Relationship Between Shell and Shell Membrane Strength and Other Egg Shell Characteristics

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ABSTRACT There was a significant difference in the shell strength of chicken eggs with different curvatures of the large end. Holding temperatures of eggs significantly influenced shell strength but not shell membrane strength. There was a significant negative correlation in chicken eggs between shell strength and membrane strength in small and medium curvature groups but not in the large curvature group. Shell strength was positively correlated with shell thickness. A positive correlation was found in turkey eggs between membrane strength and length-width ratio and between shell strength and shell thickness.


INTRODUCTION

Egg breakage which occurs accidentally in market channels between the producer and consumer has been estimated to be 3% of the total eggs produced in the United States. This breakage amounts to an annual loss of $25 million (Anonymous, 1966). In addition to this financial loss, there is also the public health hazard associated with bacterial contamination of cracked eggs.

Numerous studies have been conducted to determine relationships and correlations between shell quality and other variables known to influence egg quality and shell strength. Presently no method is completely satisfactory for evaluating egg shell strength or quality which is adaptable to commercial use.

There are several factors which influence the strength of egg shells. According to Peterson (1965) genetic strains, rate of production, diet of the hen, age of bird and environmental temperatures affect shell quality. Shell strength has been determined primarily by crushing, impact and puncturing. Romanoff (1929), Stewart (1936), Heuser and Norris (1946), Godfrey (1949), and Brooks and Hale (1955) determined egg shell strength by measuring the force necessary to crush the egg.

Tully and Franke (1934) and Baskett et al. (1937) used a puncturing device to measure shell strength. An impact-type of device was employed by Hale (1956) and Mueller (1957) to measure shell strength. James and Retzer (1967) and Wilson et al. (1968) developed a technique for measuring shell quality whereby they could electronically count the number of emitted beta particles that were returned from a given area of shell in a specified length of time. They reported significant correlations between shell strength and the counts obtained.

Many studies have been undertaken to correlate shell strength with other variables of the egg including the shell. Frank et al. (1964) determined the interrelationships among specific gravity of the intact egg, shell thickness, percent of egg as shell, shell weight, and egg weight to the force required to break the shell with a crushing or an impact-type device. All of these factors demonstrated a high degree of correlation to the crushing or impact strength of the egg shell. They found that the better estimators of shell strength were shell thickness, specific gravity and shell weight. However, despite the high correlations found between shell strength and the other variables, these variables accounted for only 60 percent of the variation in resistance to egg shell breakage.

Frank et al. (1965) studied the relationships among selected chemical properties of eggs, such as the amounts of calcium, carbonates, sialic acid, and protein content of the shell and shell membrane to the resistance of breaking egg shells. They concluded that none of these constituents attributed to the large percentage of variations found in the breaking resistance of egg shells. They concluded that none of these constituents attributed to the large percentage of variations found in the breaking resistance of egg shells. The percentage membrane of egg shells did not show any significant effect upon resistance to shell failure.

Lund et al. (1938), using a crushing and puncturing-type device, reported a coefficient of correlations of +0.633 ± 0.021 between shell...
thickness and the crushing resistance of eggs, and of +0.835 ± 0.011 between puncturing resistance and egg shell thickness. Richards and Swanson (1965) showed that egg shape, expressed as shape index, was independent of shell thickness but accounted for 15 to 35 percent of the variability in crushing strength remaining after shell thickness had been considered. Wilhelm (1940) noted seasonal variations in egg size and shell strength. A definite seasonal trend in egg shell thickness was correlated with temperature. It was also reported that ambient temperature exerted an influence on the dry weight of the shell and on the percentage shell of the total egg weight.

This study was undertaken to determine the relationship among shell strength, shell membrane strength, shell thickness, and length-width ratio of chicken and turkey eggs. The curvature of the large end of chicken eggs and its relationship to shell strength, and the influence of egg temperature on shell strength were also evaluated.

MATERIALS AND METHODS

Eggs used in these investigations were obtained from the Virginia Polytechnic Institute and State University Poultry and Turkey farms. Chicken eggs were from Single-Comb White Leghorns in their eighth and ninth months of production. The hens were housed in floor pens in a layer house. The average ambient temperature during this study was 24—27°C. (75—80°F.) They were fed a corn-soybean-type ration which met all known nutritional requirements. Eggs were collected just before noon each day and generally evaluated the same day. However, in a few cases eggs were held at approximately 5°C. (40°F.) in a household-type refrigerator for two to three days before testing. All eggs were tested for soundness and cracks eliminated.

