METHODS OF MEASURING EGG SHELL QUALITY

by

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B. S., Kansas State University, 1957

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Dairy and Poultry Science

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

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TABLE OF CONTENTS

INTRODUCTION

Egg shell quality is becoming increasingly "spotlighted" as the poultry industry becomes aware of the great losses incurred because of checks, leakers and other shell defects. As methods of gathering eggs are mechanized, and increasing numbers of eggs are cleaned by "in-line" washers, and as breeders continue to put more importance on high egg production, shell quality problems that did not exist a few years ago, are causing great concern for producers, handlers, distributors, retailers and consumers. Egg quality at the time of oviposition is at its maximum. No handling procedure or storage condition can improve initial quality. Since interior quality depends somewhat upon exterior quality for its preservation, and since interior quality depends entirely upon shell quality for its physical protection, it can be seen that shell quality not only encompasses the factor of maintaining the wholesomeness and desirability of the egg, but it is also the vehicle in which the egg is carried to the ultimate consumer.

In order to study and improve shell quality, certain tools are necessary to allow comparisons between different levels or frequencies of shell quality determinations. To improve a factor, it must be measurable, to insure that advancements will be noted. The tools for determining shell quality are many and diverse, ranging from the simple comparisons by "belling" or comparing color, to the new and sophisticated breaking devices employing electro-magnets, vacuum, and even hydrostatic pressure. Many of these are too simple and give too general a guide to be worthy of anything but a passing mention. Still others are very good in so far as quality of data is concerned, but are so complicated and slow to employ, their use is also very limited.

OBJECTIVES

The objectives of this report are two-fold:

(A) To present a review of literature concerning methods and procedures of measuring shell quality, including a summary comparing these methods and procedures. This summary will include those methods not employed in Part B of the experimental work conducted by the author. Those methods which are included in the author's study and literature review pertaining to these techniques will be discussed in detail in the results and discussion of the basic work. The review of literature will first consider reports which present the historic, or general interest point of view, and then compare reports which actually make comparisons between shell quality measuring methods.

(B) To offer an original comparison of three methods of measuring shell quality, (1) shell thickness, (2) specific gravity, and (3) percent shell. In addition, a comparison will be made between percent shell and egg weight. Correlation coefficients, regression lines, means, standard deviations and regression equations will be presented for the measurements involved. The works of other authors will be discussed and compared to the findings of this report. Although breaking strength is a valid and relatively accurate method, and even though it makes up a large segment of the literature review, it was not included in the original experimental work. The reason was that it is extremely difficult to construct an apparatus capable of giving suitable data. This statement can be verified by the report of Tyler and Geake (1963), who constructed six impact devices and one crushing device in an effort to obtain what they considered a suitable apparatus.

REVIEW OF LITERATURE

Shell Thickness

Willard and Shaw (1909) were among the first to report actual measurements of shell thickness, using .010 of an inch as the increment of measure. Herrasti (1916) reported an average shell thickness of .013 to .014 of an inch. Fronning and Frank (1958) recorded an average thickness of .014 of an inch.

The average thickness of shell seemed to correspond with the average crushing strength, according to Waite (1921). A range of from .30 to .43 mm was reported. Romanoff (1929) also used millimeters as the unit of measurement, as did Lorenz (1952), Harms (1961), Mueller (1962), Perek and Kendler (1963), and Moreng et al. (1964). All the mean shell thickness readings reported by these workers were between .26 and .43 mm.

Lund, Heiman and Wilhelm (1938) took measurements on the small and large ends of the eggs. Six readings were taken by Warren and Schnepel (1940), one on the pointed end, one on the blunt end, two on the sides of the pointed half and two on the sides of the blunt half. The mean of these six readings was recorded as the shell thickness for each shell. Wilhelm (1940) reported measurements at points around the middle of each egg, as did Carson, Eaton and Luginbuhl (1954), Griminger and Scott (1954), Fronning and Frank (1958), Harms and Waldroup (1961), Singsen et al. (1962) and Mueller (1962). Measurements were taken at both ends and at the middle or waist by Campos, Wilcox and Shaffner (1962), while Perek and Kendler (1963) measured at unspecified points on the shell. Two points on the equatorial plane were measured by Heywang and Lowe (1962) and Heywang, Reid and Kemmerer (1964).

There was no general agreement of work reviewed as to the question of shell thickness measurements with or without shell membranes. Hays and Sumbardo (1927) took readings excluding membranes, as did Evans, Carver and Brant (1944), Sizemore et al. (1953) and Wilson (1949). Those authors who measured thickness with membranes, included Berg and Bearse (1951) and Mather, Epling and Thornton (1961). Brant and Shrader (1952) suggested that for the sake of ease and speed of measurement, the membranes should be left intact. Tyler and Geake (1961) admitted that removal of the membranes poses a difficult problem, particularly where large numbers and frequent measurements are involved, but suggested that for truly accurate data, shell membranes should be removed.

Several instruments for performing shell thickness recordings have been used, including the screw micrometer and the thickness gauge. Hays and Sumbardo (1927) used the screw micrometer, as did Holst, Almquist and Lorenz (1932). Evans, Carver and Brant (1944), Berg and Bearse (1951) and Mather, Epling and Thornton (1961) employed the micrometer, but all mentioned their instrument had a convex or rounded anvil. Siesmore et al. (1953) and Sullivan and Kingan (1962) used a paper thickness gauge, while Lund, Heiman and Wilhelm (1938) had a micrometer with a convex anvil attached directly to the machine uesd for measuring breaking strength. Harms and Waldroup (1961) reported the use of a Starrett ratchet-stop micrometer calibrated in millimeters.

A description and illustration of the method for modifying a paper thickness gauge manufactured by the B. C. Ames Company, was given by Brant and Shrader (1952). The flat jaws were filed or smoothed with an emery wheel. The authors cautioned to place the rounded jaw on the surface of the egg shell and to record shell defects such as wrinkles, ridges, rough areas and body checks, along with shell thickness.

Welch, Waggoner and Gilbreath (1960) compared two devices, a Lufkin anvil micrometer and an Ames No. 25 E thickness gauge. A correlation coefficient of .860 was established between the first and second micrometer dry readings, while the first thickness gauge dry measurement had a correlation of .759 with the second thickness gauge dry measurement. This indicated the micrometer may have been more precise than the thickness measuring gauge and that fewer replications were required to obtain the same information.

Brant, Otte and Chin (1953) reported that egg breakage during marketing increased rapidly when shell thickness dropped below .013 of an inch. Shrader (1954) stated that if the egg shell is to carry its contents to market it must measure at least .015 of an inch.

Breaking Strength

Although few details were outlined, Willard and Shaw (1909) may have been the first to publish data concerning strength of egg shells, reporting on a specially devised machine which ascertained the weight necessary to perforate the shell. A drawing as well as a detailed description, were furnished by Herrasti (1916), of an apparatus for measuring the breaking strength of eggs. He was greatly impressed with the marvelous strength of the shells ". . . so great that no man, no matter how strong he may be, is able to break a sound hen's egg by squeezing it between his hands, applying the pressure according to the axis of the egg". The device included, among other cumbersome equipment, a large jack and a platform scale (capable of weighing several hundred pounds). He reported breaking pressure of 155 pounds for brown eggs and 112.5 pounds for white eggs.

Waite (1921) explored the area of the weight in grams necessary to crush the egg when positioned on its side. This test was made with a balance scale which admittedly ". . . was not a delicate instrument for the purpose but seemed to be accurate enough for all practical purposes." A range from 2341 to 4200 grams was reported, and the conclusion was reached that average shell thickness seemed to correspond with the average of crushing strength.

Kennard (1925) used a machine originally designed for testing breaking strength of bones. Eggs were placed endwise in sockets shaped to distribute the pressure over a considerable area, and also against a flat surface, instead of the sockets. In both cases, the eggs were against 1/16 inch rubber pads. The crushing strength ranged from 16.3 to 39.0 lb. An apparatus employing a pair of spring balances and a carpenters clamp was employed by Alder (1927). The small end of the egg was placed on a small padded depression in the center of a wooden lever arm, and the large end of the egg in a simular depression in a block of wood attached to the clamp. One end, free to move, was attached to the hook of the balance. The depression for the egg was at the center between these two points. Pressure was applied by tightening the clamp until the shell broke. The reading on the spring balance was recorded at that point in pounds of pressure.

A number of workers have used either the exact version or modifications of a machine described in detail by Romanoff

(1929). A flat surface was employed on which the egg rested vertically. A long platform calibrated in kilograms along its length had one end fixed, but free to rotate, and its other end rested on the upper pole of the egg, and presented a flat surface to it. Pressure on the egg was increased by slowly drawing a weighted trolley along the platform from the fulcrum toward the egg. The position of the trolley was noted when the egg cracked. Eggs usually broke at either one pole or the other and rarely at both simultaneously. Romanoff made a few tests in which the pressure was applied at the sides of the egg instead of at the ends, and reported that the average breaking strength of egg shells was less by 1 to 2 kg if the eggs were broken in the former position. The highest breaking strength was found to be 8.5 kg, while the average for 3,998 eggs was 4.46 kg.

A rather poor quality photograph which showed a machine with a piece of wood resting on the side of the egg, was furnished by Morgan, Mitchell and Roderick (1930). A plunger, free to move vertically, was forced down upon the block when water was poured into a cylinder. Thus, the weight of the block, plus the weight of the plunger, plus the weight of the water, totaled the breaking strength for the particular egg. Although few details were noted as to the apparatus employed, Morgan (1932) reported a correlation coefficient of .493 for White Leghorn eggs and .533 for Barred Plymouth Rock eggs, between breaking strength and percent shell. Breaking strength was determined by gradually increasing the weight applied to the egg at right angles to the long axis until the shell cracked.

