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Examination of the Relationships between Internal and External Egg Quality Traits: A Structural Equation Model

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ABSTRACT

This study aimed to determine the structural relationship between internal and external egg quality (IEEQ) traits. In this study, 114 eggs produced from 24 weeks-old laying hens reared at the Ondokuz Mayis University Research Farm were used. Egg weight (EW), egg width (EWi), egg length (EL) and shell weight (SW) measurements were examined as external quality traits. Also, albumen height (AH), albumen width (AW), yolk height (YH), yolk weight (YW) and yolk diameter (YD) parameters were used as internal quality traits. Structural Equation Model (SEM) was used to determine the relationships between IEEQ traits. Data analysis was performed with the LISREL package. It has been determined that the variables that are important in determining the external egg quality are SW, EWi and EL. When the variables explaining the internal traits were examined, it was determined that the YW, YD, AW, AH and YH were significant. It was determined that the relationship between external egg quality and internal quality was 0.96 and external quality explained the internal quality by 91%. It has been determined that the SEM used in this study is sufficient to explain the relationship between internal and external quality.

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Introduction

Poultry eggs are of great importance in a balanced and healthy diet. It is important to determine the quality characteristics of eggs, which have both nutritional properties and reproductive material (Aysondu and Ozyurel, 2021). For this reason, in recent years, importance has begun to be given to the quality of eggs and egg products at all stages of the egg industry, from producers to consumers (Gul et al. 2021). Egg quality is generally evaluated in two parts, internal and external quality (Mollazade et al. 2021) and it is one of the factors affecting both incubation efficiency (Boleli et al 2016) and consumer demands (Hisasaga et al. 2020). The quality factor plays a significant role in marketing, consumer satisfaction, and the shelf life of table eggs. Additionally, it has a notable impact on various criteria, including preserving egg quality during storage, hatching efficiency, hatchability, and producing healthy chicks in breeding eggs (Kamanli and Turkoglu, 2018).

It is not possible to increase egg quality after laying, but it is possible to maintain quality with minimum losses by providing necessary conditions (Erensayin 2000). In addition, improving shell quality is an important issue to minimize economic losses caused by egg cracking and breakage (Arango et al. 2016). The decrease in egg weight (EW) which is one of the egg quality criteria, is an effect of reducing components, or at least some components such as albumen, egg yolk and shell (Alves et al. 2007). For this reason, it is important to determine the characteristics that affect the internal and external quality of eggs and the relationships between them. Previous studies examined the effects of nutrition (Selim and Hussein 2020), egg processing conditions and long-term storage (Jones et al. 2018), and environmental temperature with advancing age on egg quality traits (Freitas et al. 2017). Particularly, some studies have been conducted to increase the yolk/albumen ratio (Jun et al. 2017; Sapkota et al. 2020). Sarica et al. (2012) conducted a study with principal components analysis to determine the most effective variables in internal and external egg quality (IEEQ) according to different breeds and their body weights. This study examined IEEQ traits bilateral relations between them with Pearson correlation, and the variables that most explain internal and external quality were determined under different factors with principal component analysis.

Pearson correlation (provided that the necessary assumptions are made) only determines the relationship between two variables, while canonical correlation determines the relationships between two sets of variables (Tahtali et al. 2012). However, these methods indicate the relationship between variables or the relationship between variable sets, respectively. In addition, principal component analysis can be used to determine the most effective one among the variables (Sarica et al. 2012).

As an alternative to these methods, the Structural Equation Model (SEM), which is created by combining factor analysis and multiple regression analysis, can be used to analyze the structural relationship between variables. This technique analyses the structural relationship between measured variables and latent constructs (internal and external). While the findings identify the variables with the most explanatory power among internal and external quality characteristics, they also determine their relationships with other variables. In this way, variables that are determined to be significant among the variables can be taken as breeding parameters or prioritized within the quality criteria. Researchers prefer to use this method to estimate multiple and interrelated dependencies in a single analysis (Statistics Solutions, 2021). This study aims to determine the relationship between IEEQ traits (latent variables) and determine the variable/variables (IEEQ traits) that explain these latent variables the most by the SEM.

Material and Method

Material

IEEQ traits were determined on 114 eggs obtained from Lohmann Brown laying hens at 24 weeks of age reared at the Ondokuz Mayıs University Research Farm. Egg weight (EW), egg length (EL), egg width (EWi), and shell weight (SW) were determined as external quality traits. EW was measured with a scale with an accuracy of 0.1 g (Shimadzu, Kyoto, Japan). EWi and EL were measured with a 0.01 mm precision digital calliper. Yolk diameter (YD), yolk weight (YW), yolk height (YH), albumen height (AH) and albumen width (AW) were determined as internal quality traits. These traits were measured on a mirrored glass table after the eggs were broken. AH and YH were measured using a digital tripod micrometer with 0.01 mm precision. AH was measured from the part closest to the yolk. The distance between the two widest edges of the albumen was assessed as the width of the albumen. YH was measured from the middle of the yolk (Erensoy et al. 2021).