Turkey eggs were collected from breeder hens while under a light environmental study during their first year of production. They were fed a corn-soybean-type V.P.I. & S.U. breeder ration. Eggs were collected daily, held in an egg cooler at 65°F. and 75 percent relative humidity, and evaluated after 3 to 4 days.

Length-width ratio determinations. Length and width measurements of eggs were obtained using calipers capable of measuring to an accuracy of .001 mm. The length-width ratio of each egg was calculated by dividing its length by its width.

Shell strength determination. Resistance to crushing force on the large end of each egg was determined by using an Allo Shear Press, model SP-12. The Press was set at range 5 with a ram speed of 8. A 113.5 kg. (250 lb.) compression ring was used. Each egg was placed on its small end which fitted into a properly sized donut-shaped rubber disc located on a plate below the ram. The force on the ram required to break the shell was recorded on varian paper.

Shell thickness determination. After the shell strength measurement for each egg was obtained, four pieces of shell were removed, two near each end and two approximately equal distance from the ends but on opposite sides of the egg. Shell thickness was determined using an Ames anvil-jawed micrometer graduated in .000254 cm. (.001 in.). The four measurements were averaged to obtain the mean shell thickness value.

Membrane strength determination. After the shell thicknesses were obtained, four pieces of shell membranes were selected from four areas of each egg and carefully separated from the shell by using a pulling action with the fingers. While the membranes were not examined carefully, it was felt that both inner and outer shell membranes were removed. Areas selected were at the large end, small end and at two equatorial sites opposite each other. Membrane strength was obtained from the same general area of each egg. Water or other solvents which helped in separating membranes from shells during a preliminary test was abandoned due to the general weakening effect they had on the membranes.

Membrane strength was obtained using a device shown in Fig. 1. The instrument consisted of a constant volume and pressure air pump (a), capable of forcing air or pulling a vacuum through a hole in the square shaped metal plate equipped with a rubber pad (b). Centered in this plate and pad was a .047 cm. (3/16 in.) size hole (c), which allowed for a vacuum or air pressure to be applied to a piece of shell membrane (d), held in place by a second metal plate equipped with a rubber pad (d). The shell membrane was positioned centrally between the two plates and the two plates were held firmly together by vice grips during the time the membrane strength was being obtained. The device was attached to a closed-end 203 cm. (80 in.) range mercury manometer (f), by high pressure tubing equipped with needle values.
brane strength obtained by using air pressure was measured in inches of mercury at the time of membrane rupture. Membrane strength was also obtained by producing a vacuum. However, it was found after using both methods that air pressure was preferable to pulling a vacuum. The four membrane measurements for each egg were averaged.

Storage temperature affects on shell strength. The affect of storage temperature on shell strength and membrane strength was investigated. Forty-five chicken eggs were randomly assorted into three equal groups and one group each was held overnight at room temperature, in a walk-in-cooler held at 0°C (32°F.) and in a household refrigerator at 5°C. (40°F.). Each group of refrigerated eggs was broken immediately after removing from the holding areas.

Egg shell curvature as a possible variable. The curvature of the large end of the egg was considered as a possible variable which might influence shell strength. To investigate this possibility, three egg curvature groups were selected using an air cell gauge, Fig. 2. Eggs with a small curvature were defined as those whose large end fit loosely into this gauge. Medium curvature eggs were those that fit snugly into the curvature of this gauge and large curvature eggs were those that were too large to fit into the air cell gauge. Forty-five chicken eggs were evaluated for each group. All eggs were at room temperature when broken.

During the investigation another method of breaking eggs and determining shell membrane strength was tested. Single measurement and Shear Press ram modification. It was felt that it might be possible to obtain even more accurate values and correlations among shell strength, membrane strength and shell thickness if the measurement sites of these three could coincide as closely as possible with each other. Due to the inability of making multiple shell strength measurements for each egg with the instrument being used, only one measurement was made for shell thickness and membrane strength.