Larro Research Farms (1932) used illustrations to demonstrate an egg shell testing device. According to the photographs, it consisted of a cylinder, resting immediately above the egg, which was filled with glycerine. The lower end of the cylinder was a circular rubber diaphragm. Constant pressure was exerted upon the egg from top to bottom by screwing down the plunger located inside the glycerine filled tube. The pressure was thus transmitted to the glycerine, the diaphragm and finally to the egg. The weight at which the egg cracked was recorded on a dial of the gauge in pounds per square inch and was considered the breaking strength for the egg tested which ranged from 10 to 300 lb.

Cracking strength was determined by Swenson and James (1932) with a device which dropped steel balls from increasing heights until cracking occurred. This force was expressed as "dynes", which was defined as the mass of the steel ball, multiplied by the velocity at which it was traveling at the time of impact. It was concluded, from comparing this cracking method with shell thickness readings, that there was a positive association between the thickness of the egg shell and the force in "dynes" necessary to break the shell.

Tully and Franke (1934) constructed an apparatus which increased the pressure to the blunt end of the egg by increasing the steady flow of zinc shot into a container. A baffle at the end of the funnel through which the shot fell, broke the force of gravity. Just at the instant the 1 mm diameter rod punctured the egg, the flow of shot was stopped by a trip. The egg rested on a rubber support which gave a fairly large supporting area to the egg. Each egg was punctured three times and the mean of these was considered the breaking strength reading for each egg. Thick shelled eggs gave a clean puncture, while thinner shelled eggs gave radiating cracks, as well as the usual puncturing.

Baskett, Bryden and Hale (1937) as quoted by Tyler (1962), used a flat ended, cylindrical pin, 1 mm in diameter, which pressed against the waist of the egg resting in a depression on a wooden block. Increasing air pressure, read off a gauge, was transferred through a syringe barrel to a piston to which the pin was attached. Results were recorded only when a clean hole was formed. Cracked eggs were discarded, and for the remaining, it was possible to obtain up to eight readings around the latitude of a single egg.

Again quoting from Tyler (1962), Edin, Helleday and Anderson (1937) described a device in which a brass weight was counterimposed by a cylinder which contained water. The lower end of the egg rested in a socket in a stand, and the upper end fitted into another socket in the base of the weight. When water was syphoned from the cylinder, the brass weight produced an ever increasing pressure on the egg until it crushed. The crushing strength was then given by the weight of the water removed from the cylinder.

A photograph published by Stuart and Hart (1938) showed a scale fastened to a platform which also supported a spiral gear-wheel arrangement. A wooden holder for supporting the egg in an upright position was placed on the scale and adjustments were made to compensate for the weight of the holder. An egg was placed in position and downward pressure was applied by turning a wheel which moved a rod until it began to press the egg. This pressure was transferred through the egg and the balance pointer registered the necessary strength to effect breakage. This force was expressed in pounds.

In an effort to simulate the shock encountered under conditions of handling and transportation in market channels, Kennard (1945) used eggs in a group-test. The apparatus included a carriage which accommodated up to 25 eggs. This carriage slid down an incline and came to an abrupt halt at a buffer block at the lower end of the track. All eggs were pre-tested for breakage, by belling the eggs together, and tested again by this same method, following the carriage test. From this, the percentage of eggs cracked by the "ride" was calculated.

Lillie and Thompson (1947) constructed an egg shell-breaking apparatus consisting of an ordinary 25 lb balance with a small block placed on top. This block had a depression which held the egg under a specially constructed lever which was used to apply pressure to the eggs.

Two separate approaches to breaking strength methods were reported by Novikoff and Gutteridge (1949). The first was termed the penetrometer method, in which a needle was brought into contact with the end of an egg and force applied until the shell was punctured. The applied force was read directly from a scale on which the egg rested. The second, the breakage method, included dropping the egg from rest through gradually increasing heights, until breakage occurred. The egg weight times the distance it fell, was considered as the index of the force at the point of breakage. The authors reported a consistently high positive correlation of approximately .70 between specific gravity, penetrometer and breakage methods, while a low negative correlation was obtained between percent moisture loss and the other three methods.

According to Tyler (1962), Hale (1954) employed an apparatus with a vertical glass tube of 7.8 mm diameter (inside dimensions) and a steel ball 7.2 mm diameter and 1.482 gm in weight. The ball was raised by means of a magnet which was moved up the outside of the tube. When the magnet was quickly withdrawn, the ball fell. The egg was held firmly against the bottom of the tube and the ball was dropped from a height of 14 cm. The height of fall was increased 2 cm at a time until cracking took place. The ball was never allowed to strike the same point on the egg twice, but fell on a succession of points around the middle of the egg, each about 1 cm apart.

The end point, that is, the height of fall which produced a crack, was judged by sound, but since this was open to question, a further drop of the ball resulted in the ball not bouncing, thus confirming that a crack had indeed occurred. Hale used the Standard formula to calculate the value in dynes, or in some cases, simply took the height of fall as the cracking record.

A constantly increasing load was applied at the rate of 100 gm per second to an egg lying lengthwise between two parallel plates by Brooks and Hale (1955). The machine recorded the increasing load applied to the egg at the two opposed points on its equator, and the diminution in distance between the two plates during loading. The authors stated the egg shell appeared to resemble metallic surfaces in that the real area of contact was nearly proportional to the applied load.

Rauch (1958), as reported by Tyler (1962), used a machine which employed a hand wheel attached to a screw with two plates. The egg rested between these plates and was crushed when pressure was applied by turning the screw. One plate pushed against a spring, thus providing even pressure on both sides of the egg. The pressure required to break the egg was read on a scale calibrated in kilograms.

Thornton and Moreng (1958) determined breaking strength by simply finding the percent of eggs with sound shells. The eggs were first candled, and then lightly "belled" together to determine shell soundness. Statistical analysis showed this was a reliable method of determining shell quality.

A variation of the falling ball technique was employed by The Thornber Bros., Ltd. (1960), again quoting from Tyler (1962). A series of balls of increasing weight were allowed to fall in succession from a fixed height onto the egg until it cracked. The cracking point was then stated according to the number of the ball in the series. It was not disclosed whether or not the balls were allowed to strike the egg at the same point on successive falls.

Bowman and Challender (1963) checked the eggs tested at three farms where they were produced and rechecked them at the packing station 20 miles distant. The eggs were subsequently subjected to the breaking strength test which consisted of dropping a sequence of balls of increasing weight from a fixed height of 4 3/8 inches onto the equatorial region of the egg which was positioned over a candling lamp. No attempt was made to see that the balls in the sequence hit a different place or the same point on the shell. There was a maxium of seven balls in a series ranging in weight from 2.03 to 8.35 gm. The number on the ball which produced the first crack in the egg was the break number score for that egg. Shell thickness of these eggs was measured by the method of Tyler and Geake (1961). Shell thickness measurements were closely correlated, both genetically and phenotypically, to measurements of percentage of cracks, when the correlations were based on variety means.

Tyler and Geake (1963) in a study of shell strength measuring devices described several instruments which used either impact, (which allowed an object to strike the egg) or crushing, whereby a gradually increasing load was applied to the egg. The first apparatus described employed an alloy plummet weighing two grams, which fell down a vertical glass tube of 1.28 cm internal diameter and struck the waist of the egg. The egg was not placed tightly against the mouth of the tube so the air pushed in front of the falling weight could escape and not influence impact. The plummet was attached to a string and could be dropped from various heights according to a meter rule fastened to the tube, by merely releasing the thread. The height of the final drop of the plummet was considered the cracking strength. A second device, almost identical to the above, was constructed to speed up the work, but it gave much higher readings and therefore, the two devices, with such divergent results, were not considered suitable for general use. The only explanation for the discrepancy of results for the two machines was that the first apparatus had .13 cm clearance between the plummet and the tube while the second had only .10 cm clearance.

A second method, using a free-falling object without the glass tube, was decided upon in order to overcome the shortcomings of the first method. This device used ball bearings, instead of the flat based plummets, each ball weighing 1.040 or 1.041 gm. The ball was dropped by a small electro magnet attached to a movable arm, after being firmly secured over the egg according to a plumb line. The ball rebounded to about 70% of its original height if the egg did not crack, but only a small rebound was noted with the blow which cracked the egg. This method was satisfactory, but was abandoned since two variables were introduced, making a more complicated mathematical treatment of the data necessary, namely, the distance of drop and the number of drops necessary to complete cracking. The authors believed the cracking process was affected by a summation of blows of different strengths and that each successive blow affected the cracking produced by the final blow. Rotation of the egg was tried in order that each blow struck the egg in a different position varying from .5 to 2.0 cm apart. The final crack always ran along the line of previous blows suggesting that previous blows influenced cracking strength.

Because of the above difficulties, a third method was developed which employed dropping the ball from a constant height and counting the blows required to produce cracking. This required, first of all, determining the height which would produce cracking with a reasonable number of blows. A compromise distance of 25 cm drop was decided upon. Then, it was noticed the ball failed to hit exactly the same point with each drop. This was tested by the use of a smoked plate on which the impact produced a clear circle about 1 mm in diameter with a minute black dot at its center. With 10 drops, some overlap occurred, but usually, 7 or 8 distinct circles could be identified, indicating a scatter pattern of as much as 1 mm. The explanation for this pattern was the electro-magnet trigger evidently produced a slight and variable horizontal motion as the ball dropped when the magnet was switched off.

Because of this random scattering, the authors decided to use an apparatus which would eliminate this problem. They replaced the electro-magnet with a rigidly fixed micrometer having double convex jaws and thus reduced scattering from 25 cm to an absolute minimum. This method was used for several experiments before it was finally replaced by another.