Method

Descriptive statistics (mean, standard deviation, coefficient of variation (%)) of IEEQ traits examined in the study were calculated. Normality assumptions of the data were examined with the Kolmogorov-Smirnov test. It was found that they were normally distributed ($P>0.05$). Pearson correlation coefficient values were calculated to determine the relationships between the variables examined. Confirmatory Factor Analysis (CFA) to verify the structure of IEEQ traits and SEM was used to determine the relationships between IEEQ traits. The correlation matrix was used instead of the covariance matrix in the calculation of the structural relationship due to the unit difference in the data.

SEM is a multivariate statistical technique that estimates causal relationships between variables (Rahi et al., 2018). This method is widely used in many fields such as economics, marketing, biology, and medical research (Raykov and Marcoulides 2006) because direct and indirect effects between observable and unobservable variables can be tested in a single model. As such, SEM can also be considered as more than one regression analysis performed at the same time. SEM consists of two parts: the structural model and the measurement model (Yilmaz et al. 2016). The set of connections between the observed and latent variables constitutes the measurement model (Bollen 1989; Arbuckle 2007) and the connections between unmeasured (latent) variables are defined as the structural model (Bollen 1989). Following the purpose of the study, a general model with two factors is given in Figure 1, which is edited from Kenny's (2016) work.

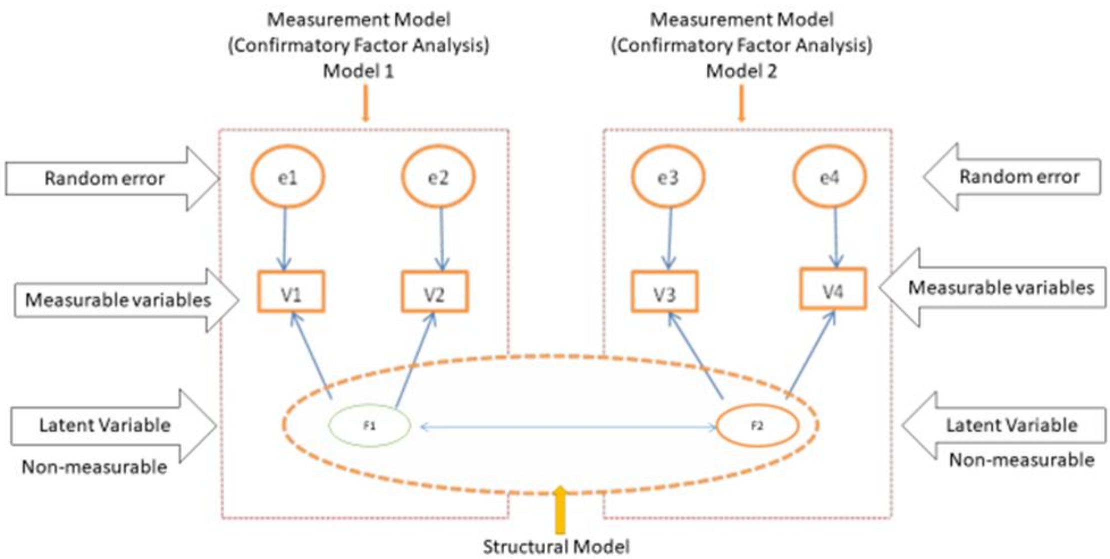

Figure 1. Two factor model

Table 1. Goodness of fit criteria

Compliance Measurement	Perfect Compliance	Acceptable Compliance
χ^2/df	$0 \leq \chi^2/df \leq 2$	$2 \leq \chi^2/df \leq 3$
Root Mean Square Error of Approximation	0≤RMSEA≤0.05	0.05≤RMSEA≤0.08
Normed Fit Index	0.95≤NFI≤1.00	0.90≤NFI≤0.95
Non-Normed Fit Index	0.97≤NNFI≤1.00	0.95≤NNFI≤0.97
Comparative Fit Index	0.97≤CFI≤1.00	0.95≤CFI≤0.97
Goodness of Fit Index	0.95≤GFI≤1.00	0.90≤GFI≤0.95
Adjusted Goodness of Fit Index	0.90≤AGFI≤1.00	0.85≤AGFI≤0.90

Table 2. Descriptive values for egg quality traits used in the study (n=114)

Traits	Mean	Std Deviation	CV (%)
EW	56.02	4.14	7.32
EL	54.02	1.51	2.78
EWi	42.48	1.16	2.82
SW	5.85	0.62	10.17
AW	64.93	4.95	7.70
AH	77.67	5.56	7.21
YD	37.09	1.41	3.77
YH	17.62	0.86	5.11
YW	12.66	0.91	7.09

