



121
240
THS



This is to certify that the
thesis entitled
REFINING EGG SPECIFIC GRAVITY
MEASUREMENT PROCEDURES

presented by

Kristen Sue Park

has been accepted towards fulfillment
of the requirements for

Master degree in Animal Science

Major professor

Date January 20, 1986



RETURNING MATERIALS:
Place in book drop to
remove this checkout from
your record. FINES will
be charged if book is
returned after the date
stamped below.

1993-09-17

342

SEP 27 1993

287

REFINING EGG SPECIFIC GRAVITY
MEASUREMENT PROCEDURES

by

Kristen Sue Park

A THESIS

Submitted to
Michigan State University
in Partial Fulfillment of the Requirements
for the Degree of

Master of Science

Department of Animal Science
1986

ABSTRACT

REFINING EGG SPECIFIC GRAVITY MEASUREMENT PROCEDURES

By

Kristen Sue Park

The objectives of this study were to: 1) simplify SG measurement procedures so they are convenient and accurate, 2) recommend standard SG measurement procedures and 3) explore the relationship between specific gravity (SG) and breakage.

Egg samples were collected every week from a flock of 8,640 DeKalb XL's from 21 to 66 (pullet cycle) and 73 to 100 weeks of age (molted cycle). SG's were measured using five solutions.

SG was related to percentage breakage after commercial processing (coefficient of determination = $-.527$). SG information from two solutions predicted the five-solution SG mean with a high degree of precision. SG information from one solution did not predict the SG mean with enough precision. SG information from three solutions did not contribute any greater precision than from two solutions. The recommended procedural standards are to: 1) not exclude hairline cracks, 2) collect 30-egg samples 3) store solutions and samples in the egg cooler to equalize temperatures and 4) use SG information from solutions 1.070 and 1.080 to estimate SG mean.

ACKNOWLEDGEMENTS

The author would like to extend deep appreciation to Dr. Allan Rahn for his enthusiasm and expertise that he provided during the course of this study. Thanks also go to Dr. Cal Flegal and Dr. James Goff for their advise and encouragement.

Special acknowledgement belongs to the people at the farm and especially to Steve who worked to keep House Seven operating smoothly.

And of course thanks to Eric who made sure the thesis was handed in on time.

TABLE OF CONTENTS

LIST OF TABLES.....	iv
LIST OF FIGURES.....	v
INTRODUCTION.....	1
LITERATURE REVIEW.....	3
PROBLEM STATEMENT.....	11
MATERIALS AND METHODS.....	14
RESULTS.....	22
Pullet Cycle.....	22
SG Trends.....	22
Procedure Simplification.....	24
Molted Cycle.....	32
SG Trends.....	32
Procedure Simplification.....	34
SG Versus Breakage.....	41
DISCUSSION.....	44
SG Trends.....	44
Procedure Simplification.....	46
SG Versus Breakage.....	48
Recommendations for Standardizing Procedures.....	50
SUMMARY.....	55
Further Suggestions.....	56
APPENDIX	
Appendix A.1. The results of adding age and age to the single solution base regression model (pullet).....	58

Appendix A.2.	The results of adding age to the two-solution base regression model (pullet).....	59
Appendix A.3.	The results of adding age and age to the single solution base regression model (molted).....	60
Appendix A.4.	The results from adding age to the two-solution base regression model (molted).....	61
BIBLIOGRAPHY.....		62

LIST OF TABLES

<u>TABLE</u>	<u>PAGE</u>
1 Relationship between the five-solution SG mean and one SG solution (pullet).....	29
2 Ninety-five percent confidence intervals for the SG mean predictions from the SG solution 1.080 (pullet).....	29
3 Relationship between the five-solution SG mean and two SG solutions (pullet).....	30
4 Ninety-five percent confidence intervals for the SG mean predictions from the SG solutions 1.070 and 1.080 (pullet).....	30
5 Relationship between the five-solution SG mean and three SG solutions (pullet).....	31
6 Ninety-five percent confidence intervals for the SG mean predictions from the SG solutions 1.075, 1.080 and 1.085 (pullet).....	31
7 Relationship between the five-solution SG mean and one SG solution (molted).....	38
8 Ninety-five percent confidence intervals for the SG mean predictions from the SG solution 1.080 (molted).....	38
9 Relationship between the five-solution SG mean and two SG solutions (molted).....	39
10 Ninety-five percent confidence intervals for the SG mean predictions from the SG solutions 1.070 and 1.080 (molted).....	39
11 Relationship between the five-solution SG mean and three SG solutions (molted).....	40
12 Ninety-five percent confidence intervals for the SG mean predictions from the SG solutions 1.070, 1.075 and 1.080 (molted).....	40

TABLEPAGE

13	The relationship of breakage to the weighted average specific gravity mean of all egg samples.....	43
14	Prediction of percentage cracks from two hypothetical egg samples.....	45
15	Specific gravity means of the same egg sample obtained from three different solution sets.....	52
16	SG mean predictions for egg samples being tested using the solutions 1.070 and 1.080 ^{1,2}	54

Appendix

A.1.	The results of adding age and age ² to the single solution base regression model (pullet).....	58
A.2.	The results of adding age to the two-solution base regression model (pullet).....	59
A.3.	The results of adding age and age ² to the single solution base regression model (molted).....	60
A.4.	The results from adding age to the two-solution base regression model (molted).....	61