The impact method finally decided upon consisted of a filter pump with a tube having a side arm connected to it, the side arm closed with a clip. Suction from the pump held the 6.3 mm diameter ball into position on the tip of the 5.2 mm internal diameter tube until release of the clip allowed the ball to drop. With this method, it was possible to strike the egg in exactly the same spot with succeeding blows, and also to establish a pattern of desired locations for a series of drops. Determining the point of first blow and deciding what spacing was desirable between blows was all that was necessary to complete a series, either in a straight line or even at right angles to previous blows.

Tyler and Geake (1963) also developed a device to study crushing methods of breaking strength which determined the amount of increasing pressure on the egg, as opposed to the impact devices described above. This involved a beaker resting on one end of an arm and a cup on the other end, the arm resting on a pivot at the exact center. A brass plate was secured over the cup, which made contact with the top of the egg resting in the cup. Very fine lead shot was funneled into the beaker at approximately 10 gm per second, the flow being stopped at the time the egg cracked. The cup, on which the egg rested, insured not only the egg cracked at its uppermost end, but also that measurements could be taken on the other end of the egg if desired. A stop was also provided under the beaker which could be adjusted so extensive damage to the egg could be avoided when the cracking point was reached. The brass plate contacting the egg was also modified to allow a rod or needle to crack or puncture the egg instead of the flat surface of the plate. This apparatus, as stated, allowed for testing either or both poles, but if desired, it could also be adjusted, by simply turning the egg in the cup, to measure pressure necessary to crack the egg at the equator or waist.

In a comparison of the above techniques, it was concluded that with a correlation coefficient of cracking strength and shell thickness of not more than .69, the contribution which thickness makes to strength is not more than 50%. Other factors contributing to strength must account for at least 50%. In cracking studies Tyler and Geake found the waist always showed greater strength than the large pole and the large pole was always stronger than the narrow end. This was the opposite of the findings for crushing methods, which showed the waist to be the weakest, the narrow pole the strongest and the broad end, intermediate. The crushing methods generally gave higher correlation coefficients than cracking methods, but even so, these showed that shell thickness contributes no more than 54% to breaking strength. It was found all methods studied gave a highly significant relationship between strength and thickness, but the magnitude of the correlation coefficient showed thickness only plays a relatively small part in producing a strong shell.

The only explanation offered by Tyler and Geake for the fact that crushing and cracking methods gave different results for a given shell thickness when the waist, broad or narrow pole were measured, was that evidently the two methods (1) breaking by crushing or (2) cracking by impact, are measuring a different characteristic other than thickness. These, it is suggested, may include crystal structure and organic material in the shell, and it is also possible other factors may vary between individual hens and also during the laying season.

Mehring (1949) used a machine with a small windless attached to a movable bar on which a small bolt was secured. The windless was operated and the bolt, which had been filed smooth, exerted pressure against the side of the egg midway between the poles. The pressure applied was read directly on a scale and was expressed in grams necessary to crack the shell. This method allowed cracking without crushing and thus allowed salvage of the intact egg.

Sluka, Besch and Smith (1965) developed a tester which employed a new concept, of increasing the hydrostatic pressure of the egg contents, in so far as measuring shell quality of eggs is concerned. The hydrostatic tester was essentially a holder which permits a leak-proof insertion of a hypodermic needle into the egg. Arrangements were made for introducing water into the egg and for measuring the resulting hydrostatic pressure. This pressure was expressed as pounds per square inch (psi). In comparing results from this method of testing shell strength and other more usual or conventional means, the authors reported a correlation coefficient of .48 between the hydrostatic tester and a dynamic drop or impact method, a figure significant at the probability level of .05. When egg size and shell thickness were compared, a correlation coefficient of .90 was obtained (significant at the .01 level). A regression of egg size to shell thickness, showed a linear relationship; egg size = 14.0 $\pm$ .57 shell thickness. No explanation was offered for the fact that shells of eggs from one hen were the weakest as indicated by drop testing, but were among the strongest when tested hydrostatically. The above indicated that of the two methods of determining shell strength, the pressure test method had a lower coefficient of variation than the drop method, but this value was much greater than for either egg weight or shell thickness. There was, according to this report, a direct linear relationship between egg size and shell thickness.

Porosity

Riezo (1899) as quoted by Romanoff (1929) found the number of pores per square millimeter of shell varied from .86 to 1.44 with an average of 1.23. Dunn (1923) concluded the larger the egg, the smaller the amount of evaporating surface relative to its weight, and the larger the egg the more pervious its shell. The formula used for calculating the surface area of eggs was $AREA = 4.65\sqrt[3]{weight^2}$.

Hays and Sumbardo (1927) used fresh eggs to study porosity in relation to hatchability. The large end of the egg was broken, and the contents removed. The shell with its membranes was washed with tap water and then filled with alcohol eosin and allowed to stand for six hours at room temperature. The stain was poured out and the shell examined with a low power microscope. The number of pores in 20 squares 5x5 mm in size were counted. The number of shell pores per square centimeter of surface in the equatorial region varied from 413 to 601.

Romanoff (1929) was among the first to recognize that size, location and number of pores might be a guide to shell strength and thickness. He reported strong, thick shells have a large number of minute pores, while weak, thin shells have few, but often quite large pores. It was concluded, therefore, that observation of the outer surface for the number and size of pores may guide in judging for breaking strength and thickness of egg shells. Romanoff (1943) seems to contradict this when reporting on the permeability of egg shells, which is directly influenced by porosity, by stating there was apparently no correlation between permeability and the breaking strength of the entire egg or thickness of the shell.

Almquist and Holst (1931) immersed an egg for two minutes in a solution of methylene blue in 95% alcohol (three grams per liter). After staining, the shell was split into halves and the contents removed. When the inside of the shell was wiped dry, a clear and permanent picture of porosity was evident. Almquist and Burmester (1934) subsequently used this method when working with abnormal types of eggs. Glassy shelled eggs tended to be extremely low in shell porosity and because of this, they retained their fresh quality much better.

Bryant and Sharp (1934) counted pores by immersing eggs in water, creating a vacuum and counting the sources of bubbles that came from the eggs. They also employed an apparatus similar to the one described by Romanoff (1929) to compare pores and breaking strength. The correlation coefficient between strength of shell and number of pores was .258 which was small but significant. To determine the effect of pores upon the loss in weight, correlations were made with two groups of eggs. The eggs were stored for 27 and 30 days at 35°C. The correlation coefficients were .45 and .46 for the relation of number of pores to loss in weight. Both values were significant.

Viscometric measurements of the passage of water and air through the shell made by Haines and Moran (1940) showed shells vary widely in porosity, even when taken on successive days from the same hen. There was no significant correlation between porosity, so determined, and the number of shell pores counted by staining methods, but there was a rough correlation between porosity determined by the viscometer and the evaporation of water during storage.

Percent Shell

Jull (1924) expressed shell weight as a percent of total egg weight. The smaller eggs were found to contain a higher percent of shell and percent shell decreased with regularity from the lightest to the heaviest eggs. Martin, Erickson and Insko (1930) included membranes in expressing percent shell. Prior to weighing and calculating percent shell, the shells were dried in an oven at 100°C for 20 hr. Massengale and Platt (1931) washed broken shells with distilled water, placed them in a drying oven for 12 hr at 85°F and determined their weight. Percent shell was calculated on the basis of the weight of the egg 24 hr after oviposition.

Under normal temperature conditions, Bennion and Warren (1933) reported a figure of 9.91% shell, but under high temperature environments, there was a drop of 5.79%. Comparing this to a drop of 5.10% in albumen and an increase of 10.86% in yolk, it was concluded that high temperatures affect percent shell more than the other quality factors examined. Carver et al. (1934) used both air dried and oven dried weights to calculate percent shell. Morgan and Mitchell (1938) used wet shells with adhering membranes to determine percent shell.

Evans, Carver and Brant (1944) allowed shells to dry at 54°C for at least three days, before determining shell weight and calculating percent shell. Calculations for percent shell were made by Polin and Sturkie (1957) after the shells were dried at 105°C for 24 hr, membranes included. Crowley et al. (1961) weighed the shells after they were washed free of adhering albumen and air dried at room temperature for 96 hr. Percent shell was then calculated.

Specific Gravity

Romanoff and Romanoff (1949) defined specific gravity as that value calculated from egg weight and the weight of an equal volume of water. They placed the average specific gravity of fresh chicken eggs at 1.095, while for off-shaped eggs the value was between 1.088 and 1.090. Further, since all eggs lose weight through evaporation of water, a decline in specific gravity occurs following oviposition. This is true of all eggs, regardless of shape, size or shell thickness. The average value for 100 eggs examined by Fronda and Clemente (1934), as quoted by Romanoff and Romanoff (1949), was 1.056, a rather low figure, and evidently, the result of testing eggs which were not newly laid.

Mussehl and Halbersleben (1923) used a commercial device which was on the market at that time, to determine specific gravity as it related to fertility, hatching power and growth of chicks. This "gadget" was later described by Munro (1940) as the "Magic Egg Tester", which its promoters claimed could be used to predict fertility, hatchability and sex of the chick. Actually, it was simply a floater upon which the egg was attached. Higher specific gravity eggs pulled the floater further under the water than lower specific gravity eggs. The scale for the floater was very coarse and indefinite and the specific gravity of the egg could only be determined by properly adjusting for size, the larger eggs pulled the floater further under water than did smaller eggs of the same specific gravity. Mussehl and Halbersleben decided there was little correlation between specific gravity, fertility and hatchability of hens eggs.

Gutteridge and Pratt (1946) used the specific gravity method of Ollson (1934), but also reported use of a value called "adjusted specific gravity." This term was evidently applied to attempt to adjust by regression for the effect of different values for specific gravity at the beginning of the experiment. In a later report, Gutteridge and Novikoff (1947) used the terms "good shell strength" and "high specific gravity" as though they were synonymous. A combination of factors, including specific gravity and number of cracked eggs, was used by Savage et al. (1952). It was found when specific gravity increased, the number of cracked eggs decreased.