CV (%): Coefficient of variation

Table 3. Correlation coefficients between egg quality traits

	EW	EL	EWi	SW	AW	AH	YD	YH
EL	0.692**							
EWi	0.906**	0.387**						
SW	0.721**	0.456**	0.624**					
AW	0.505**	0.276**	0.458**	0.425**				
AH	0.318**	0.336**	0.207*	0.366**	0.634**			
YD	0.359**	0.204*	0.362**	0.415**	0.202*	0.123		
YH	0.318**	0.239*	0.277**	0.240*	-0.103	-0.113	0.107	
YW	0.532**	0.394**	0.462**	0.585**	0.289**	0.270**	0.471**	0.390**

**P<0.01 *P<0.05

A typical model of the structural equation is as follows:

$$\eta = \beta\eta + \Gamma\xi + \zeta$$

In Equation, η : the m×1 dimensional endogenous variable vector, β: the coefficients matrix between the m×m dimensional endogenous latent variables whose elements are β_{ij}, Γ : It shows the coefficients matrix between exogenous latent variables and endogenous latent variables with m×n dimension and elements γ_{ij}, ξ :n×1 dimensional extrinsic variable vector, ζ : m×1 dimensional latent error terms vector, m is the number of endogenous latent variables, n is the number of extrinsic latent variables (Yilmaz et al. 2016).The suitability of the structural model created from the obtained data is tested with some criteria. These criteria are given in Table 1. For these criteria, there are two compliance criteria as perfect and acceptable (Schermelleh-Engel et al. 2003).

SPSS – 21 package program was used to obtain descriptive statistics, Kolmogorov-Smirnov test, and Pearson correlation analysis results, and LISREL 8.8 program was used to obtain the results of CFA and SEM.

Results

Descriptive statistics for egg quality traits are given in Table 2. The coefficient of variation (CV%) values for egg traits ranged from 2.78 to 10.17, and it can be said that the data are reliable (CV% < 30).

The correlation coefficients between the quality traits used in the study are given in Table 3. The highest significant correlation was found between EW and EWi, while the lowest significant correlation was found between YD and AW. There was no significant correlation between YH and AW, AH and YD (P>0.05).

CFA results are given in Table 4 and Figure 2. As a result of this analysis, EW was found insignificant in explaining the external egg quality along with other traits. While the most important factor in explaining external quality was SW (0.86), YW (0.72) was the most important in explaining internal quality. Also, the least important factor in explaining the external quality was EL (0.54), while it was YH (0.27) in the internal quality. According to Nunnally (1978) and Hair et al. (1998), when the reliability estimates of latent factors are examined to evaluate whether the observed variables defined under latent variables describe the structures they are related to, the structural reliability of the internal quality is 75.96%, while the external quality characteristics are 61.43% in this study (Yilmaz and Celik 2010).

The findings of the fit criteria according to the CFA results are given in Table 5. It has been determined that the model obtained is perfect according to $\chi2$/df criteria and acceptable according to other all criteria (RMSEA, NFI, NNFI, CFI, GFI and AGFI).

According to SEM results, it was determined that the variables that are important in determining the external egg quality were the SW (0.86), EWi (0.73) and EL (0.54), respectively. When the variables explaining the internal quality traits were examined, it was determined that the YW (0.72), YD (0.53), AW (0.51), AH (0.40) and YH (0.27) were significant. It was determined that the relationship between IEEQ traits was 0.96 and external quality explained the internal quality by 91%. The structural reliability of the internal quality was 75.96%, while structural reliability of the external quality was 61.43% (Table 6, Figure 3).

The findings of the fit criteria according to the structural equation model are given in Table 7. When the model fit criteria were examined, it was determined that the model obtained was perfect according to $\chi2$/df criteria and acceptable according to other all criteria (RMSEA, NFI, NNFI, CFI, GFI, AGFI).

Table 4. Confirmatory Factor Analysis results

Factors/Traits	Standard Loadings	t-Values	Structure Reliability	R^2
External Traits (Ext)				
EL	0.54	5.70**		0.29
EWi	0.73	8.27**	75.96	0.53
SW	0.86	10.20**		0.73
Internal Traits (Int)				
AW	0.51	5.18**		0.26
AH	0.40	3.99**		0.16
YD	0.53	5.47**	61.43	0.28
YH	0.27	2.54*		0.072
YW	0.72	7.59**		0.51

*P<0.05; **P<0.01; R^2: Coefficient of determination

Table 5. Compliance measurement for Confirmatory Factor Analysis

Compliance Measurement	Values	Compliance
χ^2/df	38.16/23= 1.66	**
RMSEA	0.076	*
NFI	0.90	*
NNFI	0.95	*
CFI	0.95	*
GFI	0.92	*
AGFI	0.88	*