LIST OF FIGURES

<u>FIGURE</u>	<u>PAGE</u>
1 Shallow and deep cage systems labeled by line from House Seven green room.....	15
2 House Seven laying chambers.....	16
3 SG frequency distributions from 25, 35, 45, 55 and 65 weeks of age. SG solutions represented on X-axis; percent of eggs represented on Y-axis.....	23
4 Relationship between the five-solution SG mean and age (pullet).	25
5 Relationship between SG standard deviation and age (pullet).....	26
6 Relationship between SG coefficient of variation and age (pullet).....	27
7 SG frequency distributions from 75, 85 and 95 weeks of age. SG solutions represented on X-axis; percent of eggs represented on the Y-axis.....	33
8 Relationship between five-solution SG mean and age (molted).....	35
9 Relationship between SG standard deviation and age (molted).....	36
10 Relationship between SG coefficient of variation and age (molted).....	37
11 The relationship of percent breakage to specific gravity mean...	42

INTRODUCTION

It has been suggested that operational decision-making and management can be improved by monitoring egg shell strength. Undergrade and loss eggs can be reduced over the life of a flock and can result in a significant increase in revenues for the firm. Researchers have recommended that the specific gravity (SG) flotation method of evaluating egg shell strength be used to closely monitor the performance of the laying flock (Swanson, 1979; Ernst, 1979; Strong and Reynnells, 1983).

Other methods of measuring egg shell strength include 1) non-destructive deformation, 2) impact fracture force, 3) Quasi-static compression fracture force, 4) puncture force, 5) beta backscatter, 6) shell thickness and 7) percent shell. These methods require expensive laboratory equipment or are very time consuming and are inappropriate in field situations. The SG flotation method, however, is inexpensive and quick to perform making it the only method preferred for field use.

The SG of the shell itself is over twice as high as the other contents of the egg (Olsson, 1934). This means that any change in the amount of shell of an egg will have a major influence on the SG of the entire egg. Essentially, the SG of an egg is an indicator of the relative amount or percentage shell. This is the underlying reason that

egg SG is used as an indicator of egg shell strength.

The SG of eggs is commonly measured by one of two methods. The Archimedes' method involves weighing the individual egg in air then reweighing the egg while it is submerged in water. The flotation method involves immersing the egg in salt solutions of increasing SG and removing the eggs as they float. The SG of the salt solution in which the egg first floats is the approximate SG of the egg. The flotation method of measuring egg SG is the most practical for use in the field. It requires materials that are inexpensive and readily available and requires a minimum of time and effort because eggs can be tested in batches rather than one at a time. The method is also nondestructive, so after the eggs are tested they may be sold. In summary, egg SG is highly correlated to percent shell and is an inexpensive, easy, quick and nondestructive method of assessing egg shell strength.

LITERATURE REVIEW

Specific gravity (SG) is a measure of density and is defined as the weight of an object relative to the weight of an equal volume of water at 4 C. The SG of eggs can be measured by several methods, the two most popular being Archimedes' method where the egg is weighed in air and then weighed while it is submerged in water and the flotation method where eggs are immersed in salt water solutions of increasing SG and removed as they float in each solution. Thompson and Hamilton (1982) reviewed and compared both methods for precision and accuracy. Solutions used for the flotation method ranged from 1.062 to 1.102 SG in increments of 0.004. Eggs were weighed to 0.01 grams when subjected to Archimedes' principle. The agreement between the means and the individual measurements was very similar, and the differences of the individual measurements were also very small with 95 percent of the differences within 0.004 and 50 percent of the differences within 0.002. The estimates of variance were also similar enabling the researchers to state that precision also was not a hindrance to using the SG floating method.

Sources of error of SG measurements have been documented. Olsson (1934) observed weight loss of the egg over time due to evaporation. He recommended that SG measurements be taken as soon as possible after the

egg is laid. Wells (1967a) also associated evaporative weight loss to a decrease in SG.

Hamilton and Thompson (1981) conducted research to determine the absolute changes in SG over time. Eggs were stored at 10 C in plastic bags and SG readings were taken after 1, 2, 4, 7, 15, and 21 days. SG was shown to decrease significantly over time in a linear fashion at a decline of -0.00046 per day (i.e. slope = -0.00046).

Strong and Reynnells (1983) also found a decreasing linear trend between SG and time. They found an average decrease of 0.001 per day. Time was measured from the time eggs were delivered to the egg processing plant, where the tests were conducted, to the time the measurements were taken. Eggs may have been stored up to four days at the farm before delivery to the plant.

Another source of error occurs when SG measurements are taken over a wide range of solution temperatures. Temperatures in egg processing facilities not environmentally controlled may range from 22 to 32 C. Voisey and Hamilton (1977) found an increasing relationship between the sample SG mean and the ambient temperature.

Voisey and Hamilton (1977) also studied the effects on SG measurements when eggs and solutions were stored at different temperatures. When eggs were stored in coolers at 13 C and solutions were stored in the work area at 24.5 C, SG readings were changed by 0.001 in the first solution, but were unchanged by the time eggs were immersed in the last solution. After 179 eggs were tested the errors were not significant as egg and solution temperatures tended to equalize.

Hairline cracks introduced insignificant errors to the SG measurements as studied by Voisey and Hamilton (1977). Eggs were measured before and after introducing cracks to the egg sample. The means before and after cracking were $1.077 \pm .0095$ and $1.076 \pm .0095$, respectively.