Salt solutions ranging from 1.066 to 1.102, with grade intervals of .004, were kept in stoppered bottles and tested each week with a hydrometer, by Gabuten and Shaffner (1954). Specific gravity readings were taken as being the concentration of the salt solution in which the egg just floated below the surface. Anderson et al. (1957) used the method described by Munro (1940) with a range in solutions from 1.066 to 1.088, with range adjustments coincident with changes in the specific gravity ranges of the eggs tested. A class solution interval of .002 was maintained and solutions were standardized prior to each daily trial. Specific gravity solutions ranging from 1.044 to 1.120 with increments ranging from .002 to .005 were reported by Pope et al. (1960), Petersen et al. (1960), Huston and Carmen (1961), Sullivan and Kingan (1962), Arscott, Rachapaetayakom and Bernier (1962), Hunt and Aitken (1962) and Berg, Bearse and Merrill (1964).

MacIntyre, Chancey and Gardiner (1963) reported that as an indicator of actual calcium requirements of laying hens, shell quality, as measured by specific gravity, may be more sensitive and accurate than egg production. Naber, Mackay and Touchburn (1963) measured specific gravity by immersing eggs in saline solutions of known specific gravity, and reported there was no relationship between abnormal eggs and specific gravity. Egg shell abnormalities were expressed as the percent of eggs laid that showed cracks, checks, blind checks, rough texture or extreme porosity.

Egg Weight Loss

Although egg weight loss is closely related to and perhaps caused by porosity, numerous investigators have treated it independently and without regard to porosity in reporting upon shell quality measurements. The formula $AREA = 4.65 \sqrt[3]{weight^2}$ was used by Dunn (1923) to compare egg size and egg weight loss. The relationship was expressed as having two causes: (1) the larger the egg the smaller the amount of evaporating surface relative to its weight and (2) the larger the egg the more pervious the shell.

Godfrey and Olson (1937) used freshly laid eggs to record weight loss in a forced draft incubator at 99.5°F and 60% relative humidity for 14 days. Quinn, Gordon and Godfrey (1945) used this same general procedure and concluded ". . . this method has a distinct advantage because weight loss can be determined under strictly comparable conditions of moisture and temperature in the incubator. It is a simple, total score method, of measuring shell quality instead of several shell characteristics such as porosity, wet or dry shell weight, thickness of shell, membrane character and thickness or exterior characteristics."

Mueller and Scott (1940) expressed weight loss of eggs as the weight loss per unit of shell area. This criterion was preferred over shell weight, shell thickness or number and size of pores. The eggs were weighed on the first day and also the 18th day after incubation in a forced draft machine at 99°F and a wet bulb reading of 85°F. The authors provided the following formula for predicting the loss in weight expressed in milligrams per square centimeter of shell area: $X = 16.274 \cdot Y - 13.52$, where Y is the loss in mg/cm^2/24 hr.

Tyler (1945) stated that weight loss measures in quantitative terms the total effect of the presence of pores. Accordingly, he stated, this was the best method of pore determination, preferable to actual pore counts and rate of air or gas passage, because it was more realistic to measure the amount of water loss than exact number, or type and distribution of pores. Shrader (1954) stated that shell strength can be measured by rate of evaporation when eggs are put into a warm incubator.

Shell Texture

Platt (1929) was one of the first workers to report comparisons between eggs on a shell texture basis. Five grades were originally set up, but it was found that it was impossible to distinguish between them with accuracy, so the grades good or poor only were used according to how nearly eggs approached these standards. Massengale and Platt (1931) candled chicken eggs to determine within 24 hr the texture, or as they referred to it, the number of air spots in the shell. A scale system was set up for differentiating on a texture basis, number one being practically void of air spots and number five practically covered with these spots.

Miller and Beares (1934) classed smoothness into four categories, grade zero constituting an entire absence of roughness caused by lime deposits, with grades 1, 2, and 3 designating progressive degrees of roughness. A modification of this scoring system was employed by Berg and Bearse (1951). Zero was established as the starting point and 3 the end point, with six increments of 0.5 to express increasing numbers of calcareous nodules on the shells. Scott (1944) also established four arbitrary grades to classify shell texture (roughness).

Working with turkey eggs, Phillips and Williams (1944) segregated five classes according to shell texture: (1) dark brown spots, (2) buff spots, (3) barely visible spotting which gave the shell a tinted appearance, (4) chalk white, and (5) pronounced calcareous deposits.

Shell Weight

Although an intricate part of percent shell, shell weight is used by several investigators as a shell quality measurement in itself, without expressing it in relation to the size of the egg (weight). Hart et al. (1925) expressed shell data as "dried weight of shells in grams", and referred to hens treated with ultra-violet light, as laying eggs with markedly increased amounts of "lime" in their shells. They did not mention whether or not their shell weight data included shell membranes.

Buckner (1927) referred to weight of shells and increased weight of shells, but gave no further details except to conclude that approximately 5.5 gm of calcium carbonate are needed every 24 hr to replenish the amount of calcium removed by shell production. Asmundson and Pinsky (1935) used weight of the shell plus membranes to express differences in shell quality caused by thyroid activity. Membranes were also included in shell weight work by Polin and Sturkie (1957), and shells were dried for 24 hr at 105°C before they were weighed. A direct ratio for shell weight (dried, without membranes) was developed by Heywang, Reid and Kemmerer (1964).

McNally (1965) compared frequency distribution curves of the shell weight of sound and cracked eggs. A range of from 3.5 to 6.0 gm was found for cracked eggs shell weight, while eggs with shells weighing less than 3.5 gm were lost in the poultry house. Eggs with shells weighing over 6.0 gm were reportedly seldom broken under good handling methods. The percentage of eggs cracked increased logarithmically as the egg shell weight decreased from 6 to 3.5 gm. Egg shell weight increased semilogarithmically over the 50-70 gm range of egg content weight (egg weight less shell weight). In conclusion, McNally suggested the calculated average percentage of cracked eggs in relation to shell weight, in eggs weighing between

56-76 gm, was a good scoring method for measuring egg shell quality.

Shell Weight Per Unit Area

Hendricks, Lee and Godfrey (1931) calculated a shell thickness index. Weight of the shell was divided by two-thirds the area of the contents of the egg. This was proportional to the weight of the shell per unit area of the egg. Warren and Schnepel (1940) applied the formula developed by Dunn (1923) for calculating the surface area of an egg:
AREA = 4.65 $\sqrt[3]{\text{weight}^2}$, except Warren and Schnepel substituted the value of 4.67, which was calculated from eggs they tested. The resulting value, weight per square centimeter of shell, compared precisely with figures for shell thickness of the same eggs, although no actual statistical analysis was applied.

Dunn's formula was also used by Hutchinson (1953). The weight of membranes was included, and the shells were dried at 100°C. A range from .0729 to .0762 was found in grams per square centimeter of shell. Jenkins and Tyler (1960) included membranes and expressed shell quality in terms of "weight per unit area plus membranes". The formula used was $S = 4.67\ W^{\frac{2}{3}}$, where S = surface area in cm^2 and W = fresh egg weight in grams. Taylor and Hertelendy (1962) determined the dry weight of shells (plus membranes) and applied the formula of Jenkins and Tyler (1960) to determine the weight per cm^2 of shell surface.

Egg Shape

Benjamin (1920) as quoted by Mueller, Maw and Buss (1960) could find no significant difference in shape index between the first and second year of production. However, the shape index increased until the fifth or sixth month of production and then decreased gradually, in each of the two years. On the other hand, Marble (1943) found no significant seasonal variation in shape indexes of eggs produced by Barred Plymouth Rock hens. Mueller, Maw and Buss (1960) in exploring effects of age and season upon egg quality factors, concluded the shape indices of eggs produced during the pullet year were significantly higher than shape indices of eggs produced during the second year of laying. Season of the year had no effect on shape index.

Taylor and Martin (1929) classed eggs into round, ovid and long, without actual measurement of the eggs involved. It was found the average of percent shell was lower for round eggs, although this was not significant. It was concluded no significant differences existed between eggs of different shapes as to thickness and percent shell. Stewart (1936), in a study of the effect of egg shape and shell thickness upon shell strength, concluded that when equal pressure was applied to both ends of the egg, breaking strength did not depend, to any appreciable degree, upon egg shape. A similar report was made by Edin, Hellsday and Anderson (1937) according to Tyler (1961).

It was reported by Frank, Swanson and Burger (1962) that egg shell strength, as stated in terms of the weight necessary to crush the intact egg, cannot wholly be explained by shell thickness, specific gravity, percent shell or egg weight, when these factors are considered either in combination or individually. Therefore, it was concluded, that additional factors, particularly those involved in the geometric structure of the intact egg, might shed some light upon the residual variation in shell strength.

The formula: $\frac{\text{maximum diameter}}{\text{maximum length}}$ X 100, was employed by Richards and Swanson (1965) to compute shape index. The maximum diameter and length of each egg was measured to the nearest .1 mm with a flat-jawed caliper. The authors reported shell thickness was the best single predictor of crushing strength because it explained about 56% of the variation in crushing strength. Egg shape was able to explain only between 5 and 11% of the total variation. This represented 33, 35 and 15% of the variability remaining after shell thickness had been considered in three experiments. Therefore, the proportion of total variation in crushing strength explained by the combination of shell thickness and egg shape was 71, 71, and 64%, respectively, in the three trials. It was concluded that egg shape, expressed as shape index, was found to be independent of shell thickness and accounted for 15 and 35% of the variability in crushing strength remaining after shell thickness had been considered.

