THE DEVELOPMENT OF THE WATER LOADED PRESSURE METHOD FOR MEASURING EGGSHELL QUALITY

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Summary

A water loaded pressure device using water as the breaking froce was developed to evaluate eggshell strength and compared with a dropping ball techniques. Further, relationships of shell thickness and weight of eggs to shell strength were also studied. Values for both of the shell strength measuring methods showed a highly significant correlation ($p < 0.001$) with shell thickness. The water loaded pressure method had a much higher simple correlation coefficient for shell thickness ($r = +0.786$) than the dropping ball method ($r = +0.577$). The shell strength measured by the water loaded pressure method appeared not to be correlated to egg weight. On the other hand, the negative sign of the standard partial regression coefficient and the partial regression coefficient of egg weight in the estimated multiple regression equation implied that for a given shell thickness a larger egg tended to have less shell strength than a smaller egg.

(**Key Words** : Eggshell Thickness, Water Loaded Pressure, Eggshell Quality)

Introduction

A dropping ball apparatus had been used to evaluate shell strength in our laboratory. However, difficulties and variations in measuring shell strength by means of the impact methods (Tyler, 1961; Tyler and Geake, 1963) made it desirable to develop another method. A device using water as the breaking force was therefore developed.

This experiment was conducted to compare the two methods, the dropping ball and the water loaded pressure methods. Furthermore, the relationships between egg size, shell thickness and shell strength as measured by these two methods were studied.

Materials and Methods

Over 200 eggs were collected from commercial type flocks fed practical diets. The eggshells were observed visually and the cracked eggs were discarded. Of these, 100 eggs were used for shell strength measurement by means of the water loaded pressure method and an equal number for shell strength measurement by means of the dropping ball method.

Data from both methods were analyzed by means of correlation coefficients and multiple regression analyses (Steel and Torrie, 1960).

Water loaded pressure method

After being weighed individually, the 100 eggs were subjected to shell strength measurements using the water loaded pressure device shown in figure 1.

The apparatus consisted of a rigid frame supporting a round steel bar 12.7 mm in diameter. A light plastic water container (D) weighing 73.5 grams hung from the end of the bar (C). The water container was connected to a reservoir through very soft, thin rubber tubing (E). The equipment was built in such a way that the equator of the egg was pressed against the breaking bar (B) when the egg platform (I) beneath the egg was adjusted (J) to where the water was not interrupted as long as the egg withstood the pressure. The pressure on the egg was gradually increased by water flowing into the container. Upon shell failure, the water flow stop pinched the tubing and

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Received February 4, 1996
Accepted August 22, 1996

automatically stopped the water flow.

The water was measured with a graduated cylinder assumed to have a specific gravity of 1.000. The weight of the bar at C with the empty bottle (D) in place was determined at the outset of the work and considered to be constant. Shell breaking strength was determined as follows ;

Breaking strength in kg =

$$\frac{\text{ml water} + \text{weight at C (g)}}{1{,}000} \times \frac{D_1}{D_2}$$

where D_1 is distance from A to C, D_2 is distance from A to B.

From the equator of the cracked eggs, a piece of shell without the membrane was removed. The shell thickness was determined using a micrometer screw gauge (FHK, Ozaki Co.).

Dropping ball method

A dropping ball device was also used to measure the shell strength. The equipment was a modified version of that described by Mueller (1959).

It was designed to allow for dropping a steel ball bearing 9.52 mm in diameter and weighing 3.52 grams from increasing heights on the equator of the egg until the shell cracked. Each height increase was 12.5 mm, and the height of the drop at which the shell cracked or was dented recorded as breaking strength.

A piece of shell without membrane was taken from the equator area of the cracked egg and its thickness was measured as before.

Results

The relationships of shell thickness and egg size to breaking strength as measured with the water loaded pressure device are presented in table 1. The simple correlation coefficients between shell thickiness and breaking strength, egg weight and breaking strength, and shell thickness and egg weight were + 0.786, + 0.034 and + 0.197, respectively. The shell thickness was highly correlated with the eggshell strength ($p < 0.001$), but the egg size appears not to be correlated. The correlation coefficient of +0.197 for egg weight and shell thickness is not significant. This value is higher than that of +0.05 to +0.07 reported by Richards and Staley (1967), but somewhat lower than +0.26 to +0.34 reported by Frank et al. (1964).