Hammerle (1969) described SG of eggs as a physical property of eggshell strength. He also stated that physical properties do not estimate material properties for engineering materials. No correlation has been found between measurements of material strength and density. Other physical properties described which are often related to shell strength and which are estimated by SG are shell thickness and percentage shell.

Hamilton (1982) referenced an article by Anderson et al. (1974) who found little variation of material strength in either white or brown shelled eggs and concluded that little could be done genetically to improve material eggshell strength.

Olsson (1934) studied the SG of the egg and its four main components. He stated that the SG of the parts of a new-laid hen's egg were: yolk=1.032; albumen=1.038; shell membranes=1.005 to 1.010; and shell=2.325. Olsson then deduced that even though the SG of yolk and albumen and membrane were significantly different, they would not contribute to many changes in SG of the whole egg as the proportional weight among them does not vary much. However, variation in the percentage shell would influence SG.

Olsson (1934) investigated the relationship between the SG and the percentage of shell. Three populations of hens were used and SG was

determined by Archimedes' principle. The correlation between SG and percentage shell for populations 1, 2 and 3 were .937, .982 and .94, respectively.

Correlations between the SG of eggs and other measurements of shell strength vary somewhat. Potts and Washburn (1974), using five strains of commercial egg layers reported correlations between SG and shell thickness ranged from .56 to .88 across all five strains with no significant differences among strains. The correlations between SG and nondestructive deformation tests ranged from -.77 to -.82. The correlation between SG and breaking strength as measured by the Instron Quasi-static loader ranged from .72 to .80.

Potts et al. (1974) investigated which egg trait among SG, shell thickness, width/length, egg weight and tint contributed the most variation in the egg strength measurements of nondestructive deformation and Quasi-static breaking strength. Three brown egg strains and three white egg strains were used from two different hatches. Eggs were collected from two different periods within each of the hatches. Stepwise regression analyses were performed using dependent variables of deformation and breaking strength. SG explained most of the variation in deformation when the set of independent variables was nondestructive egg characteristics. When the set of independent variables included destructive characteristics, shell thickness explained most of the variation in brown shelled eggs while SG explained most of the variation in white shelled eggs. When breaking strength was the dependent variable in the second set of regression analyses, shell thickness explained most of the variation in brown eggs and SG in white strains in

the first collection period. In the other period, thickness explained most of the variation in both brown and white eggs.

A curvilinear relationship between SG and percentage cracks was demonstrated by Wells (1967a). SG was measured using Archimedes' principle and was performed during the week after the eggs were laid. All eggs including cracks were tested. Eggs were collected at point of lay where the stresses applied to the egg were between oviposition and when the egg rolled forward to the edge of the battery cage.

Holder and Bradford (1979) saw a significant decrease in percentage cracks as SG increased when the eggs were processed through a 10 case per hour egg sizer. SG was determined by the flotation method using five SG solutions in increments of 0.005. All eggs from each category were sent through the sizer and then candled for cracks.

Wells (1967a) collected eggs from hens housed in single cage batteries and calculated the percentage cracks. Resistance to crushing, resistance to impact, percentage shell and SG by Archimedes' principle were tested. The correlation of percentage cracks to SG was $-.733$. Correlations of percentage cracks to: resistance to crushing, resistance to impact and percentage shell were $-.678$, $-.716$ and $-.769$, respectively. Wells deduced that SG could evaluate shell strength as reliably as the laboratory methods used above.

Wells (1967b) also used percentage cracks as an indicator of shell strength to compare the reliability of SG and deformation as evaluators of shell strength. Two trials were run each with two commercial hybrids. In trial I, 40 sound eggs were collected from each of 20 pens of light hybrids and two samples of 40 eggs were collected from each of

18 pens of medium hybrids. Readings were taken the same day eggs were laid. In trial II, percentage cracks were calculated from total production. One sound egg per week for a 10 week period for medium hybrids and one sound egg per week for a 20 week period for medium hybrids were used to calculate SG and deformation. The correlations between SG and deformation for both trials and all hybrids ranged from $-.804$ to $-.898$. Correlations between percentage cracks and deformation and percentage cracks and SG ranged from $.324$ to $.531$ and from $-.443$ to $-.496$, respectively. From these figures, Wells concluded that the choice of shell strength evaluator depended on factors other than correlation to percentage cracks.

Strong and Reynnells (1983) studied SG in relation to percentage cracks in field and controlled conditions. In their first experiment, eggs were obtained from a processing plant and SG, shell thickness and percentage cracks were measured under controlled conditions. Seven SG solutions, 1.065 to 1.095 in 0.005 increments were used. In the second experiment, five SG solutions were used and measurements were taken by plant personnel. Eggs were brought from the farm to the plant where storage time at the farm may have been as long as four days. The correlation between percentage cracks and SG under controlled conditions was $-.76$ whereas the correlation under field conditions was $-.37$.

Relationships between SG and breakage during commercial handling, washing and candling were investigated by Thompson, et al. (1985). Eggs were ranked in quartiles by each of several egg strength measurement methods. The eggs were then washed and candled using commercial machinery. Percentage damage to eggs ranked using SG was no different

when ranked using other methods of assessing egg shell strength. High frequency of damage to eggs in the top quartile raised questions regarding the ability of current eggshell strength measurement methods to accurately predict potential breakage. The researchers believe that a substantial proportion of breakage from commercial handling cannot be predicted by using current shell strength measurements.