<u>Shell Thickness-Percent Shell</u>. Taylor and Lerner (1939) in a study of inheritance of egg shell thickness used 10 eggs from each bird to calculate average individual percent shell and shell thickness correlations. Eggs were weighed, broken, and shell membranes removed. The shells were dried in an oven at 100°C for 24 hr, weighed, and the shell thickness measured at four or more points ranging from the blunt to the pointed end. Correlations between shell weight and shell thickness ranged from .583 to .834. Correlation coefficients between shell thickness and percent shell ranged from .740 to .982. The authors concluded while to a great degree shell thickness was independent of egg weight it seemed to be adequately represented by percentage shell and to a lesser degree by the weight of shell. The coefficients between egg weight and shell weight ranged between .558 and .820. This would seem to indicate egg weight has a greater influence on percent shell than has shell weight. While the increase of egg weight increases percent shell, the increase in shell weight operates in the other direction. In summary, Taylor and Lerner believed percent of total egg weight represented by egg shell was as accurate an expression of individual variations in shell quality, as more cumbersome formulas which take into account effects of differences in total egg weight upon shell weight.

Miller and Bearse (1934) dried shells used in their observations for 18 hr at 110°C, and after finding shell weight, calculated percent shell. This was converted into a shell thickness index by using the following formula:

$$\text{INDEX} = \frac{\text{weight of shell}}{(\text{weight of contents})^{\frac{2}{3}}}$$

The shell percentage observation was not used because the authors found eggs with similar shell thickness may show different shell percentages resulting from differences in egg size. A small egg having a given shell thickness would have a larger percent shell than a large egg having the same shell thickness. This conclusion does not agree with Taylor and Lerner, above.

A convex-anvil micrometer was used by Wilhelm (1940) to record shell thickness at points around the waist of the egg. Shells were dried for at least three days at 100°F. Wilhelm agreed with Taylor and Lerner (1939) that egg weight has a greater influence on percentage shell than has shell weight, but qualified this by stating the former is true only when eggs laid throughout the entire year are considered. When only the eggs laid after mature egg size was reached were considered, it was apparent to Wilhelm shell weight exerted the greatest influence. The relationship between percent shell and shell thickness was greater for the entire year than when considered after March 1 only. He assumed this was true since both dry weight of shell and shell thickness declined while egg size remained relatively constant after mature egg size was reached. The correlation coefficient between shell thickness and percent shell was .805 for the entire trial, but only .482 after egg size leveled off. Both coefficients were highly significant. A highly significant correlation coefficient was reported between shell thickness and dry weight of shell, and the correlation obtained after mature egg size was reached was significantly higher.

Mueller (1957) related selected egg characteristics to resistance of shell against puncture by pressure and impact. Shell thickness accounted for 60.4% of the variations in resistance to pressure puncture and 12.5% for impact puncture. Percent shell accounted for 62.5% against pressure puncture and 13.2% of the variation in resistance to impact methods. Specific gravity, shape index and egg weight were also compared, but shell thickness and percent shell and shell thickness gave the highest values. Mueller concluded from these results, that of the characteristics tested, percent shell and shell thickness were the best indices of resistance to puncture by pressure. The puncture devices employed were applications of increasing weight through a tip of .30 mm diameter and dropping a plummet with a tip of .45 mm diameter, from increasing heights.

In studies of the effect of environment on performance, Mueller (1961) used percent shell and shell thickness data but did not give correlation coefficients. However, he did admit that in interpreting percent shell data, the effect of the egg weight on percent shell should be considered. Simple calculation, he pointed out, shows an identical change in shell thickness will cause a greater change in percent shell if the egg is small than if it is large.

Thornton (1960) weighed eggs to the nearest .5 gram, measured shell thickness with an outside micrometer with a rounded anvil and flat spindle, and dried the shells over night at 160°F. Shell thickness (including membranes) and percent shell, were correlated. A coefficient of .997 between the two was recorded which was highly significant. A further calculation of the regression line gave a ^{b}value of .023. Thus, for each increase of .10 mm in shell thickness, an additional .23 shell percentage units resulted. This showed that very small differences in shell thickness may have a marked and consistent influence on percent shell.

Tyler and Geake (1961) used 100 pieces from each shell to obtain a mean true shell thickness. The shells were boiled in a 2.5% NaOH solution which gave true shell weight without any trace of membranes. These membrane-free shells were also used to determine true shell weight in calculating percentage shell. The authors expressed the belief that with other methods available, percentage shell should cease to be used as a method of assessing shell quality, since it is no more difficult to divide shell weight by a value for surface area, (derived from egg weight), from a table, than to divide by egg weight itself. It was further concluded that true shell weight per unit area (mg/cm^2) is probably a better measure than shell thickness itself, since shell thickness is based on a relatively few direct readings, rather than the whole shell. Tyler and Geake proposed, however, that even weight per unit area of shell plus membranes, gives a very good assessment of shell thickness for routine purposes and is easy to measure. It was suggested it might be necessary to establish a suitable equation for each group of birds or even each bird.

Shell thickness was measured with a micrometer and an average of three readings, one taken at the largest circumference and one at each end of the shell, was considered the shell thickness score, by Hurwitz and Griminger (1962). These readings were taken on membrane-free shells. The shells were dried at 105°C and weighed for calculating percent shell, using the formula

$$\frac{\text{Shell Weight}}{\text{Egg Weight}} \times 100.$$

A different curve was found for percentage shell than for all other shell quality criteria used, breaking strength, shell weight, shell weight per unit area, and shell thickness, particularly for the first 10 periods of egg production studied. While the breaking strength and thickness curves did not show a tendency to decline during the time tested, percentage shell declined both in high and low calcium groups. Shell weight per unit area, on the other hand, was in good agreement with breaking strength and shell thickness. From the definition of percent shell, the authors noted, it is obvious this parameter is influenced by both shell weight and egg weight, the later essentially expressing egg volume. According to the empirical formula of Mueller and Scott (1940), surface area A (in cm^2) = $4.67 \cdot W^{2/3}$, where W is the egg weight in grams. Since by definition, $Z = \frac{S}{4.67 \cdot W^{2/3}}$; this can be transformed into the following: $Z = \frac{S}{W} \cdot \frac{W^{1/3}}{4.67}$. By definition, P (percent shell) = $\frac{S}{W} \cdot 100$, it follows that $P = 4.67 \cdot Z \cdot W^{-1/3}$. Hence, for a constant shell weight per unit of surface area, percentage shell will decrease exponentially with increases in egg weight. The decrease in percentage shell during the 10 periods studied was therefore a reflection of the relatively rapid increase in egg size.

Asmundson and Baker (1940) expressed this same conclusion about percent shell. Assuming the egg to be a solid of revolution, they revealed for any given shell thickness, percentage shell will decrease with increased egg volume. According to their findings, a change in shell thickness has three times as great an effect on percent shell (and in the opposite direction) as the same relative change in egg volume. If eggs produced by an individual hen increased 1% in shell thickness and 3% in volume, they would still have the same percent shell.

Shell Thickness-Specific Gravity. Romanoff and Romanoff (1949) stated that specific gravity of the egg shell is nearly twice that of the egg contents. The entire egg's specific gravity is, therefore, largely influenced by the proportional amount or thickness of shell. Since the thickness of shell is extremely variable among eggs of each species, so also is specific gravity of these eggs. A range of 1.056 to 1.116 was reported in a large number of chicken, turkey and duck eggs. The factors that determine the thickness of shell (pathology, nutrition and heredity) are also responsible for specific gravity of the chicken egg.

Specific gravity was determined in sodium chloride solutions varying in intensity from 1.066 to 1.094 at 55°F by Mountney and Vandersant (1957). The solution of lowest density in which the eggs would just float was considered as the specific gravity reading. Shell thickness was determined by measuring with an Ames paper thickness gauge in .001 of an inch, on the small, large, and middle portions of the shell, membranes included. Correlation coefficients for the relationship between specific gravity and shell thickness, and specific gravity and shell weight were statistically significant. For specific gravity and shell thickness the coefficients were .472, .725 and .757 for eggs from the three trials. From these results, it was concluded that of methods tested (specific gravity, interior quality, dye penetration, shell thickness and shell weight), only the relationships of shell thickness, specific gravity and shell weight were statistically significant. Shell weight was determined by weighing the whole egg, removing the contents and weighing the dried shells.

Godfrey and Japp (1949) found a highly significant correlation coefficient ranging from .754 to .919, between shell thickness and specific gravity. They included membranes and measured thickness with a convex anvil micrometer graduated in

.001 of an inch. Six measurements were involved, two each at the ends and equatorial plane. Specific gravity was determined by the method of Munro (1940). A further study revealed specific gravity and shell color gave a correlation coefficient of .267 and shell thickness and shell color .101. It was concluded that although not as highly associated with shell thickness and specific gravity, egg shell color may be used to improve shell quality through selection by breeders in brown egg laying birds.

Baker and Curtiss (1958) used the saline solution floating method to determine specific gravity, with a range of from 1.068 to 1.100, and intervals of .004. This gave nine classes from 1.068 to 1.100. The solutions were held in covered porcelain pans and were checked with a hydrometer at the start and after each 100 eggs were tested. Shell thickness was measured, membranes intact, in .01 of a mm, with a paper gauge modified to accommodate the curvature of the shell. Measurements were made in the equatorial region to reduce the coefficient of variability. Specific gravity and shell thickness were highly correlated at a low of .693 in February to a high of .893 in June. These were significant at the probability level of .01. The authors correlated specific gravity, shell thickness, shell mottling and internal quality and concluded that specific gravity and shell thickness have little relationship to shell mottling. They further concluded internal quality and specific gravity are not related nor are internal quality and shell thickness.

Although no correlation coefficients were quoted, Swanson, Burger and Frank (1961), in a study of breaking strength, found that standard partial regression coefficients calculated from shell thickness, specific gravity and breaking strength data, suggested shell thickness was not as reliable in estimating shell strength as was specific gravity. Two devices were used to test shell strength, one employed a falling steel ball within a glass tube to measure impact, and the other, a rigid steel frame with a movable shaft assembly, which gave a direct measure of pressure necessary to crush the egg.

