suggested by Hegab and Hanafy (2019). Albumen percentage (AP) and yolk percentage (YP) were estimated by the relationship between the AW or YW and the EW (Juárez-Caratachea et al., 2011). Yolk color (YC) was determined with a Roche colorimetric fan (DSM YolkFan®).

Data analysis

All statistical analyzes were performed using the SAS program, ver. 9.4 (SAS, 2016).

The data on the external and internal features of the egg evaluated in the study was analyzed by descriptive statistics using PROC MEANS. Pearson's correlation coefficients (r) between the variables of greatest importance in the evaluation on egg quality (EW, PD, ED, SI, SW, ESA, AW, YW) were estimated using PROC CORR. The relationship between external and internal traits was determined by linear regression models EW, SW, AW and YW using PROC REG through STEPWISE option SELECTION statement with the main objective that significant predictor variables ($P < 0.05$) were included in the model. The precision of each model obtained was evaluated considering the coefficient of determination (R^2) and the mean square error (MSE).

RESULTS AND DISCUSSION

Evaluation of external and internal egg quality traits

The results on the external traits egg quality are shown in Table 1. EW, PD and ED values were 75.54 ± 8.07 g, 5.25 ± 0.80 cm and 3.45 ± 0.81 cm, respectively. These data are different from those reported in local turkeys raised in regions of Nigerian (Adeyeye, 2009; Isidahomen et al., 2014; Popoola et al., 2015), Croatia (Galic et al., 2017), Bulgaria (Hristakieva et al.., 2017) and India (Anna-Anandh et al., 2012). Previously, it has been described that, in this poultry species, the main factors that influence the variation of external egg traits, mainly in weight, are the genotype (Isidahomen et al., 2014), the phenotype (Juárez-Caratachea et al.,2018) and the age of the birds (Ghane et al., 2015; Mróz et al., 2019). In other domestic poultry species such as quail, some environmental factors such as temperature and humidity indices have been reported to have a negative impact on external egg quality traits (El-Tarabany, 2016).

In the study, an SI value of 65.08 ± 6.17% was found, with a variation range between 57.41 and 81.25%, which shows heterogeneity in the shape of the collected eggs. This variability could be attributed to seasonal environmental factors, age and the type of feeding offered to birds (Alkan et al., 2015). SI is a trait that influences the internal parameters of egg quality, therefore, it should be considered for future genetic improvement programs of the species (Duman et al., 2016). Furthermore, it is related to the direction of rotation during incubation, which determines the embryonic movements for the use of nutrients (Galic et al., 2018). The values of SW (9.82 ± 1.26 g) and SP (13.06 ± 1. 14%) obtained were slightly higher than the values found in the eggs of Mexican (Juárez and Gutiérrez, 2009; Juárez-Caratachea et al., 2011) and Nigerian local turkey hens (Adeyeye, 2009; Isidahomen et al., 2014). Egg geometric calculations, including ESA estimation, are of great economic and biological importance as they can be used to predict chick weight at birth (Narushin, 2005). An ESA = 58.57 ± 24.12 cm^2, lower than the value determined by Galic et al., (2018) was determined in Zagorje turkey eggs from Croatia (90.50 cm^2). In general, the external egg quality traits evaluated had coefficients of variation less than 30%.

The results of the internal egg quality traits are presented in Table 2. An AH, AW and AP of 5.74 ± 1.05 cm, 40.64 ± 5.80 g and 53.96 ± 5.86%, respectively, were recorded. Juárez-Caratachea et al., (2011) mentioned that the internal traits, such as albumen height, indicate the degree of freshness of the eggs, and these values are lowered from 3 to 5 days post-oviposition, for this reason it is recommended to store the eggs at a controlled temperature and humidity. On the other hand, Isidahomen et al., (2014) found that egg albumen weight is significantly affected by the genotype, and they reported an AW of 43.70 ± 0.47 g, 54.00 ± 0.32 g and 47.45 ± 0.39 g in local

Table 1: Descriptive statistics of external egg quality traits of Mexican native turkey hens

Variable	Description	Mean±SD	Minimum	Maximum	CV
EW	Egg weight (g)	75.54±8.07	60.00	89.00	10.69
PD	Polar diameter (cm)	5.25±0.80	4.20	7.20	15.26
ED	Equatorial diameter (cm)	3.45±0.81	2.80	5.30	23.70
SI	Egg shape Index (%)	65.08±6.17	57.41	81.25	9.48
SW	Shell weight (g)	9.82±1.26	7.00	12.00	12.86
SP	Shell percentage (%)	13.06±1.14	10.14	16.44	8.72
ESA	Egg surface area (cm^2)	58.57±24.12	36.81	115.13	41.19
SSA	Shell weight/surface unit (g/cm^2)	0.18±0.04	0.08	0.24	26.42