A measure of the strength of the relationship between variables given by $100 \cdot r^2$ indicates that about 62% of the total variation in breaking strength was accounted for by the shell thickness. Only a negligible portion of variability was explained by the egg weight. Egg size accounted for

TABLE 1. RELATIONSHIP BETWEEN SHELL THICKNESS, EGG WEIGHT AND BREAKING STRENGTH OBTAINED WITH THE WATER LOADED PRESSURE METHOD ON 100 EGGS

Parameters		Shell thickness (X_1)	Egg weight (X_2)	Breaking strength (Y)
Means ± SD		33.4±3.0 (10^{-2} mm)	65.2 ± 4.6 (g)	3.12 ± 0.62 (kg)
Simple correlation coefficients	X_1	1.000		
(r)	X_2	0.197	1.000	
	Y	0.786**	0.034	1.000
$100 \cdot r^2$	X_1	–		
	X_2	3.9	–	
	Y	61.8	0.1	–
Standard partial regression coefficients		$b_1' = +0.815$	$b_2' = -0.126$	
Multiple regression equation		$\hat{Y} = -1.413 + 0.169X_1 - 0.017X_2$		
Multiple correlation coefficient (R)		+0.797		
Coefficient of determination ($100 \cdot R^2$)		63.6		

** Significantly different ($p < 0.01$).

only 4% of the variation in shell thickness.

The multiple correlation coefficient of + 0.797 indicates that about 64% of the total variation in breaking strength was explained by the two variables, shell thickness and egg weight. The two standard partial regression coefficients of + 0.815 for shell thickness and − 0.126 for egg weight reveal the importance of shell thickness in predicting shell strength. The standard partial regression coefficients for egg weight (−0.126) indicates the lesser importance of its role in predicting shell strength.

A multiple regression equation includes the partial regression of shell strength on shell thickness (b_{y1} = + 0.169) and on egg weight (b_{y2} = − 0.017). On the other hand, negative signs of standard partial regression coefficient and partial regression of egg weight in the multiple regression equation imply that for a given shell thickness a larger egg has a lower shell strength than a smaller egg.

A significant correlation coefficient of + 0.577 between shell thickness and the height of ball drop was obtained with the dropping ball method (table 2). This is in good agreement with the value of + 0.581 reported by Tyler and Geake (1963). Frank et al. (1964) obtained a high value of + 0.73 in the first trial of a dropping ball device similar to that used in this study, but obtained a low value of + 0.35 in a second trial with the same technique. They considered this variation a large experimental error in measuring shell strength.

The analysis of data disclosed that thickness accounted for only about 33% of the total variation in resistance of the eggshell to cracking. This value is much lower than that of 62% obtained with the water loaded pressure method.

TABLE 2. RELATIONSHIP BETWEEN SHELL THICKNESS AND CRACKING STRENGTH OBTAINED WITH THE DROPPING BALL METHOD ON 100 EGGS

Parameters	Shell thickness (X)	Height of ball drop (Y)
Means ± SD	34.9 ± 3.0 (10^{-2} mm)	11.9 ± 2.0 (cm)
Correlation coefficient (r)	+ 0.577**	
Linear regression equation	$\hat{Y} = -1.23 + 0.38X$	
$100 \cdot r^2$	33.3	

** Significantly different ($p < 0.01$).

Discussion

In our studies, the eggshell strength was highly correlated with the shell thickness. These results are similar to those reported by some other workers (Frank et al., 1964; Richards and Swanson, 1965; Gaisford, 1965) regardless of the presence of membrane on the eggshell when measuring shell thickness. Carter (1970) stated that the structural strength of an eggshell was derived from two variables, the shell thickness and shape, and thus the structural strength of an eggshell was a function of the average curvature and thickness of the eggshell at the loading point. For instance, an increase in radius of shell curvature at the loading point resulted in reduction of shell strength. According to him, this was considered a partial reason for egg breakage increases with the age of hens. This was also in part an explanation for the narrow pole of the egg having greater breaking strength than the broad pole, as had been reported by Tyler and Geake (1963).