Doyon, et al. (1985) collected eggs from five strains of commercial breeding flocks from 197 to 490 days of age to investigate the changes in eggshell quality over age. Eggshell strength was assessed using SG, deformation and breaking strength. SG decreased over time up to approximately 400 days of age when it then leveled off. The rate of decrease in SG from one strain was different but the same from all other strains. Deformation increased and breaking strength decreased over time. The SG variance measured by the standard deviation was stable over time whereas the deformation standard deviation appeared to increase with age. The breaking strength standard deviation appeared unstable over time but no trend was revealed.

Izat, et al. (1985) measured several egg quality characteristics which were shell thickness, SG, shell weight, percent shell, shell weight per unit surface area, and shell density to determine effects of age and season on egg quality. SG declined as age increased and was lower in the spring and summer than in fall and winter. Shells were significantly more dense in the spring and summer and less dense in the fall and winter. Statistically, age had no significant effect on shell density.

Recommendations have been made in popular and scientific articles concerning the use of SG as an evaluator of egg shell strength. For use at the industry level, Swanson (1979) recommended that data be collected routinely and then utilized in management procedures. He suggested using five SG solutions in increments of 0.005. Any increments less than that are impractical since the correct adjustment of the solutions becomes important. He also pointed out that one SG solution would be easy to use.

McKeen (1983) recommended that SG testing be used to detect actual or pending shell problems. Four solutions in increments of 0.005 were used by him in illustration. If only one solution is to be used 1.080 was recommended while 1.075 and 1.080 were recommended for testing with two solutions. Accumulated percentages were calculated and plotted on log-probability paper to present SG information graphically. As the plotted line shifted upward, eggshell quality decreased, and as the slope of the line increased the SG of the eggs became more uniform.

Strong and Reynnells (1983) suggest using three solutions, 1.075, 1.080 and 1.085, in the field and testing every two weeks to maintain timely data. They believe that comparisons should only be made within a company, as different feeding programs and environmental factors make comparisons meaningless. SG information was presented as the SG sample mean or weighted average.

PROBLEM STATEMENT

The review of research involving SG as a measure of egg shell strength indicates that the SG flotation method provides an assessment of egg shell strength comparable to other strength measurements and is practical for field use. However, problems exist which prevent SG testing from being used in the industry effectively. One problem is the lack of a predictive association between percentage breakage and SG scores. Therefore, many are uncertain as to what SG scores really express. If managers could predict percentage breakage from SG scores, they could improve decision-making and management to better flock performance and business profits. If a manager predicted a 15 percent breakage rate he or she could decide to improve performance by reformulating feed, modifying temperature and/or ventilation, monitoring disease status, inducing molt or terminating the flock. The manager could also decide to alter the handling, transport or market end point by shipping eggs directly to the breaker/further processor.

Another problem that makes using SG scores difficult is the lack of procedural standards. These would allow SG scores to be compared to different flocks, farms, companies, ages, etc.. One to five salt solutions, with gradation increments of 0.004 or 0.005, are used in SG testing procedures. Calculations are influenced by the upper and lower,

open-ended SG categories which make comparisons among different testing procedures very difficult. Test scores have been interpreted by different methods which include percentages, accumulated percentages, log probability graphs, curvilinear graphs and SG means. Scores interpreted by one method are difficult to compare to scores interpreted by a different method.

The third problem associated with SG is related to testing procedures. Simplified procedures which use only one to three SG solutions may indeed save the user time and expense, but the scores obtained from such procedures may not contain enough information to make accurate assessments about egg shell strength.

The difficulty in establishing a prediction estimate of percentage breakage lies in the multitude of other factors influencing breakage. Egg packers, candlers, washers and graders, transportation systems, personnel and chance all play major roles in determining breakage rates. Major research is needed in this area before SG scores or any other measure of shell strength can be used to predict breakage and loss through the commercial egg system. However, SG can still be used effectively to aid in management and decision-making. Scores can be compared to either strain standards as they are developed or to past performance standards. And if testing procedures and interpretation methods are standardized, scores may be related to other farms, flocks, or competing companies.

Because SG testing will be more universally accepted if it is quick, easy to use and inexpensive, the primary purpose of this research is to simplify SG testing procedures and calculations so they are both

convenient and accurate. The results of this study will then be used to recommend procedural standards. Distributional properties will be studied to aid in selecting which procedures will be analyzed and to aid in understanding the SG characteristics. The other purpose of this study is to recommend standard procedures and interpretation methods that will be practical for use in the industry. These recommendations will be supported by the work from past SG studies and by the results of simplifying testing procedures. Given the scope of the first problem discussed, defining a relationship that will predict percentage breakage from SG scores will not be an objective of this study. A relationship of SG to breakage after gathering, transport and processing will be investigated though to provide more information to this area of SG testing.

METHODS AND MATERIALS

This study was conducted at the Michigan State University Poultry Research and Teaching Farm in the House Seven commercial egg research facility. There, egg quality studies using SG testing was one of several ongoing studies.

House Seven contained two identical laying chambers or rooms. Each room was 6.1m x 31.1m x 2.54m (20' x 102' x 8'4") and was equipped as the mirror image of the other. Each room contained one system or row of Chore-Time deep pyramid cages 40.6cm x 50.8cm (16" x 20") and one system or row of Chore-Time pyramid reverse cages 30.5cm x 40.6cm (12" x 16"). These cage rows were a modified stair-step, four-tier design that contained eight lines of cages per row and 60 cages per line. Figure 1. shows the general cage designs for the shallow and deep cage systems. Because performance of different colony sizes and different bird densities was one of the other studies in House Seven, five and six bird colonies were placed in the deep cages in alternating lines, and three and four bird colonies were placed in the reverse cages in alternating lines. The end result was a total of two rows of deep cages with five or six birds per cage and two rows of reverse cages with three or four birds per cage and a total of 32 lines. Figure 2 presents a general layout of the House Seven laying chambers. The house capacity was 8640 birds.

