Modeling Internal Quality Parameters of Shell Eggs under Temperature and Relative Humidity Interaction

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Abstract

The study was to model and predict relationships among internal quality parameters of eggs stored under varying temperature and relative humidity combinations. A total of 192 chicken eggs was used. 48 randomly selected eggs were assigned to each of the four temperature and relative humidity combinations (ambient temperature 29^{o}Cx normal RH 60%; ambient temperature29^{o}Cxhigh RH 80%; refrigeration temperature10^{o}Cx normal RH 60%; refrigeration temperature10^{o}Cx high RH) stored for 8 weeks. 6 eggs were randomly selected weekly from each group and thereafter their albumen pH, haugh unit, albumen index and yolk index were determined. Linear and quadratic functions of simple regression were fitted to ascertain how the Albumen pH could predict other internal quality parameters of Haugh unit, Albumen index and Yolk index. Results showed that Haugh unit and Albumen index were best predicted by eggs' Albumen pH at refrigeration and normal RH (p <0.01) storage. The corresponding R^2 of 0.90 and 0.86 from quadratic and linear functions from albumen index showed that the total variation in this internal quality parameter is explained by the albumen pH. Yolk index was not predicted from albumen pH at ambient temperature by 60% or 80% RH storage. The study also revealed that relation of either haugh unit or albumen index with albumen pH is curvilinear. The quadratic regression consistently had higher R^2 across four treatment groups. Finally, haugh unit and albumen index can be predicted from albumen pH within 8 weeks of storage under refrigeration temperature at either 60% or 80% relative humidity conditions.

Keywords: *Albumen Index; Albumen pH; Haugh unit; Prediction; Yolk Index*

1.Introduction

Egg is a valuable product in human nutrition, trade and livelihood provision. Its quality expression is particularly important for food safety and standard. Egg Quality defines those characteristics of an egg that affect consumers acceptability and preference (Chambers et al., 2017; Hisasaga, Griffin and Tarrant, 2020). The quality of shell eggs can be determined externally through the shell and internally by focusing on the content (Niekerk, 2014, USDA, 2020). These internal and external descriptions of egg quality are altered over storage time and given environmental conditions around the food product (Feddern et al., 2017; Dong et al., 2017; Oliveria et al., 2020). Among several other factors that affect egg quality, temperature and relative humidity have widely been noted (Yimenu, Kim and Kim, 2017; Yimenu, Koo and Kim 2018; Fikin, Akterian and Staakov ,2020).

Given the deteriorative nature of shell eggs during storage, especially in tropical environments, using models to predict their quality parameters will be very helpful in standardization, food safety and trade facilitation. Modeling has been an essential tool in studying the importance, effects and prediction of parameters in agricultural systems science (Jones et al., 2016). However, several studies exist on modeling egg quality, some dwell on isolated influences of environmental factors using correlational studies (Du et al., 2018; Yimenu et al., 2018) use of kinetic modeling to egg quality (Yimenu et al., 2018) more recently with logistic model to shelf-life prediction (Quan et al., 2021) and through principal component analysis and artificial neural network (Malfatti et al., 2021). Important as these insight into the effects of individual factors remain, understanding how their combined interactions exert influence on quality of egg would no doubt be more revealing. Akter et al., (2014) had asserted that interactions of environmental factors on egg quality were not fully understood. In experimental studies, interaction effect of treatments is relevant in determining results of treatments on experimental units as well as dependent variables. As an attempt to fill this gap, the present study examines the relationships of various internal quality parameters of egg under different combined effects of temperature and relative humidity during storage. This study is considered important to Nigeria because of the varying temperature and relative humidity that is conditioned by its tropical location and current climate change that invariably exert formidable influence on quality deterioration of shell eggs.

During the storage of shell eggs, changes in physical, chemical, biological, and functional characteristics of egg albumen constituents may occur principally due to storage conditions such as time, temperature, and relative humidity (Yimenu et al., 2018). The albumen pH can be used as an indicator of the albumen quality of eggs (Scott and Silversides 2000). Freshly laid eggs have albumen pH of about 7.6 with an optimum that range from 7.5 – 8.5 and this increases to 9.5 during storage (Caner et al., 2015). The pH affects the structure of ovomucin in the thick albumen (a reflection of the quality of albumen) which leads to loss of its viscosity resulting from evaporation of moisture and increased release of CO_2 in the albumen (Matthew et al., 2016).