The percentage of the total variation in breaking strength accounted for by the combined effect of shell thickness and egg weight was 63.6%. This result indicates that about 40% of the total variation remains to be explained by factors which are not identified in this experiment. It may be that egg shape and shell membrane thickness might account for a portion of the 40% of the total variation. Richards and Swanson (1965) found that the egg shape index explained 15 to 35% of the variation in crushing strength remaining after shell thickness had been considered. Carter(1970) also considered egg shape as an important factor in determining eggshell strength. Even though Frank et al. (1965) did not find any correlation of membranes to shell failure, a contribution of the membrane to the shell strength has been noted (Godfrey, 1949; Vandepopuliere et al., 1974; Britton, 1977).

Values for the water loaded pressure method have a higher simple correlation coefficient for shell thickness and breaking strength than those for the dropping ball method. This indicates that shell thickness accounts for a higher percentage of the total variation in the shell strength measured with the water loaded method than in the shell strength measured with the dropping ball device. The low value with the dropping ball device is thought to be partly due to poor precision and to variation in visible surface. As described in the Materials and Methods section, 12.5 mm increments in height of drop were used and this allows for less precision than measuring the mass of water in the water loaded pressure method. Furthermore, it was observed that a 3.52 g ball bearing causes various types of damage - a very small circular crack, a little dent, a very small linear crack which was almost invisible with the naked eyes or a fairly large linear crack far from the impact spot. It is felt that these two factors are largely responsible for the lower correlation coefficient with the dropping ball method than that with the water loaded method. In addition, Tyler and Geake (1963) pointed out that the cracking strength was affected by a summation of blows of different strength. They previously reported that rotating the egg slightly after each blow did not eliminate the discrepancy unless the egg was rotated at least 90°.

The water loaded pressure method avoids some of the difficulties found in the dropping ball method, but has its own drawbacks. Elasticity of the water tubing at the point of compression (F and G in figure 1), water temperature and shape of egg might influence breaking strength. Further, in studies of various types of shell strength measuring devices, Tyler and Geake (1963) found that when dynamic loading methods were applied to three different parts of an egg (waist, broad pole and narrow pole), the waist was the strongest and the narrow pole was the weakest for a given shell thickness, while when the static loading methods were used, the opposite order was observed. This suggested that different characteristics were observed by the two types of measuring devices. In spite of these shortcomings, these two techniques seemed to be feliable methods of measuring shell strength and thus can be used in the shell quality studies.

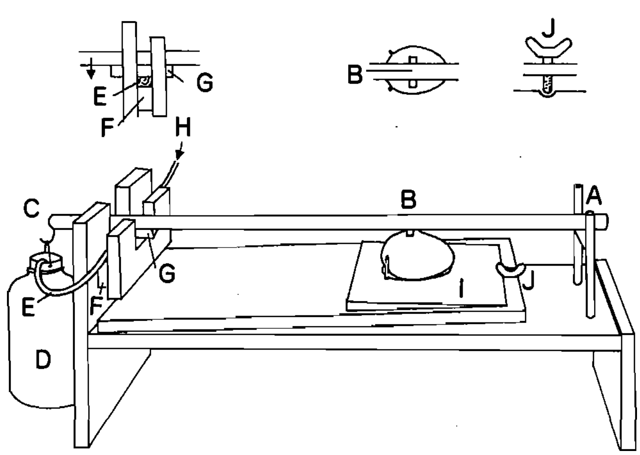

Figure 1. Shell breaking strength measuring device (water loaded pressure method).
A, fulcrum: B, breaking bar: C, hook for water bottle: D, water bottle: E, rubber tubing: F, rubber tubing rest: G, water flow stop: H, water reservior: I, egg platform: J, egg platform adjusting screw.

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