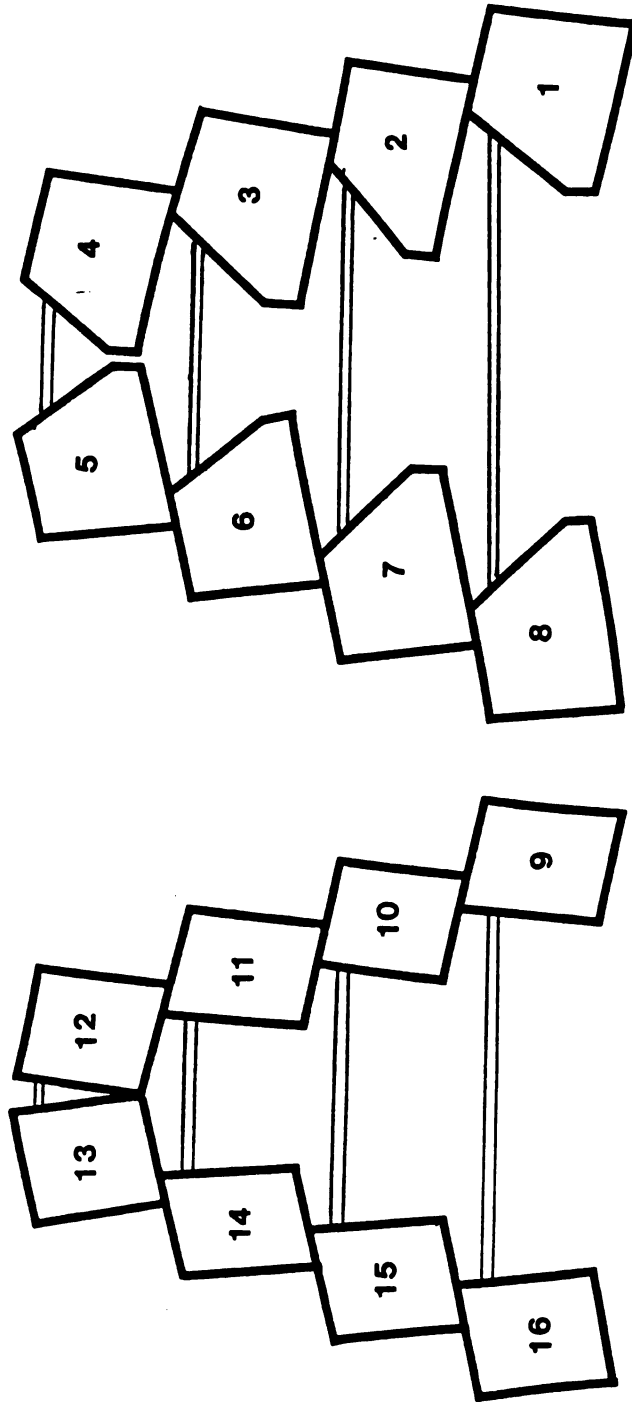


Figure 1. Shallow and deep cage systems labeled by line from House Seven green room.

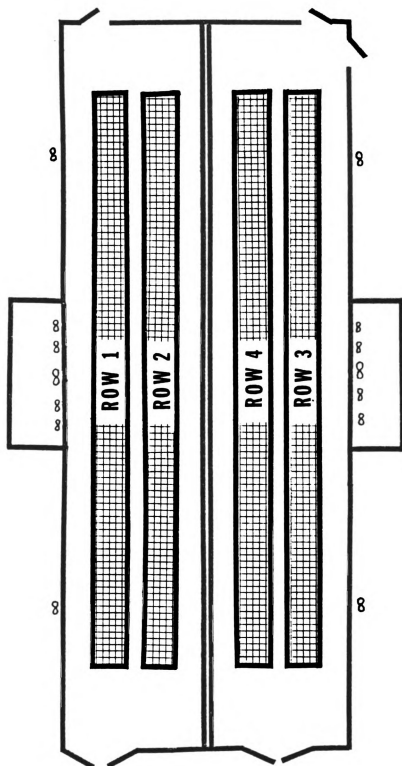


Figure 2. House Seven laying chambers.

ENVIRONMENT-The in-house target temperature range was 22.2 to 24.4 C (72 to 76 F). This was regulated by the ventilation fans and no supplemental heat was required. Ventilation in each room was provided by two 45.7cm (18") variable speed, four 70cm (24") and one 91.4cm (36") thermostatically controlled fans. The 45.7cm (18") variable speed fans operated continuously with a minimum air movement of 0.00566 cubic meters per minute per bird (0.20 cfm/bird). When the room temperature rose above 24.4 C (76 F) and the 45.7cm (18") fans were operating at maximum capacity, the 70cm (24") and 91.4cm (36") fans were phased in to attempt to maintain target temperatures. Air inflow was regulated by a static pressure system which controlled air inlet openings.

Light was provided by 75 watt white, incandescent bulbs and intensity was adjusted to 0.75 foot-candles as measured from the bottom tier of cages. At housing the lighting period was increased from 14 to 14 1/2 hours of light. Light was then increased 1/4 hour per week until 16 hours of light were provided at 25 weeks of age.