2.Materials and method

2.1. Experimental Area

The experiment was carried out at the Animal Science Laboratory of Federal College of Education (Tech) Umunze, Anambra state, Nigeria. Umunze is located within latitude 5^o 58` 0`` N and longitude 7$^o$ 14` 11`` E. The area is situated within the tropical rain forest belt.

2.2. Egg collection and storage

Eggs used for this study were collected from 34 weeks old Bovan brown layers raised in a commercial farm at Awka, Anambra state, Nigeria. These layers were housed in deep litter and fed a commercial layer ration. The birds received additional light to provide 16hrs of light and

8hrs of darkness. The total of 192 eggs were collected within 2hrs after they were laid with sterile hand gloves. Eggs were divided equally into 4 groups of 48 eggs each and placed in separate plastic basins. Two of these basins were further placed in bigger plastic bowls containing 2 litres of water each. These bigger bowls were then tightly covered with their lids. This was done to provide moisture necessary to achieve a higher relative humidity. Thereafter, a set of eggs contained only in a plastic bowl but not immersed in water and one immersed into bigger moist bowl were stored in a refrigerator. A second set was kept in a ventilated room at ambient temperature. The plan resulted to four treatments:

1. Ambient temperature + normal RH (T_1)
2. Ambient temperature + high RH (T_2)
3. Refrigerated temperature + normal RH (T_3)
4. Refrigerated temperature + high RH (T_4)

Six (6) eggs were sampled weekly from each treatment combination for internal quality examination. The storage period was for 8 weeks giving storage durations of 7, 14, 21 28, 35, 42, 49, and 56 days.

2.3. Temperature and relative humidity measurements

The instrument used for measuring temperature and relative humidity was the 4 in 1 professional digital meter (Anemometer, thermometer, hygrometer and light meter). The model specification is LUTRON LM 8000. Ambient temperature was determined as the mean of the maximum temperature readings of the thermometer at three consecutive weekly samplings when the 4 in 1 digital meter was placed at the level of the egg basins in the ventilated storage room. This value was calculated as 29^{o}C. Refrigeration temperature was determined as the reading of the thermometer when the 4 in 1 digital meter was placed inside the refrigeration compartment. The value recorded was 10^{O}C.
Normal RH was determined as the mean of the maximum RH readings of the hygrometer at three consecutive weekly samplings when the instrument was placed inside the egg basin without water. The mean value of RH determined was 60%. High RH was determined as the mean of the maximum RH readings of the hygrometer at three consecutive weekly samplings when the 4 in 1 digital meter was lowered into the big bowl containing water and to which an egg basin was immersed. The value was determined as 80% (All measurements were according to the specification of LUTRO LM 8000).

2.4. Internal egg quality determination

2.4.1. Albumen pH measurement

The pH of the albumen was measured with a pH meter (Schott ® cg840, Hofheim, D (6238) after calibration of the electrode with buffeted solution of pH 7 and 10. The buffer solution used is Tris-EDTA-BORATE Electrophoresis buffer manufactured by AFIS Bio chemicals. The albumen was carefully separated from the yolk of the broken egg and the pH meter probe inserted into the thick albumen as the stabilized reading was measured and recorded. Between eggs, the probe was cleaned with distilled water. This was done in line with standard methodology reports (Tona et al., 2013).

2.4.2. Haugh unit (HU)

To determine HU, eggs are weighed using a balance, then broken out and then the albumen height measured midway between yolk and the edge of the albumen with the Vernier caliper. Individual HU (Haugh, 1937) score was calculated as:

$$HU = 100\log(H + 7.57 - 1.7w^{0.37}) \quad (1)$$

Where: w = egg weight in gram

H = height of albumen in mm

2.4.3. Albumen index (AI)

Albumen index is calculated according to Singh and Panda (1987) as:

Albumen Index = Albumen height/ (Albumen length +Albumen width)/2 (2)

2.4.3. Yolk index (YI)

Following Funk (1948) Yolk index is estimated as:

Yolk index = Yolk height/Yolk width (3)

The height (cm) was measured as the highest of the yolk at the midpoint with a Vernier caliper, while the yolk width (cm) was measured as the widest horizontal circumference with a Vernier caliper.