Hurwitz and Griminger (1962) measured shell thickness at the point of largest circumference and at each end of the shell. These three measurements (without membranes) were averaged for the shell thickness score. A micrometer was used for measuring. The authors did not actually measure specific gravity, but made the statement that specific gravity would be expected to be subject to the same draw-backs as percent shell, that is, it would be influenced by changes in egg weight, and thus fail to reveal true changes in shell strength when changes occurred in egg weight. Shell thickness was referred to as a good indicator of breaking strength, the two parameters giving a correlation of .736. However, shell thickness, they concluded, will sometimes fail to indicate breakability, since shell density and texture enter into breaking strength scores and are not allowed for in shell thickness measurements.

Tyler and Geake (1961) believed that specific gravity of eggs, although only empirically related to shell thickness, gives an excellent assessment of it, although care must be used to measure it accurately. This includes using increments of .001 in specific gravity solutions, checking solutions with a specific gravity bottle, rather than a hydrometer, constant checking to adjust for evaporation errors, and a refinement of the technique in determining the end point, that is, the solution in which the egg just floats. With reduction of intervals to .001 units, this latter becomes a very difficult and time consuming problem. The authors stated that for reasonably accurate work, the precautions necessary made it rather less suitable than other shell quality assessment tools, but for less critical studies where two or three groups only are necessary, it is probably a suitable method to determine broad classifications. In their own work, Tyler and Geake employed the Archimedes principle for determining specific gravity. Further, part of the eggs were measured by flotation, with .001 increments and the readings checked by weighing, at set intervals, a sample, in a specific gravity bottle.

Percent Shell-Specific Gravity. Warren et al. (1950) measured shell thickness in terms of percent shell, weighing the whole egg and the shell, plus membranes, after the shells were oven dried for 24 hr. Shell weight was divided by whole egg weight. They also tested the tendency of eggs to float in salt solutions of varying concentrations, with a series arranged to give 12 grades of specific gravity. It was reported that shell thickness, as measured by percent shell, was better than specific gravity, because of size differences. This does not seem consistent with the author's earlier statements, that in general, results of percent shell and specific gravity were in agreement. They did not employ statistical measures to compare the two methods, but concluded that specific gravity as a measure of shell thickness was too greatly subject to experimental error to justify its use.

Hutt and Gowe (1948) quoted Olsson (1934) in showing that specific gravity was very highly correlated to percent shell, at a range of .94 to .98. This is in agreement with Mountney and Vandersant (1957) who reported the correlation coefficient between specific gravity and percent shell to be in a range of .371 to .756 depending upon the breed of birds laying the eggs measured. They concluded that only the coefficients for specific gravity and shell thickness and specific gravity and percent shell were statistically significant. Hurwitz and Griminger (1959) stated that due to the increase in egg size with age, the use of shell weight as percent of total weight, and therefore, use of the specific gravity method, does not necessarily represent actual changes in shell strength that might or might not occur as the laying season progresses.

In a study of breaking strength, Frank, Swanson and Burger (1962) measured specific gravity and percent shell, but did not correlate the two. The statement was made that results produced suggest specific gravity was the most reliable single measurement of shell strength and thus implied it was a better shell quality measure than percent shell.

Egg Weight-Percent Shell. In a treatment of the relationship of weights of parts of the egg to total egg weight, Jull (1924) reported a correlation coefficient of .644 between shell weight and egg weight, which was the lowest correlation among all other parts examined. The smaller eggs contained the highest percent shell and albumen and the lowest percent yolk. Percent shell seemed to decrease with regularity from the lightest to the heaviest egg weight class.

Taylor and Martin (1929) classed eggs according to their original weight into (1) 24 oz or over per dozen, (2) 22-24 oz per dozen, and (3) less than 22 oz per dozen. It was found the weight of eggs tested showed no relationship to thickness of egg shell as expressed in percentage shell terms. Taylor and Lerner (1939) found gross coefficients of correlation between egg weight and shell weight ranging between .558 and .820. They concluded egg weight has a greater influence on percent shell than has shell weight. While the increase in egg weight increased percent shell, the increase in shell weight operated in the opposite direction.

Wilhelm (1940) quoted Taylor and Lerner above, in saying that egg weight has a greater influence on percent shell than shell weight, but Wilhelm gave data to show this was true only when eggs laid throughout the year were considered, as opposed to including only eggs produced after mature egg size was reached. When the latter was done, shell weight exerted a greater influence on percent shell than egg weight. It was decided shell thickness is not independent of egg weight.

SUMMARY OF REVIEW OF LITERATURE

Breaking strength is a relatively accurate method of assessing shell quality. Correlation coefficients between this method and others are, as a rule, highly significant. However, the main problem in this procedure, is the difficulty in constructing an instrument which will give accurate data. This statement can be verified by examining the work of Tyler and Geake (1963). In so far as the literature reviewed is concerned, it is virtually impossible to compare data obtained by different workers. Stuart and Hart (1938) expressed their results in pounds of strength. Novikoff and Gutteridge (1949) calculated weight times distance to determine an index of force. Hale (1954), as quoted by Tyler (1962), presented a value termed "dynes". Bowman and Challender (1963) recorded weight of the falling ball which produced cracking. Sluka, Beach and Smith (1965) used pressure per square inch (psi) to express results of their hydrostatic tester. Although each of these produced data accurate within the bounds of their set of circumstances, it is difficult to imagine a comparison among them.

Egg weight loss is a rather involved process, requiring a lapse of several days in which the eggs are incubated.

Although Godfrey and Olson (1937) stated this method was superior to shell thickness as a quality measure, the obvious disadvantages more than off-set the advantages.

Shell texture is of little value as a general guide to shell quality. Since it is completely subjective, it is open to obvious errors.

Shell weight has been explored by relatively few workers, since it is common practice to express shell weight in terms of percentage of the whole egg. Obviously, shell weight alone is of limited value, since it does not take into account egg size, which definitely affects shell weight.

Shell weight per unit area, apparently resolves the problems inherent in shell quality measurements of shell weight and percent shell. In expressing shell weight in terms of area, rather than size or weight, the influence of egg weight is eliminated. However, as pointed out by Tyler and Geake (1961), this measure involves the use of a formula and table which should be representative of the eggs being tested, and this limits the application of this measure.

EXPERIMENTAL PROCEDURE

Eggs were obtained from Kansas State University poultry flocks of commercial strain birds. Collection Period I in the Spring of 1960 included 300 eggs from Honneger hens in their 44th week of production after reaching 50% rate of lay. Collection Period II in the Fall of 1960 consisted of 300 eggs from Hy-Line hens in their third week of production after reaching 50% lay.

All eggs involved were selected on a random basis, stored over-night at approximately 53°F, and the data collected the following day. Egg weight was taken on a gram scale to the nearest .1 gm after which specific gravity was determined. Salt (NaCl) solutions were used which were prepared in increments of .005 units of specific gravity, with a range from 1.060 to 1.100. The concentration or specificity, of each solution increment, was checked at regular intervals during the process of collecting the data. Eggs were first immersed in water and then into the salt solutions, going from the weaker or lowest concentrated salt solutions to the stronger or more highly concentrated solutions. No effort was made to wash or dry the eggs in the process of transferring between solutions since it was believed the carry-over from the weaker solutions to the stronger ones tended to offset any evaporation differences which may have resulted from the solutions being exposed to the air during the testing period.

Eggs were then broken and the shells placed in an oven and dried at approximately 100°C for at least 24 hr. Shell weight was determined to .001 gm and also calculated as a percentage of initial total egg weight, or shell weight times 100 divided by egg weight. Shell thickness was determined on three separate segments from around the equatorial region (waist) of each shell. The average of these three readings was considered the shell thickness measure for each egg. An Ames modified paper thickness gauge with convex jaws was employed, and readings were taken to the nearest .005 inch. Shell membranes were measured intact on the oven dried shells.

Correlation coefficients were calculated for each shell measurement criterion with each of the other two measurements, and also for percent shell and egg weight. In addition, the regression lines, means, standard deviations, and regression equations were also calculated.

RESULTS AND DISCUSSION

Shell thickness, as a rule, is highly correlated with the other shell quality measures included in this paper. Taylor and Lerner (1939) found correlation coefficients ranging from .583 to .834 between shell thickness and shell weight, while a range of .740 to .982 was reported for shell thickness and percent shell. A highly significant coefficient was observed by Wilhelm (1940) between shell thickness and dry weight of shell, while a range of .482 to .805 existed between shell thickness and percent shell. Thornton (1960) reported a coefficient of .997 between shell thickness and percent shell, with a regression line computation of ^{b}value = .023, which meant that for each increase of .10 mm in shell thickness, an additional .23 shell percentage units resulted.

Correlation coefficients of .472, .725, and .757 for eggs in three separate trials, between shell thickness and specific gravity were reported by Mountney and Vandersant (1957). Godfrey and Japp reported figures of .754 to .919 between these same quality measures. Baker and Curtiss (1958) found correlations of .693 in February and .893 in June, between shell thickness and specific gravity. Hurwitz and Griminger (1962) reported a correlation coefficient of .736 existed between shell thickness and breaking strength. Mueller (1957) stated that shell thickness accounted for 60.4% of the variations in resistance to pressure puncture.

In the present study, distribution of shell thickness data are presented in Figure 1. As can be seen, Collection Period II with the younger birds, resulted in higher readings. However, there was much less difference between the two collection periods for shell thickness than for percent shell and specific gravity. More eggs in both collection periods fell into the category of .014 inch than into any other category, in other words, the mode for each collection period was .014 inch. The means were .0139 and .0144 inch for Collection Periods I and II, respectively. The correlation coefficients, regression lines, means, standard deviations and regression equations for shell thickness and specific gravity are shown in Figures 4 and 5 and these same values for shell thickness and percent shell are shown in Figures 6 and 7. Correlation coefficients for eggs from Collection Period I were: specific gravity and shell thickness, .803, and for percent shell and shell thickness, .842. For Collection Period II they were: specific gravity and shell thickness, .787 and percent shell and shell thickness, .761.