FEED-Diets were formulated according to standard commercial egg practice by Wayne Feeds and were reformulated as needed according to the age of the bird, feed consumption, average bird weight, average egg weight and egg production. Diets were identical in both rooms except for the source of calcium supplement. Birds in room one, or the green room, were fed a calcium source of 50/50 limestone and oystershell. Birds in room two, or the white room, were fed a calcium source of 100 percent limestone. Feed was served to the birds by four automatic feed carts. One cart serviced one row. Each cart was filled twice a day from separate bulk storage tanks. Load cells placed under the carts at 'home

position' made it possible to weigh the carts before and after each fill so that feed disappearance could be recorded for each cage row. Spouts from the feed cart led into each feed trough and could be adjusted to allow more or less feed into each trough. Carts were run on time clocks and were run 1/2 hour after lights were turned on in the morning, in the early afternoon, and three hours before lights were turned off in the evening.

Water was provided from Swish water cups placed on the side of every other cage so that one cup serviced two cages. Water meters were attached to the water lines servicing each row so that water disappearance could be measured for each row.

EGG COLLECTION-Eggs were collected twice a day at 9:00 a.m. and 1:00 p.m. EST. Production for each line was recorded. The eggs were placed in flats by hand, stored in the egg cooler at 12.8 C (55 F) and sold to a commercial packer.

MANURE COLLECTION-Droppings were contained in shallow pits under the cage rows. The pits were scrapped twice a day into a cross gutter at one end of the laying rooms and then moved outside.

BIRDS-8640 DeKalb XL pullets were housed in the facility at 19 weeks of age. All the birds were from one source and had been raised according to commercial practices. They had been cage-reared and vaccinated for Marek's Disease, Newcastle, Bronchitis, Infectious Bursal Disease, Fowl Pox and Avian Encephalomyelitis.

At 67 weeks of age, the flock was induce molted. Food was withheld for nine days and lighting was reduced to nine hours of light. On the ninth day of molt, the birds were fed a molt ration containing one

percent calcium until day 28 when calcium was increased to two percent. Light was increased by 1/2 hour per week starting on the 28th day until they reached the target of 16 hours of light. A full-feed layer ration was fed starting on the 36th day. At 101 weeks of age, the flock was terminated.

Because of mortality during the pullet lay cycle, many cages were without the full complement of birds (i.e. five or six per deep cage; three or four per shallow cage). On the 28th day post molt, birds were taken from the bottom tier of cages to fill the upper cages to the correct colony size. This left two to three birds per cage in the bottom tiers (i.e. lines 1, 8, 9, 16, 17, 24, 25 and 32).

Thirty eggs per line were collected once a week from 21 to 66 weeks of age (the pullet cycle). From 73 to 100 weeks of age (the molted cycle), 30 eggs from each line in the upper three tiers were collected. The bottom tiers were excluded. SG samples from the molted flock were collected once a week from 75 to 100 weeks of age. The eggs samples were collected between 8:00 and 10:00 EST and were collected from the population of eggs laid the previous 24 hours. The 1:00 p.m. egg collection was skipped the day before allowing samples to be taken from a normal proportion of afternoon and morning eggs. This was done because of studies showing that eggs laid in the morning tend to have poorer shell quality than those laid in the afternoon (Roland, et al., 1973; Potts and Washburn, 1974; Choi, et al., 1981). Random collection within each line was carried out each week by picking a random number between one and sixty. This represented the *n*th cage in a line which was where egg collection started. From this point, the first 30 eggs on the egg

belt were picked up excluding soft-shelled eggs and leakers. Egg samples were then stored for 24 hours along with the SG solutions to allow solution and egg temperatures to equalize.

The SG solutions used in this research were 1.065, 1.070, 1.075, 1.080 and 1.085. Feed grade salt and tap water were mixed and adjusted to the proper SG using a hydrometer with a range of 1.060 to 1.10 and gradations of 0.0005. The solutions were stored in five-gallon plastic tubs with sealable lids. These solutions were adjusted every week just prior to use. Thirty eggs, the sample from one line, were placed in a wire mesh basket constructed to fit just inside the plastic tubs. The eggs and basket were immersed in each solution starting with the lowest solution of 1.065. Eggs that floated were removed and placed in a flat in front of that solution. The eggs were then immersed in the next highest solution and the procedure repeated. Eggs that did not float in the highest solution were placed in a separate flat. The number of eggs that floated in each solution was recorded along with the number of eggs that did not float in any solution.

The eggs were assigned the SG of the solution in which they floated, and the eggs that did not float in any solution were assigned the SG of 1.090. The SG mean of the sample was calculated by summing the product of the SG solutions and the number of eggs that floated in them and then dividing this sum by the total number of eggs in the sample. The weekly weighted average SG mean of all egg samples was calculated by multiplying each sample mean by the egg production from that line, summing all weighted means and then dividing the summation by total egg production.

To evaluate the accuracy of simplified SG testing versus the more elaborate, five-solution SG testing, it was assumed that the SG sample mean was the best method of interpreting egg SG scores. It was also assumed that the five-solution mean was an actual indicator of the true SG mean. Linear regression models were used to analyze the relationships between simplified testing and five-solution testing. The regressand in the models was the five-solution mean. The set of possible regressor variables included the percentage of eggs floating in the solutions chosen for simplified testing and the age of the birds. The linear regression equations will be presented in the text with the corresponding t-values in parenthesis below. The relationship of breakage from the commercial egg grader/packer to the weighted SG mean was analyzed by regressing breakage on the weighted average SG mean. Breakage is defined as the percentage leakers plus the percentage checks after transportation, washing and grading.