2.5. Model specification

Simple regression analysis was used to ascertain the weight and direction of the explanatory variable (X) on the dependent variable (Y) making allowance they may be correlated. The albumen pH was selected as the explanatory variable due to the fact that change in pH of albumen is expected to have influence on the other internal quality parameters of egg (haugh unit, albumen index, yolk index) which were the respective dependent variables. Additionally, Albumen pH is expected to be influenced by storage duration of the egg. The albumen pH was then also regressed against storage duration as explanatory variable at various temperature and relative humidity combinations. Linear and Quadratic functional forms were estimated and explicitly stated respectively in equations 1 and 2 as:

$$Y = \beta_0 + \beta_1 X + e \quad (4)$$

$$Y = \beta_0 + \beta_1 + \beta_2 X^2 + e \quad (5)$$

Where:

Y – dependent variables as defined earlier

β_0- intercept

$\beta_1$and β_2 – regression coefficients

X – explanatory variables as defined earlier

e – error term

3.Results and discussion

The results on regression equations for linear (y_1) and quadratic (y_2) functions for other three internal egg quality parameters (haugh unit, albumen index and yolk index) as well as the various models coefficient of correlation are shown on Table 1, Table 2 and Table 3 respectively, while those for Albumen pH and length of storage were in Table 4. The graphical representations of Haugh unit, Albumen index and Yolk index under four treatment groups of temperature by relative humidity combinations were shown respectively in figures 1,2 and3.

3.1. Relationship between haugh unit and albumen pH

There were highly significant ($p < 0.01$) correlation between haugh unit and albumen pH when eggs were refrigerated at normal RH level (Table 1). However, the result showed a significant ($p<0.05$) relationship between these two parameters of egg quality for eggs in storage at ambient temperature by high RH treatment. The r between haugh unit and albumen pH at ambient temperature by normal RH, though strong was not statistically significant ($p > 0.05$). The coefficient of determination R^2 for linear and quadratic functions (0.96 and 0.97) were highly significant ($p<0.01$) at refrigeration temperature and normal relative humidity of egg storage. The quadratic functions generally yielded higher percentage values of total variation in the HU that is explained from albumen pH and which were represented as 40.67%, 77.68%, 96.90% and 72.82% when compared to 38.67%, 70.05%, 95.65% and 72.83% of their counterpart linear functions across all treatments (Table 1).

Table 1. Correlation and regression of haugh unit (y) against albumen pH (x) at different temperature by relative humidity conditions.

Functions	Regression equation	Coefficient of correlation (r)	Coefficient of determination R^2	SE	p	SIG
Ambient temperature + normal RH						
Linear function	$y_1 = -147+25.8x$	0.62NS	0.38	12.8	0.099	NS
Quadratic function	$y_2 = 18.8x^2-255x+891$	0.62NS	0.41	12.8	0.271	NS
Ambient temperature +high RH						
Linear function	$y_1 = -276+45.6x$	-0.84*	0.70	13.8	0.029	*
Quadratic function	$y_2 = -25.3x^2+407x-1550$	-0.83*	0.78	13.8	0.024	*
Refrigeration temperature + normal RH						
Linear function	$y_1 = -6.75+147x$	-0.98**	0.96	1.49	$2.62e^{-05}$	**
Quadratic function	$y_2 = 1.22x^2-26.9x+229$	-0.97**	0.97	1.49	0.0002	**
Refrigeration temperature + high RH						
Linear function	$y_1 = -6.78+149x$	-0.85*	0.73	1.60	0.025	*
Quadratic function	$y_2 = 0.148x^2-9.21x+158$	-0.85*	0.73	1.60	0.038	*

NS = Not significant; * = $p < 0.05$; ** = $p < 0.01$

Table 2. Correlation and regression of albumen index (y) against albumen pH (x) under the four temperature by relative humidity conditions.

Functions	Regression equation	Coefficient of correlation (r)	Coefficient of determination R^2	SE	p	SIG
Ambient temperature + normal RH						
Linear function	$y_1 = -0.15+0.026x$	0.59NS	0.36	0.0133	0.25	NS
Quadratic function	$y_2 = 0.054x^2-0.79x+2.86$	0.60NS	0.51	0.0133	0.17	NS
Ambient temperature +high RH						
Linear function	$y_1 = -0.29+0.047x$	-0.83*	0.68	0.015	0.011	*
Quadratic function	$y_2 = -0.011x^2+0.20x-0.82$	-0.82*	0.70	0.015	0.051	*
Refrigeration temperature + normal RH						
Linear function	$y_1 = -0.016+0.25x$	-0.94**	0.86	0.0036	0.0006	**
Quadratic function	$y_2 = 0.004x^2-0.085x+0.53$	-0.93**	0.90	0.0038	0.003	**
Refrigeration temperature + high RH						
Linear function	$y_1 = -0.014+0.24x$	-0.81*	0.66	0.0035	0.014	*
Quadratic function	$y_2 = 0.00168x^2-0.042x+0.35$	-0.81*	0.66	0.0035	0.065	*