[*]Acceptable; [**]Perfect

Table 6. Structural Equation Model results

Factors/Traits	Standard Loadings	t-Values	Structure Reliability	R^2
External Traits (Ext)				
EL	0.54	6.96**		0.29
EWi	0.73	5.23**	75.96	0.53
SW	0.86	5.53**		0.73
Internal Traits (Int)				
AW	0.51	5.18**		0.26
AH	0.40	3.99**		0.16
YD	0.53	5.47**	61.43	0.28
YH	0.27	2.54*		0.072
YW	0.72	7.59**		0.51
Int ⟶ Ext	0.96	7.11**	-	0.91

*P<0.05; **P<0.01; R^2: Coefficient of determination

Table 7. Compliance measurement for Structural Equation Model

Compliance Measurement	Values	Compliance
χ^2/df	38.16/23= 1.66	**
RMSEA	0.076	*
NFI	0.90	*
NNFI	0.95	*
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GFI	0.92	*
AGFI	0.88	*

[*]Acceptable; [**]Perfect

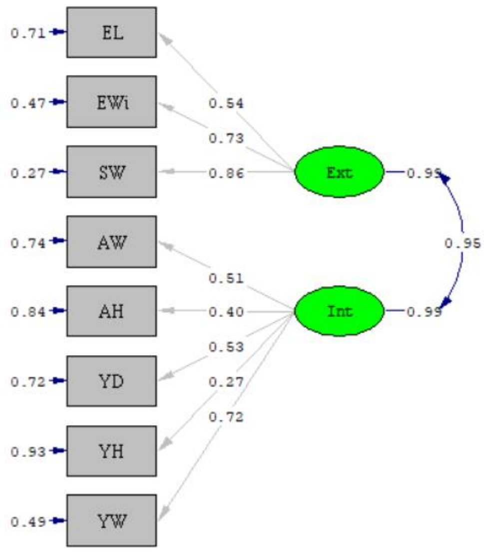

Figure 2. Confirmatory Factor Analysis results

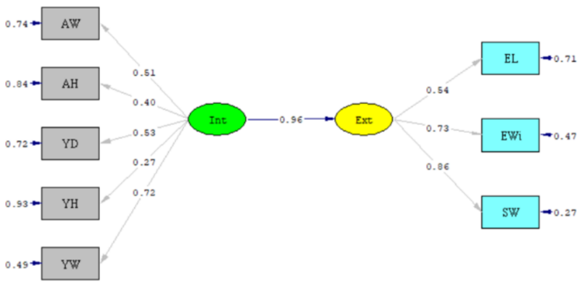

Figure 3. Structural Equation Model result

Discussion

Eggs are of the highest quality at the time of laying and impossible to increase afterward (Mauldin 2002). For this reason, studies have accelerated for the preservation and sustainability of egg quality since laying time. It is important to determine the most important criteria used in quality evaluation and the relationships between the criteria to ensure this quality protection. Some studies have examined the effect of egg storage on quality. Feddern et al. (2017) reported that higher egg quality (first week) was mainly associated with higher EW and specific gravity, Haugh Unit, and AH. Sarica et al. (2012) reported that the most effective parameters in genotypes were the breaking strength and shell thickness among the egg external quality traits, and the AH, albumen index and Haugh Unit among the internal quality traits.

Hrnčár et al. (2017) reported that egg weight, egg shape index, yolk percentage, egg shell (ES), albumen weight and YW increased, while ES and albumen percentage decreased with the advancing of the laying period. In addition, studies have been carried out on the determination of egg quality in different laying hen breeds (Freitas et al. 2017; Saribas and Yamak 2020).

In our study, SW and EWi were among the external qualities; YW, YD, and AW were determined as the most influential parameters among internal quality traits. Egg quality criteria can be determined by considering external quality traits, primarily among these variables. In addition, according to the result of the structural equation model, it was determined that a one-unit change in external quality variables would cause a 0.96-unit change in internal quality variables. It has been determined that the SEM used in this study is sufficient to explain the relationship between internal and external quality. The results of this study can contribute to increasing the internal and external quality of both hatching and table eggs.

Conclusion

Eggs have a large share in human nutrition, health and the commercial sector. For this reason, studies should be reliable and applicable first. In previous studies, the relationships between IEEQ traits were examined by correlation analysis and the results were interpreted. However, in this study, the relationship between the variables explaining the IEEQ were examined with the SEM, which is used especially in social sciences, and found to be applicable. As a result, it was determined that while the SW had the highest importance and explanatory power in the external egg quality, the YW had the highest importance and explanatory power for the internal quality. Also, a significant correlation (0.96) was found between IEEQ traits. It is thought that the use of different variables in addition to the variables used in this study and the determination of such relationships for eggs obtained from different poultry breeds and species will contribute to the literature.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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