RESULTS

PULLET CYCLE

SG Trends:

The egg frequencies among the six SG categories appeared to be normally distributed. Figure 3 illustrates percentage distribution at 25, 35, 45, 55 and 65 weeks of age. The test of multinomial goodness of fit was used to test the hypothesis of normality for the frequency distributions illustrated. Expected values were calculated for each category using the weighted SG mean and the standard deviation. The hypothesis of normality was not rejected. The distributions during weeks 25 and 35 may have appeared as a result of insufficient SG solutions in the top categories. As age increased the distribution shifted left and expanded. Ninety point four percent of all eggs from the pullet cycle fell into the categories 1.075, 1.080, 1.085 and 1.090. This agrees with findings from Strong and Reynnells (1983) who found 90 percent of eggs from three pullet flocks and three molted flocks fell into the above categories.

The SG mean (SGM), standard deviation (SD) and coefficient of variation (CV) were calculated for each sample and showed definite trends over the age of the flock. The linear regression of SGM on age was:

$$1.0813 = 1.0904 - 0.0002090 \times \text{age} \\ (5360.68) (-46.73)$$

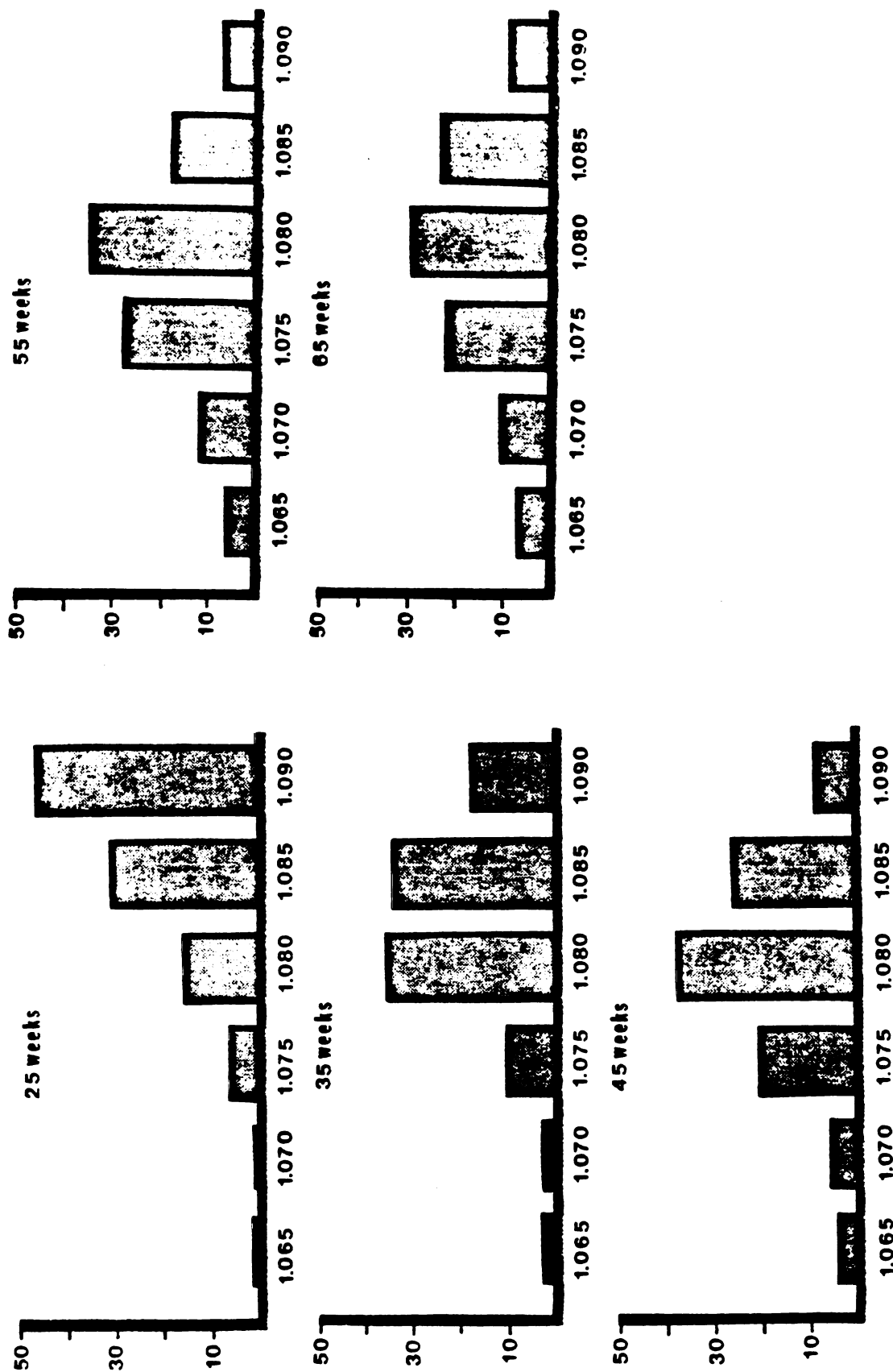


Figure 3. SG frequency distributions from 25, 35, 45, 55 and 65 weeks of age. SG solutions represented on -axis; percent of eggs represented on -axis.