NS = Not significant; * = $p < 0.05$; ** = $p < 0.01$

Table 3. Correlation and regression of yolk index (y) against albumen pH (x) under the four temperature by relative humidity conditions

Functions	Regression equation	Coefficient of correlation (r)	Coefficient of determination R^2	SE	p	SIG
Ambient temperature + normal RH						
Linear function	$y_1 = -0.122+0.032x$	0.20NS	0.04	0.04	0.62	NS
Quadratic function	$y_2 = 0.19x^2-2.86x+10.5$	0.21NS	0.19	0.05	0.59	NS
Ambient temperature +high RH						
Linear function	$y_1 = -0.37+0.070x$	0.33NS	0.11	0.05	0.43	NS
Quadratic function	$y_2 = -0.13x^2+1.96x-7.07$	0.31NS	0.25	0.05	0.49	NS
Refrigeration temperature + normal RH						
Linear function	$y_1 = -0.039+0.79x$	-0.79*	0.63	0.01	0.019	*
Quadratic function	$y_2 = -0.019x^2-0.28x-0.51$	-0.80*	0.69	0.01	0.045	*
Refrigeration temperature + high RH						
Linear function	$y_1 = -0.029+0.70x$	-0.65NS	0.42	0.009	0.083	NS
Quadratic function	$y_2 = -0.025x^2+0.38x-0.96$	-0.66NS	0.51	0.009	0.170	NS

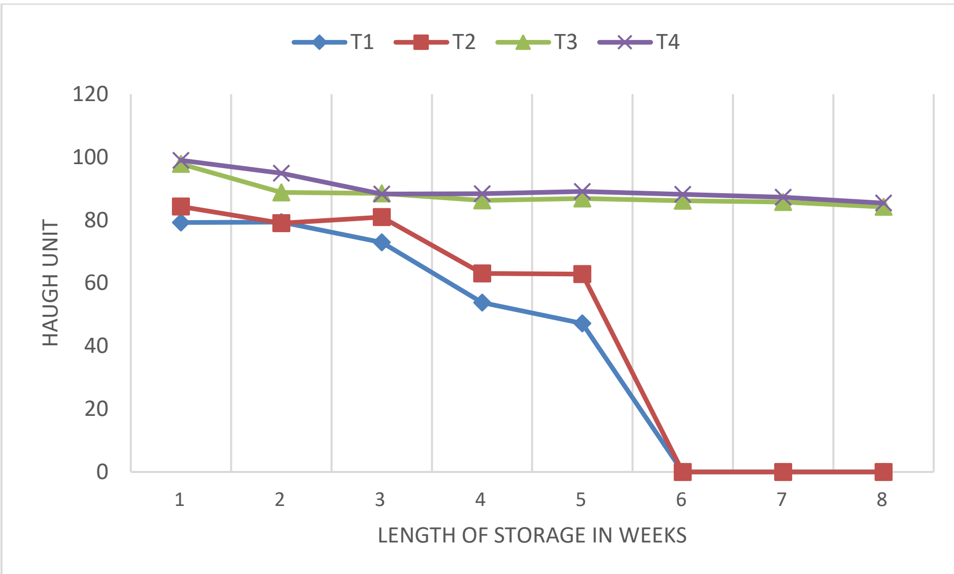
NS = Not significant; * = $p < 0.05$

Table 4. Correlation and regression of albumen pH (y) on length of storage (days) (x) at different temperature by relative humidity conditions

Functions	Regression equation	Coefficient of correlation (r)	Coefficient of determination R^2	SE	p	SIG
Ambient temperature + normal RH						
Linear function	$y_1 = 8.09 – 0.026x$	0.51NS	0.26	0.308	0.198	NS
Quadratic function	$y_2 = -0.001x^2+0.086x+6.79$	0.70NS	0.50	0.308	0.178	NS
Ambient temperature +high RH						
Linear function	$y_1 = 8.05 – 0.031x$	0.75*	0.56	0.253	0.033	*
Quadratic function	$y_2 = -0.001x^2+0.56x+7.04$	0.87*	0.76	0.254	0.025	*
Refrigeration temperature + normal RH						
Linear function	$y_1 = 7.80+0.028x$	0.78*	0.61	0.216	0.022	*
Quadratic function	$y_2 = -0.008x^2+0.081x+7.18$	0.84*	0.70	0.216	0.043	*
Refrigeration temperature + high RH						
Linear function	$y_1 = 7.92+0.024x$	0.70NS	0.49	0.203	0.051	NS
Quadratic function	$y_2 = -0.0009x^2+0.078x+7.28$	0.78NS	0.61	0.203	0.086	NS