It was also felt that the curvature of an egg might influence the shell breaking strength when using a ram with a flat surface. To overcome this possibility, the ram of the Allo Kramer Shear Press was fitted with a centrally located convex probe 0.95 cm. (6/16 in.) long with a diameter equal to size to the holes in the metal plates of the membrane strength apparatus, Fig. 3. This probe was used to puncture a specific area of the egg where shell curvature variations among eggs would be considered minimal. This modification also allowed for the measurement of shell and membrane areas of the same diameter as that of the hole in the plates and of the ram probe.
Another method of determining membrane strength was used since upon close examination of the membrane prior to rupture, a small volume of air passed through the porous shell membrane. Validation of this escape of air through the membrane was observed by noting that smoke or a colored gas would pass through the membrane upon application of air pressure or vacuum. It was felt that this escape of gas might tend to alter the membrane strength by enlarging the pore size and/or by causing a drying effect on the membrane.

An alternate method for measuring shell membrane strength was tested. This method consisted of using a device to hold the membrane and then using the ram probe of the Allo Kramer Shear Press to puncture the membrane, Fig. 4.

The device consisted of two metal cylindrical cones machined so that one would fit precisely over the other. Running lengthwise through the cones was a 0.65 cm. (4/16 in.) diameter hole allowing the 0.47 cm. (3/16 in.) diameter ram probe to extend partially into the cones to rupture the shell membranes. The shell membranes were positioned between the cones allowing for a tight seal. To minimize the possibility of obtaining inaccurate membrane strength due to the compression of air exerted by the probe, a small hole was made through the two cones below the membranes to allow air to escape, Fig. 5.

Statistical analyses. Values obtained from testing the influence of storage temperatures and shell curvatures on shell and membrane strengths were treated to Analysis of Variance according to the method of Snedecor (1956) and by Multiple Range Test, Duncan (1955). Correlation coefficients were calculated among the variables-length-width ratio, shell strength, membrane strength, egg weight, and shell thickness. In order to study the relationship between each pair of variables while adjusting for the effect of the variables not being considered, partial correlation coefficients were determined according to the method of Graybill (1961). This procedure was used to measure the linear relationship between two of the variables while in effect holding the other variables constant.
TABLE 1.—Measurements of chicken eggs of three shell curvatures, 45 eggs for each group

<table>
<thead>
<tr>
<th>Shell curvature</th>
<th>Shell strength¹</th>
<th>Shell thickness</th>
<th>Membrane-strength¹</th>
<th>Length-width ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(units)</td>
<td>(mm.)</td>
<td>(cm.)</td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>53.1ª*</td>
<td>0.30ª*</td>
<td>28.9ª</td>
<td>1.45ª**</td>
</tr>
<tr>
<td>Medium</td>
<td>46.6b</td>
<td>0.31ª</td>
<td>26.7ªb</td>
<td>1.39b</td>
</tr>
<tr>
<td>Large</td>
<td>47.1ªb</td>
<td>0.33ªb</td>
<td>23.4ªb</td>
<td>1.32c</td>
</tr>
</tbody>
</table>

¹ Egg shells were broken using probe on ram, membrane strength on Shear Press using new device.
² Values with different superscripts are different *P<.05, **P<.01.

The correlation coefficients of shell strength and membrane strengths were found to be similar in chicken eggs between the two methods (data not shown). As a result, values obtained by the two methods were combined. Correlation coefficients were obtained for shell curvature groups in chicken eggs but not in turkey eggs.

RESULTS AND DISCUSSION

The results obtained from measuring different characteristics of eggs of three shell curvatures are shown in Table 1. Shell thickness increased but membrane strength decreased as shell curvature increased which suggests that a compensating effect might exist between these two variables. There was a significant difference in shell thickness between the small and large curvature eggs but not between small and medium curvature groups. A significant difference was noted in membrane strength between small and large eggs but not between small and medium eggs and between medium and large eggs.

The length-width ratios decreased as the egg curvature size increased. As expected there was a highly significant difference in the length-width ratios of the three curvature groups. Shell strength was significantly greater in small eggs than in medium or large eggs. These results suggest that eggs should either be divided into curvature groups when shell strengths are to be determined or that equal numbers of different curvature groups be used.