SD: Standard deviation error: CV: Coefficient of variation

Table 2: Descriptive statistics of internal egg quality traits of Mexican native turkey hens

Variable	Description	Mean ±SD	Minimum	Maximum	CV
AH	Albumen height (cm)	5.74±1.05	4.00	9.00	18.30
AW	Albumen weight (g)	40.64±5.80	33.00	78.00	14.27
AP	Albumen percentage (%)	53.96±5.86	43.90	87.64	34.39
YH	Yolk height (cm)	1.55±0.23	0.90	1.90	14.88
YW	Yolk weight (g)	25.44±5.19	14.00	35.00	20.41
YP	Yolk percentage (%)	32.85±4.31	23.33	42.68	13.15
HU	Haugh units	67.76±10.90	43.69	92.34	16.08
YC	Yolk colour	8.54±1.02	6.00	11.00	11.99

SD: Standard deviation error; CV: Coefficient of variation turkeys, exotic and their cross, respectively. The value of AP obtained in the present study is consistent with that mentioned by Sun et al., (2019) that albumin constitutes the majority of the egg of poultry (around 60%).

Yolk trait values obtained in the present study (YH = 1.55 ± 0.23 cm, YW = 25.44 ± 5.19 g and YP = 32.85 ± 4.31%) were similar to those reported in turkey eggs of local genotypes (Juárez-Caratachea et al., 2011; Hristakieva et al., 2011; Isidahomen et al., 2014; Popoola et al., 2015) but contrasting with the values obtained in turkeys with improved lines (Ghane et al., 2015; Sun et al., 2019), this variation is justified by the weight of the egg of each genotype. The mean values of the registered Haugh units (67.76 ± 10.90) were lower than the values reported in native turkeys from other regions in Mexico: 76.1 ± 5.7 (Juárez-Caratachea et al., 2011) and 80.9 ± 1.3 (Juárez and Gutiérrez, 2009). It indicates a lower freshness of the eggs evaluated in the present study, therefore, lower product quality, because the higher the HU value, the better the egg quality (El-Tarabany, 2016). Previously it has been reported that the HU value in the eggs of laying hens decreases significantly with longer storage time and population density (Menezes et al., 2012).

YC value = 8.54 ± 1.02 was recorded in this study; however, it is not enough to reach the yolk color score required to be considered as a commercial egg and according to the Official Mexican Standard (NMX-FF-079-SCFI-2004) it must be between a range from 9 to 13, considering Roche colorimetric fan scores. Therefore, egg color yolk is one of the main characteristics considered by consumers, for example, the consumption with yellow or orange yolks is higher because this characteristic is associated with some health benefits, such as the prevention of cancer, blindness and the bone system (Titcomb et al., 2019). YC in laying hens' eggs has been reported to be significantly affected by the type of production system, mainly due to the diet offered to birds (Yenice et al., 2016). With the exception of the AP, the internal quality traits of the evaluated egg showed a CV ≤ 20%.

Analysis of the relationships between external and internal egg quality traits

The matrix of Pearson's correlation coefficients between the external and internal egg quality traits is shown in Table 3. The EW presented highly significant and positive correlations (P <0.0001) with the YW (r = 0.85), SW (r = 0.75) and AW (r = 0.57) traits, likewise, had a moderately significant correlation (P <0.05) with PD (r = 0.31). For their part, Juárez-Caratachea et al., (2011) found that the egg weight of native Mexican turkeys showed high and positive correlations with shape index (r = 0.80), albumen index (r = 0.69) and diameter longitudinal of the egg (r = 0.63). In other domestic poultry species such as chickens (Juárez-Caratachea et al., 2010), Guinea fowl (Nowaczewski et al., 2008), partridge (Alkan et al., 2015) and quail (El-Tarabany, 2016; Hegab and Hanafy 2019) it has also been reported that the weight of the egg has significant correlations with albumen weights, yolks and shell. The strong linear relationships between the egg traits mentioned above, imply that these traits are probably under the influence of the same genetic action (Fajemilehin, 2017).

Both, PD and ED showed highly significant and positive correlations (P <0.0001) with the ESA (r = 0.96, r = 0.99, respectively) and the SI (r = 0.61, r = 0.84, respectively) traits, also, both diameters were highly correlated (r = 0.93). This indicates that the width and length features of the egg can be used as selection criteria to improve the geometry of the egg. A negative and moderately significant correlation (P <0.05) was registered between SI and YW (r = -0.32), this suggests that the higher the shape index, the weight of the yolk decreases.