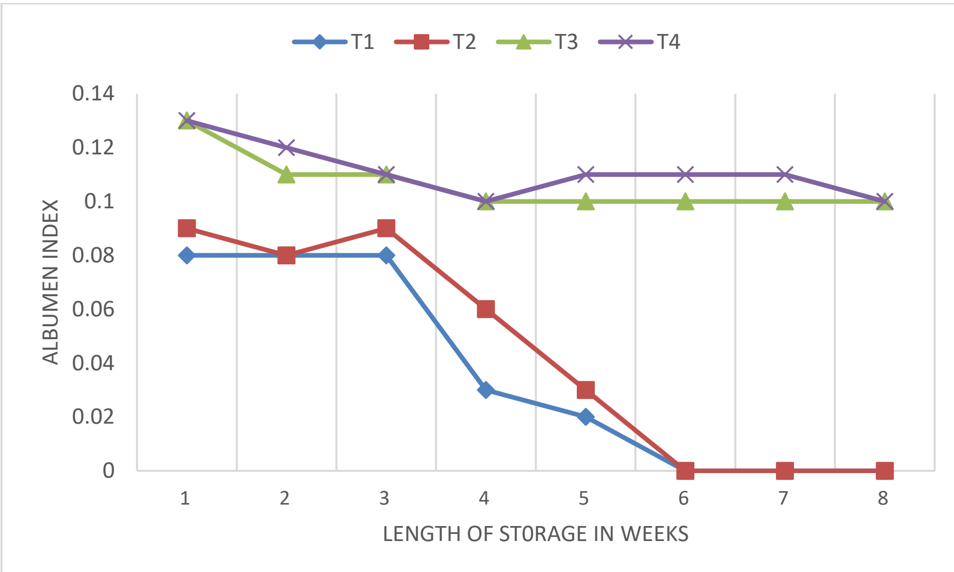
NS = Not significant; * = $p < 0.05$;

Figure 1. Relationship between haugh unit and storage duration as function of temperature and relative humidity condition.



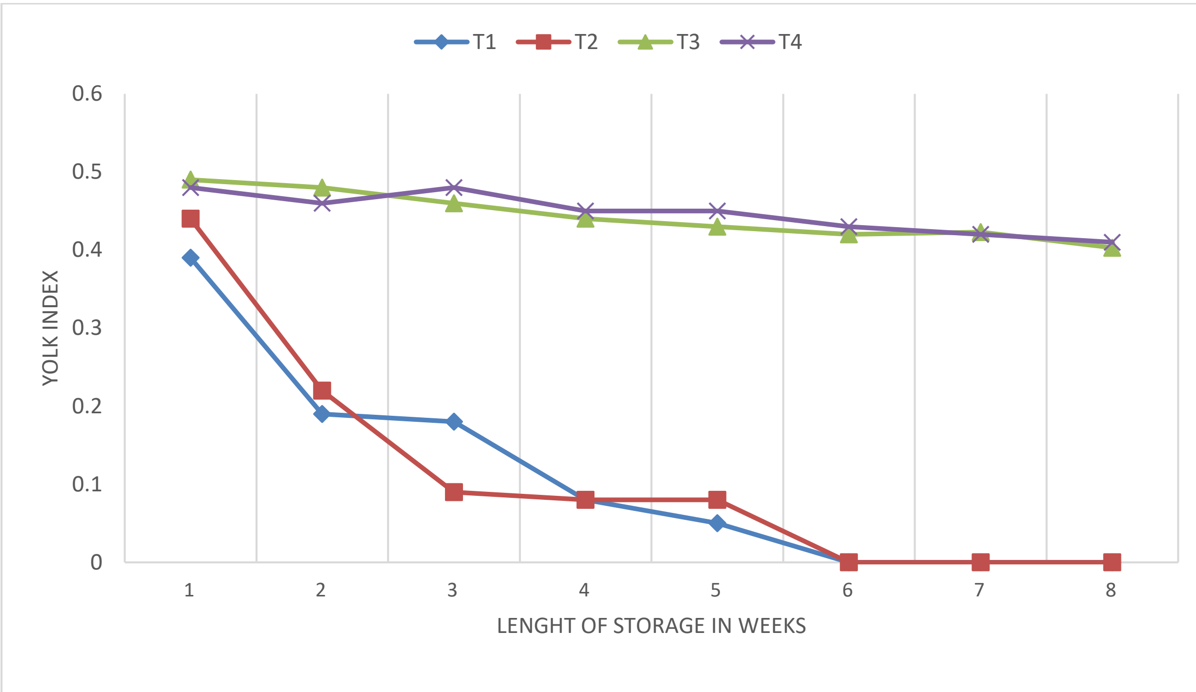
T_1 – Ambient temperature + normal RH, T_2 – Ambient temperature + high RH
T_3 – Refrigerated temperature + normal RH; T_4 – Refrigerated temperature + high RH