Shell strengths and membrane strengths of eggs held overnight at three different tempera-

TABLE 2.—Measurements of chicken eggs held overnight at three different temperatures, 15 eggs for each group

<table>
<thead>
<tr>
<th>Holding areas and temp.</th>
<th>Shell strength¹</th>
<th>Membrane strength¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(units)</td>
<td>(cm.)</td>
</tr>
<tr>
<td>Room temp., 25°C</td>
<td>29.2ª*</td>
<td>44.5</td>
</tr>
<tr>
<td>Walk-in cooler, 0°F</td>
<td>36.6b</td>
<td>45.2</td>
</tr>
<tr>
<td>Household refrig., 5°C</td>
<td>31.6ªa</td>
<td>48.0</td>
</tr>
</tbody>
</table>

¹ Egg shells broken using flat surface of ram, membrane strength by air pressure.
*Values with different superscripts are different at the .05 level of probability.

TABLE 3.—Partial correlation coefficients of different measurements of chicken egg curvature groups

<table>
<thead>
<tr>
<th></th>
<th>S.S.¹</th>
<th>S.T.</th>
<th>M.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.S.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-W ratio</td>
<td>-.1912</td>
<td>-.1028</td>
<td>.0792</td>
</tr>
<tr>
<td>S.S.</td>
<td>...</td>
<td>.5364**</td>
<td>-.3672**</td>
</tr>
<tr>
<td>S.T.</td>
<td>...</td>
<td>...</td>
<td>.2841</td>
</tr>
<tr>
<td>L-W ratio</td>
<td>-.0984</td>
<td>-.3085**</td>
<td>-.1807</td>
</tr>
<tr>
<td>S.S.</td>
<td>...</td>
<td>.3361**</td>
<td>-.2411*</td>
</tr>
<tr>
<td>S.T.</td>
<td>...</td>
<td>...</td>
<td>-.0857</td>
</tr>
<tr>
<td>L-W ratio</td>
<td>-.2433*</td>
<td>-.4353**</td>
<td>-.1182</td>
</tr>
<tr>
<td>S.S.</td>
<td>...</td>
<td>.3322**</td>
<td>-.1954</td>
</tr>
<tr>
<td>S.T.</td>
<td>...</td>
<td>...</td>
<td>.0967</td>
</tr>
</tbody>
</table>

**P<.01.
*P<.05.
tures are reported in Table 2. Eggs held at room temperature (25°C), in a walk-in cooler (0°C), and in a household refrigerator (5°C), had shell strength values of 29.2, 36.6 and 31.6, respectively. Shell strengths were similar between eggs held at room temperature (25°C) and those held in a household refrigerator (5°C), but these two groups were significantly different from eggs held in a walk-in cooler (0°C). Differences were noted in membrane strengths of eggs held at the three temperatures. However, these differences were not significant.

Partial correlation coefficients of the different measurements of chicken eggs divided into curvature groups are shown in Table 3. In small eggs, there was a highly significant positive correlation (.5564) between shell strength and shell thickness, and a negative correlation (−.3672) between shell strength and membrane strength. In medium eggs, a highly significant negative relationship was noted between the length-width ratio and shell thickness (−.3085), and between shell strength and membrane strength, (−.2411). A positive correlation (.3361) was found between shell strength and shell thickness.

In large eggs significant negative correlation (−.2433) was found between the length-width ratio and shell strength and a highly significant positive correlation (.3322) between shell strength and shell thickness. A negative correlation (−.4353) was noted between length-width ratio and shell thickness. The correlation coefficients between shell thickness and membrane strength in the three groups were not significant.

It appears from these results that differences in the length-width ratios and/or in the curvature of the eggs could have an influence on the significance between these egg measurements.

As shown in Table 4, there was a .005 level of negative correlation coefficient (−.2240) between length-width ratio and membrane strength of turkey eggs. A positive correlation (.1696) significant at the .025 level, was noted between shell strength and shell thickness. There was no significant relationship in turkey eggs between any of the other measurements tested.

These results suggest that there are different degrees of relationships among these measurements of turkey and chicken eggs. Also, it appears that shell breaking strength and membrane strength could be influenced by factors such as breed, size of egg or other factors not yet identified.

REFERENCES

Lund, W. A., V. Heiman and L. A. Wilhelm, 1938. The