The prediction equations developed for external and internal egg quality traits are shown in Table 4. For the prediction of EW, four equations were obtained, however, the best equation (Eq. 4) explained 76% of the observed variation and considered PD, SI, SW and ESA as predictors. SW was explained by 59% when EW and SI were included in the equation. On the other hand, EW was the only trait used as a predictor of AW and only explained 33% of the variation. Finally, a regression model was developed

Table 3: Correlation coefficients between external and internal egg quality traits of Mexican native turkey hens

Variable	EW	PD	ED	SI	SW	ESA	AW	YW
EW	1.00							
PD	0.31*	1.00						
ED	0.09^{ns}	0.93**	1.00					
SI	-0.25^{ns}	0.61**	0.84**	1.00				
SW	0.75**	0.33*	0.19^{ns}	-0.06^{ns}	1.00			
ESA	0.14^{ns}	0.96**	0.99**	0.78**	0.21^{ns}	1.00		
AW	0.57**	0.15^{ns}	0.08^{ns}	-0.02^{ns}	0.34*	0.09^{ns}	1.00	
YW	0.85**	0.21^{ns}	-0.00^{ns}	-0.32*	0.61**	0.04^{ns}	0.19^{ns}	1.00

**P<0.0001; *P<0.05; ns: not significant. EW: Egg weight; PD: Polar diameter; ED: Equatorial diameter; SI: Shape index; SW: Shell weight; ESA: Egg surface area; AW: Albumen height; YW: Yolk weight

Table 4: Regression equations to predict egg weight, shell weight, albumen weight and yolk weight using external egg quality traits of Mexican native turkey hens

Eq. No	Equations	R^2	MSE	Pr>F
Egg weight (EW, g)				
1	EW (g) = 4.82 (±0.50**)×SW	0.57	28.15	<.0001
2	EW (g) = -0.26 (±0.09*)×SI + 4.74 (±0.47**)×SW	0.61	25.78	<.0001
3	EW (g) = 3.96 (±0.98**)×PD + -0.59 (±0.12**)×SI + 3.80 (±0.49**)×SW	0.69	21.03	<.0001
4	EW (g) = 48.64 (±9.99**)×PD + 1.54 (±0.48*)×SI + 2.83 (±0.48**)×SW + -1.86 (±0.41**)×ESA	0.76	16.36	<.0001
Shell weight (SW, g)				
5	SW (g) = 0.11 (±0.01**)×EW	0.57	0.69	<.0001
6	SW (g) = -0.12 (±0.01**)×EW + 0.02 ($±0.01^{ns}$)×SI	0.59	0.67	<.0001
Albumen weight (AW, g)				
7	AW (g)= 0.41 (±0.07 **)×EW	0.33	22.76	<.0001
Yolk weight (YW, g)				
8	YW (g)= 0.54 (±0.04**)×EW	0.72	7.44	<.0001
9	YW (g)= 0.52 (±0.04 **)×EW + -0.10 ($±0.05^{ns}$)×SI	0.74	7.17	<.0001

R^2: Determination coefficient; MSE: Mean square error. EW: Egg weight; PD: Polar diameter; ED: Equatorial diameter; SI: Shape Index; SW: Shell weight; ESA: Egg surface área; AW: Albumen height; YW: Yolk weight. P-value; * P<0.05; **P<0.001; ns: not significant

to predict YW from EW and SI, which explained 74% of the observed variation. In laying hens, the weight of the egg can be adequately predicted using the values of the albumen weight, yolk and shell with an R^2 = 93.4%, the weight of albumen from the weight of the egg and shell (R^2 = 77%) and the weight of the yolk using the weight of the egg (R2 = 60%) in a unique way (Orhan et al., 2016; Çiftsüren et al., 2018). On the other hand, in Guinea fowl the egg weight can be accurately predicted from the length (R^2 = 21%) and the width of the egg (R^2 = 16%), the weight of the shell using length as predictors, the width and weight (R^2 = 8.8%) and the weight of the yolk based on the weight of the egg (R^2 = 60%) (Fajemilehin, 2008).

CONCLUSION

The quality parameters based on external and internal traits of the Mexican native turkey hens egg showed considerable variability, being greater in external traits. The evaluated traits showed that they are closely related. These relationships can be used in predicting those most important external and internal features evaluating egg quality. The egg weight is the main trait that influences the internal traits, therefore, it must be considered in future to select programs focused on improving parameters about egg quality with poultry species.

CONFLICTS OF INTEREST

Authors doesn´t have conflicts of interest.

Authors' contribution

BRS, PMN, FACV and RPS conceptualized and designed the experiment; RPS and FACV analyzed the data and wrote the manuscript and JGHH and JBO revised the manuscript. All authors read and approved the submission of the manuscript.

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