These results compare favorably with those of the other workers. Since there is little doubt that shell thickness is a good indicator of shell quality, it would appear that any choice regarding use of this tool is one involving personal preference of each worker. If results are to be compared between workers, standards should be set up which would allow for this comparison. This standard should be based upon, (1) the tools used, (2) the absence or presence of membranes and (3) the number of and location of readings.

On the surface, percent shell would appear to be a good indicator of egg shell quality. Warren et al. (1950) stated percent shell and specific gravity were in agreement as shell quality measures. Taylor and Lerner (1939) concluded percent of total egg weight represented by shell was an accurate expression of individual variations in shell quality. Hutt and Gowe (1948) quoted Olsson (1934) as stating that percent shell and specific gravity are correlated at .94 and .98. Mountney and Vanderzant (1957) reported a range of .371 to .756, depending upon the breed of birds. Mueller (1957) found 62.5% of the variation in resistance to pressure puncture was accounted for by percent shell, and concluded percent shell and shell thickness are the best indices of resistance against puncture by pressure.

Despite these favorable comments regarding the use of percent shell for determining shell quality, there have been many authors who have pointed to the serious shortcomings of this method. Miller and Bearse (1934) calculated a percent shell value, but did not report it in their data because they believed eggs with similar shell thickness may show different shell percentages resulting from differences in egg size. Wilhelm (1940) pointed out that egg weight has a greater influence on percent shell than has shell weight, but qualified this by observing the former is true only when eggs laid throughout the entire year were considered. The relationship between percent shell and shell thickness was greater for eggs laid during the entire year, than for eggs laid after March 1, because shell weight and shell thickness declined while egg size remained relatively constant after mature egg size was reached. The correlation coefficient between shell thickness and percent shell was .805 for the entire year, but only .482 after egg size leveled off.

Asmundson and Baker (1940) recorded a three-fold effect on percent shell of a change in shell thickness. If the eggs produced by an individual hen increased 1% in shell thickness and 3% in volume, they would still have the same percent shell. Mueller (1961) admitted that in interpreting percent shell data, the effect of egg weight on percent shell should be considered, since simple calculation shows that an identical change in shell thickness will cause a greater change in percent shell if the egg is small than if it is large. Hurwitz and Griminger (1962) reported a different curve for percentage shell than for other shell quality criteria, and attributed this to the relatively rapid increase in egg size. Tyler and Geake (1961) expressed the feeling that percent shell should cease to be used as a method of assessing shell quality, due to the adverse effects of egg weight, but also due to the availability of superior methods.

The distributions of percent shell measurements for the present investigation are shown in Figure 2. As was expected, percent shell readings for Collection Period I were slightly lower than for Collection Period II due presumably to the differences in ages of the birds. Figures 6 through 9 present regression lines, means, standard deviations, correlation coefficients and regression coefficients for percent shell-shell thickness and percent shell-specific gravity for both collection periods. As can be seen from these data, the correlation coefficients for these measures fall in line with those reported by other workers. From these figures, percent shell would seem to be as good a measurement for shell quality work as any. However, it should be pointed out that data included herein are from one collection of 300 eggs in the spring from hens nearing the end of their first year of lay, and another collection of 300 eggs taken the following fall, from pullets just starting their first year of lay. Therefore, the figures presented do not take into account measurements of eggs laid over a period of months, and therefore may not reflect variations in percent shell caused by differences in egg weight.

Specific gravity is widely used as an indirect measure of shell quality. In a majority of the reports reviewed, it was considered a good method of assessing thickness of shell. A correlation coefficient range of .94 to .98 between specific gravity and shell thickness was reported by Olsson (1934) as quoted by Hutt and Gowe (1948). Godfrey and Japp (1949) found coefficients ranging from .754 to .919 between the same tools. Mountney and Vanderzant concluded that specific gravity was one of the statistically significant shell quality criteria. Specific gravity and shell thickness were found to be highly correlated at the probability level of .01 by Baker and Curtiss (1958). Swanson, Burger and Frank (1961) suggested that shell thickness is not as reliable in estimating shell strength as specific gravity, even though specific gravity is an attempt to measure indirectly shell thickness. Tyler and Geake (1961) stated that specific gravity, although only empirically related to shell thickness, gives an excellent assessment of it, if proper precautions are taken to assure it is accurately taken. In a comparison of percent shell and specific gravity, Frank, Swanson and Burger (1962) stated that specific gravity was the most reliable single indicator of shell strength.

Although no actual measurements were reported, Hurwitz and Griminger (1962) stated that specific gravity would be expected to be subject to the same short-comings as percent shell, which appears to be influenced by changes in egg weight, and thus fail to reveal true changes in shell quality when changes occur in egg weight.

Percentage distribution of specific gravity measurements are presented in Figure 3. The other shell quality measures including correlation coefficients between shell specific gravity and percent shell and shell thickness are shown in Figures 4, 5, 8 and 9, for the two collection periods. Specific gravity and percent shell were the most highly correlated of all measurements, which may have been caused by the lack of similarity in the distribution patterns used (a smaller range was used for specific gravity than for percent shell, resulting in higher percentages of egg within each measurement value).

It would seem to this author, that since there is little doubt specific gravity is a suitable shell quality measure, certain standards should be set up to make comparison between workers more meaningful. A standard range of solutions should be accepted, as should the increment interval between saline concentrations. Another area which was not explored in the literature, and which might possibly be involved in the accuracy of specific gravity work, is the temperature at which eggs and also solutions used, are kept prior to, and during, the actual readings. Another factor which should be standardized, is the age of eggs prior to measurement.

The effects of egg weight upon shell weight and therefore percent shell lack uniformity based upon literature reviewed.

Taylor and Martin (1929) stated that egg weight has no relationship to shell thickness. Jull (1924) found that percent shell seemed to decrease from the lightest to the heaviest eggs. Taylor and Lerner (1939) observed that egg weight has a greater influence on percent shell than has shell weight. This was accepted by Wilhelm (1940) only when eggs laid for the entire year were considered. When eggs produced only after mature egg size was reached were measured, shell weight exerted a greater influence on percent shell than did egg weight and thus, shell weight is not independent of egg weight.

Figures 10 and 11 present the relationship of egg weight to percent shell. In both cases, Collection Period I and Collection Period II, a negative correlation coefficient was established. This indicates the greater the egg weight, or the larger the egg, the lower the percent shell. The correlation coefficient was higher for eggs from the younger birds from the second collection period than for the older birds from the first collection period.

SUMMARY

Of the various methods of measuring shell quality included in the review of literature, certainly the most interesting is breaking strength. A wide variety of devices were used, some very crude, others extremely complex. If any of these could be perfected, or if a new apparatus could be developed, that would be simple in principle and operation, with acceptable accuracy and repeatability, breaking strength would probably become the most widely used tool for shell quality determination. After all, this is the factor that should be of most concern, the force necessary to crack or puncture an egg. It is the problem of cracked eggs that prompts most studies of shell quality. Shell thickness, percent shell, specific gravity, shell shape and other direct or indirect measures are actually only means to the end of finding why and how eggs become cracked between the hen house and the consumer. The most direct answer to this question could be found in determining the breaking strength of the egg.

Specific gravity is the method this author would recommend, because it gives a very good evaluation of the shell quality factor, even though it is an indirect measure of shell thickness. It is a relatively simple operation which can be reduced to a routine after proper precautions are taken. This is important where relatively large numbers of eggs are involved. Another economic factor is the salvaging of the intact egg which is not possible with various other methods herein discussed.

Shell thickness is the second choice of the three tested. If proper steps are taken, such as several readings averaged to derive a mean shell thickness recording, and if shell membranes are removed to prevent their influence on true shell thickness, this method can be a very good measure of shell strength. If available, a micrometer is preferred over its rival instrument, the thickness gauge, due to higher accuracy and superior repeatability. Shell thickness recordings can be reduced to a highly efficient routine as can be specific gravity readings, but shell thickness work requires disposal of broken eggs and, of course, the eggs are not salable as shell eggs.

Regardless of the high correlation coefficients found in this report and in the literature reviewed, between percent shell and other shell quality criteria, it is the opinion of the author, that with other tools at hand, percent shell is unworthy of serious consideration. Certainly specific gravity and shell thickness are no more difficult, nor time consuming, and are not subject to the obvious criticism of inaccuracy due to a variable such as egg weight.

Egg weight and percent shell in this study were correlated with a negative value, which means that as egg weight increases, percent shell decreases. This relationship is part of the reason for stating that of the three shell quality indicators presented, percent shell is the most variable and subject to error.

ACKNOWLEDGMENTS

The writer wishes to express appreciation to Dr. Jack L. Fry, formerly of Kansas State University and presently with the Department of Poultry Science, University of Florida, and Dr. Paul E. Sanford, Department of Dairy and Poultry Science, Kansas State University, for the time, effort and persistent encouragement, without which, this report could never have been completed.

Appreciation is also gratefully extended to the late Professor Thomas B. Avery for the training and guidance so willingly offered.

Further, the writer extends thanks to Professor C. F. Petersen and Dr. E. A. Sauter, of Poultry Science Department, University of Idaho, for invaluable comments and suggestions during the final stages of the preparation of the report.