Figure 2. Relationship between albumen index and storage duration as function of temperature and relative humidity condition



T_1 – Ambient temperature + normal RH, T_2 – Ambient temperature + high RH
T_3 – Refrigerated temperature + normal RH; T_4 – Refrigerated temperature + high RH

Figure 3. Graph of yolk index against storage duration as function of temperature and relative humidity conditions



T_1 – Ambient temperature + normal RH, T_2 – Ambient temperature + high RH
T_3 – Refrigerated temperature + normal RH; T_4 – Refrigerated temperature + high RH

3.2. Relationship between albumen index and albumen pH

In Table 2, the coefficients of correlation between albumen index and albumen pH were also generally strong across the four treatments. The relationships were similar to relationship observed between haugh unit and albumen pH in Table 1. The r values at ambient temperature by normal RH were not statistically significant ($p > 0.05$) whereas at high R.H and on both levels of temperature (ambient and refrigeration), R-values were significant ($p < 0.05$). The R-values at refrigeration temperature by normal RH were highly significant ($p < 0.01$). The significance of regression equations maintained similar pattern with coefficients of correlation observed across all treatments. The R^2 values were generally higher for quadratic functions than for linear functions.

3.3. Relationship between yolk index and albumen pH

The coefficients of correlation between yolk index and albumen pH were weak and not statistically significant ($p > 0.05$) at ambient temperature by normal RH and ambient temperature by high RH whereas at refrigeration and high RH storage, their relationship recorded higher r values, but was not statistically significant ($p > 0.05$) (Table 3). However, these two parameters had R value that was significant at storage under refrigeration and normal RH. The R^2 for the quadratic functions were generally higher compared to that of linear functions across all the treatments.

3.4. Relationship between albumen pH and length of storage

Table 4 shows the correlation and regression relationship between albumen pH and length of storage. The coefficient of correlation (r) between these two egg quality determinants were positively high across the four treatments. The r value at ambient temperature + normal RH and refrigeration temperature + high RH were not significant ($p>0.05$), whereas eggs stored at ambient temperature + high RH and refrigeration + normal R H showed statistically significant R-value. This non-significance in correlation of this quality indicator and length of storage that is independent of temperature and relative humidity conditions may not be clearly explained but may point to the fact that there is always change in albumen pH irrespective of storage environmental conditions. The coefficient of determination (R^2) for the quadratic equations in the model showed consistently higher values across the four treatment groups when compared with their counterpart linear functions. This indicates that the relationship between Albumen pH and storage duration of eggs is better fitted in a non-linear function.

Conclusion

Haugh unit, albumen index and yolk index as internal quality parameters of eggs at varying temperature and relative humidity combinations (29^{o}c x 60%; 29^{o}c x 80%; 10^{o} c x 60% & 10^{o} c x80%)of storage can be predicted from the albumen pH with a curvilinear regression model. Although, a more precise result of these internal quality values will be predicted when eggs are under refrigeration storage (10^{oC}) and at relative humidity ranging between 60-80 per cent. Again, graphical representations of haugh unit and albumen index of eggs under the four treatments during storage in Figures 1 and 2 had shown that Haugh unit and albumen index will consistently yield similar results and graphical pattern in internal quality over storage periods. The implication of using both is therefore indicative of repeating parameters that measure the same internal quality factor of shell eggs

Conflict of Interest

The author disclosed no conflict of interest.

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