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APPENDIX

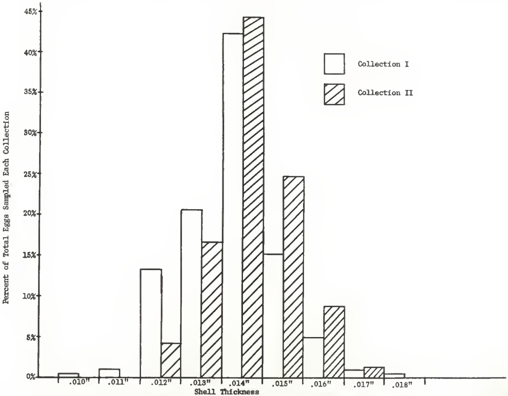


Figure 1. Percentage Distribution of Shell Thickness Measurements

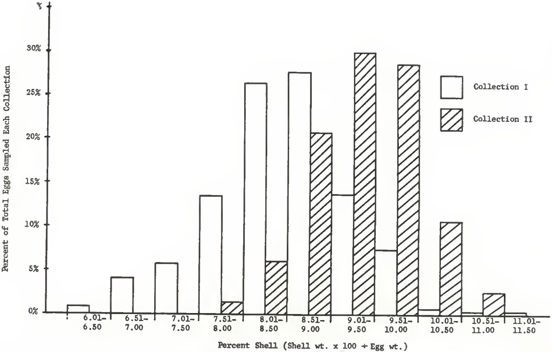


Figure 2. Percentage Distribution of Percent Shell Measurements

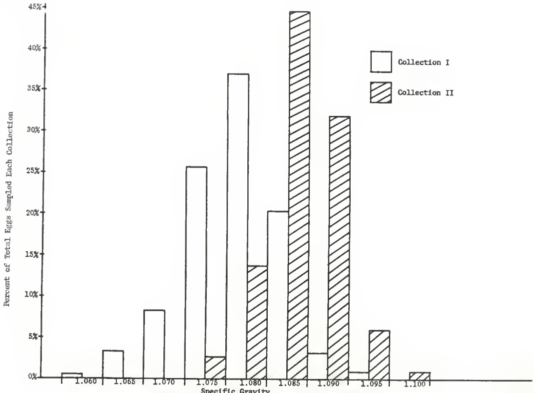
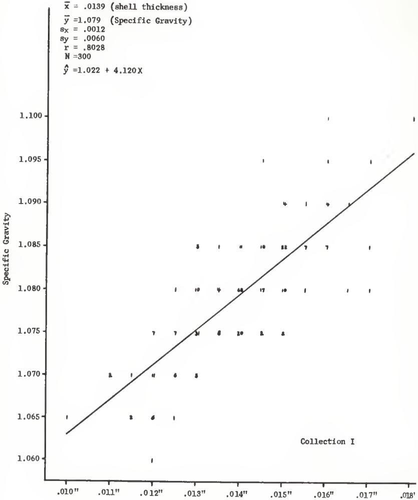


Figure 3. Percentage Distribution of Specific Gravity Measurements



Shell thickness
Figure 4. Relationship of Shell thickness to Specific Gravity

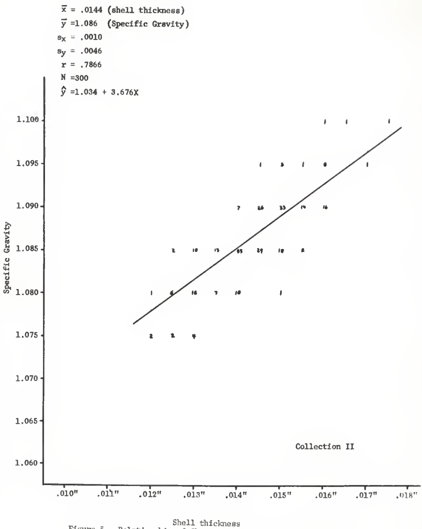


Figure 5. Relationship of Shell thickness to Specific Gravity

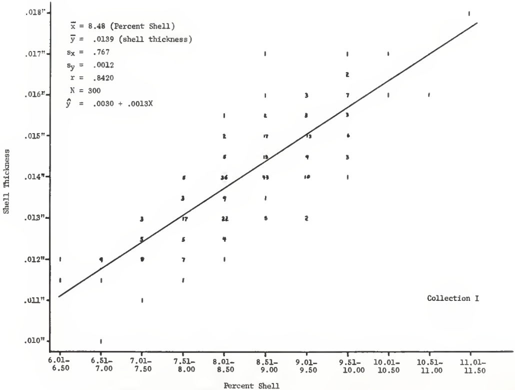


Figure 6. Relationship of Percent Shell to Shell Thickness

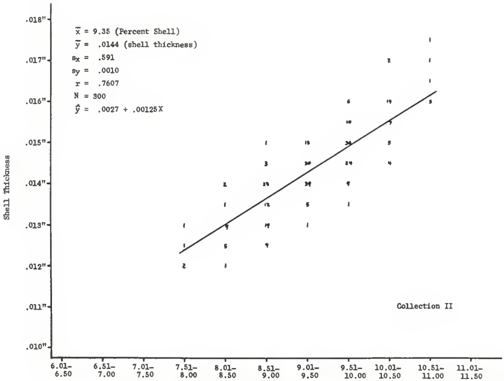


Figure 7. Relationship of Percent Shell to Shell Thickness

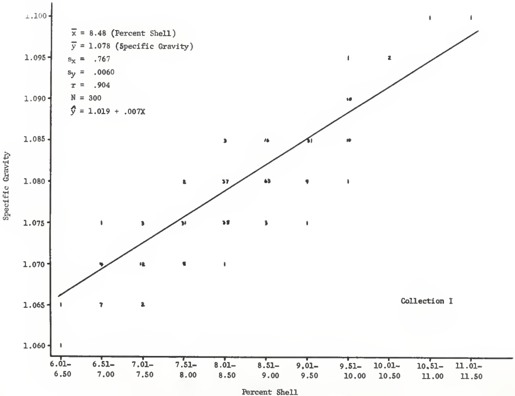


Figure 8. Relationship of Percent Shell to Specific Gravity

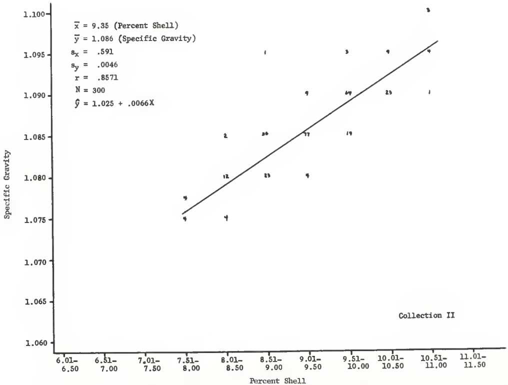


Figure 9. Relationship of Percent Shell to Specific Gravity

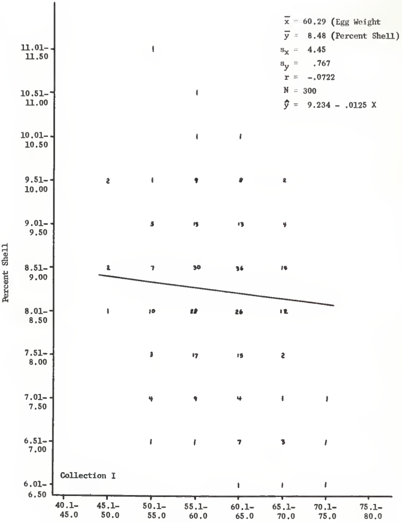


Figure 10. Relationship of Egg Weight to Percent Shell

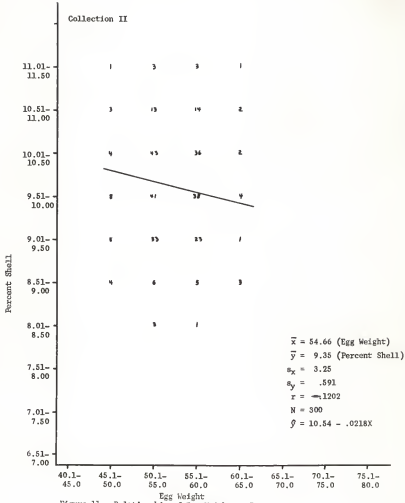


Figure 11. Relationship of Egg Weight to Percent Shell

METHODS OF MEASURING EGG SHELL QUALITY

by

EDWARD E. STEELE

B. S., Kansas State University, 1957

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Dairy and Poultry Science

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

An extensive review of the literature was conducted to study methods of measuring egg shell quality. Shell thickness, breaking strength, porosity, percent shell, specific gravity, egg weight loss, shell texture, shell weight, shell weight per unit area and egg shape were described and discussed by the authors reviewed. The relationships between shell thickness, percent shell, specific gravity and egg weight were examined in greater detail and correlation coefficients between them were presented. It was concluded that although breaking strength is a good measure of shell quality, it is very difficult to construct suitable devices which are comparable in performance. Egg weight loss, shell texture, shell weight, egg shape and porosity have inherent flaws or are not practical. Shell weight per unit area is a good measure, but must rely on the use of a table and formula representative of the eggs tested, and therefore, is limited.

In addition to the review of literature, a study was conducted to compare the relationships between shell thickness, percent shell, specific gravity and egg weight. Two separate periods were selected in which 300 eggs each from different aged birds in different seasons were compared for the above factors. Statistical data including correlation coefficients, regression lines, means, standard deviations and regression equations were obtained. High positive correlation coefficients were found between shell thickness and specific gravity, shell thickness and percent shell and specific gravity and percent shell for both collection periods. A negative correlation coefficient was established between egg weight and percent shell in both collection periods, indicating the larger the egg the lower the percent shell.

It was concluded that specific gravity is the most suitable of the measures investigated because of its high correlation to shell thickness and percent shell, and because of its relative ease and efficiency of collection. Shell thickness is more subject to error but should be preferred above percent shell, which is too dependent on egg weight, to be relied upon for truly accurate assessment.