Figure 4 illustrates the decline in the SGM as age increased. This supports findings by Doyon, et al. (1985) who showed a similar decline in SGM from 197 to 490 days of age and was expected as it follows the general decline in egg shell strength.

The relationships between the SD and age and the CV and age are shown in Figures 5 and 6, respectively. The SD increased linearly as age increased which is contrary to what Doyon et al. (1985) observed. The regression equation is:

$$.005423 = .003178 + 0.000052 \times \text{age} \\ (37.56) \quad (27.75)$$

The CV also increased as age increased. The regression equation was:

$$.502 = .290 + 0.005 \times \text{age} \\ (36.99) \quad (28.19)$$

Procedure Simplification:

The first step toward simplifying SG testing procedures was to determine whether one solution would provide sufficient information to predict the SG mean. Linear regressions were used to analyze the relationship between the information obtainable from one versus five SG solutions. The solutions 1.075, 1.080 and 1.085 were analyzed. They were chosen because the SG mean fell most often in those categories. A fourth single solution procedure was also analyzed. The SGM was around 1.085 from 21 to 31 weeks of age when it started declining rapidly. One solution of 1.085 could feasibly be used through 30 weeks of age and then changed to 1.080 from 31 weeks of age on.

The regressand in the models was the SGM and the regressor was the percentage of eggs floating in the single solution that was being analyzed. Table 1. shows the coefficients of determination (R^2) and the

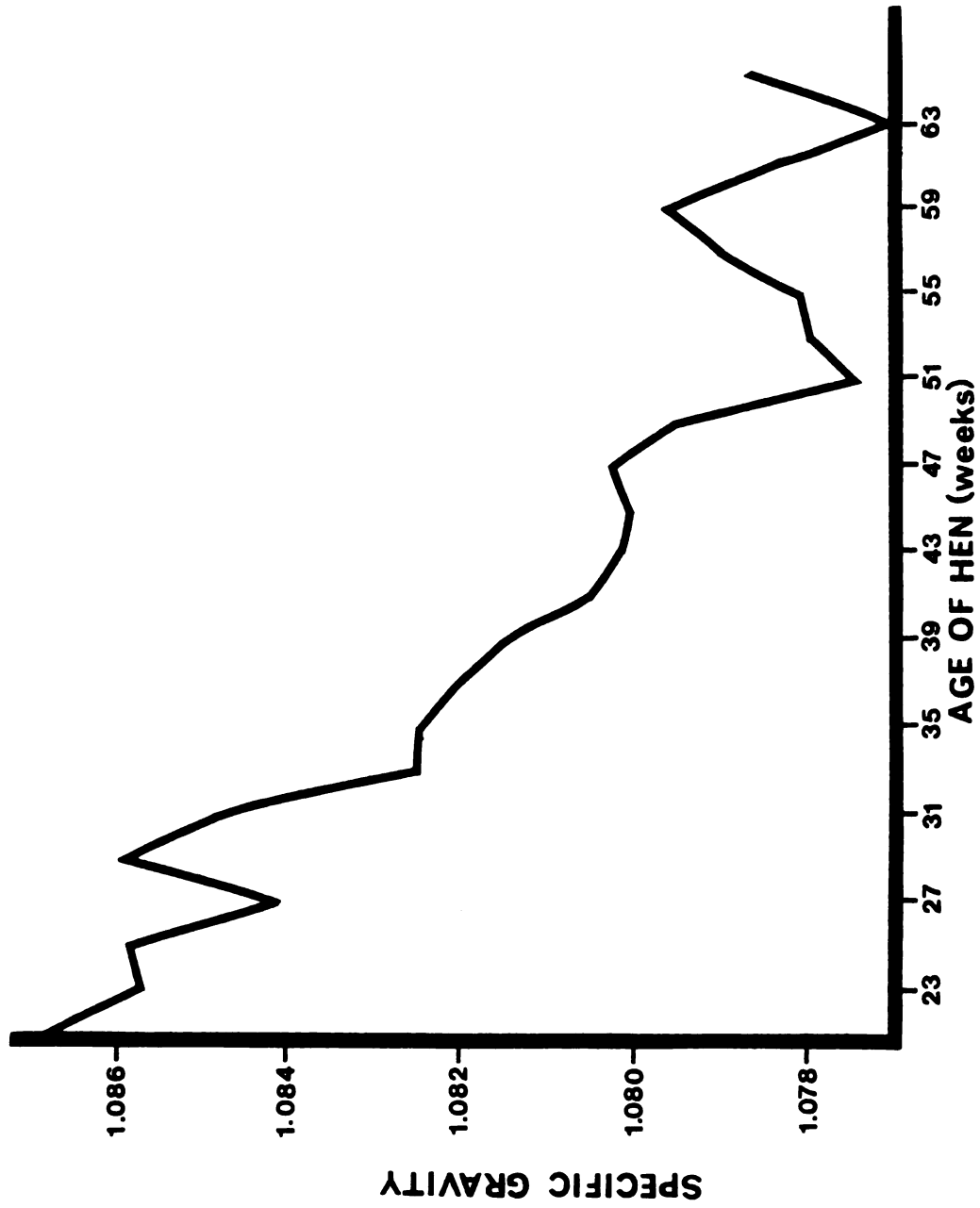


Figure 4. Relationship between the five-solution SG mean and age (pullet).

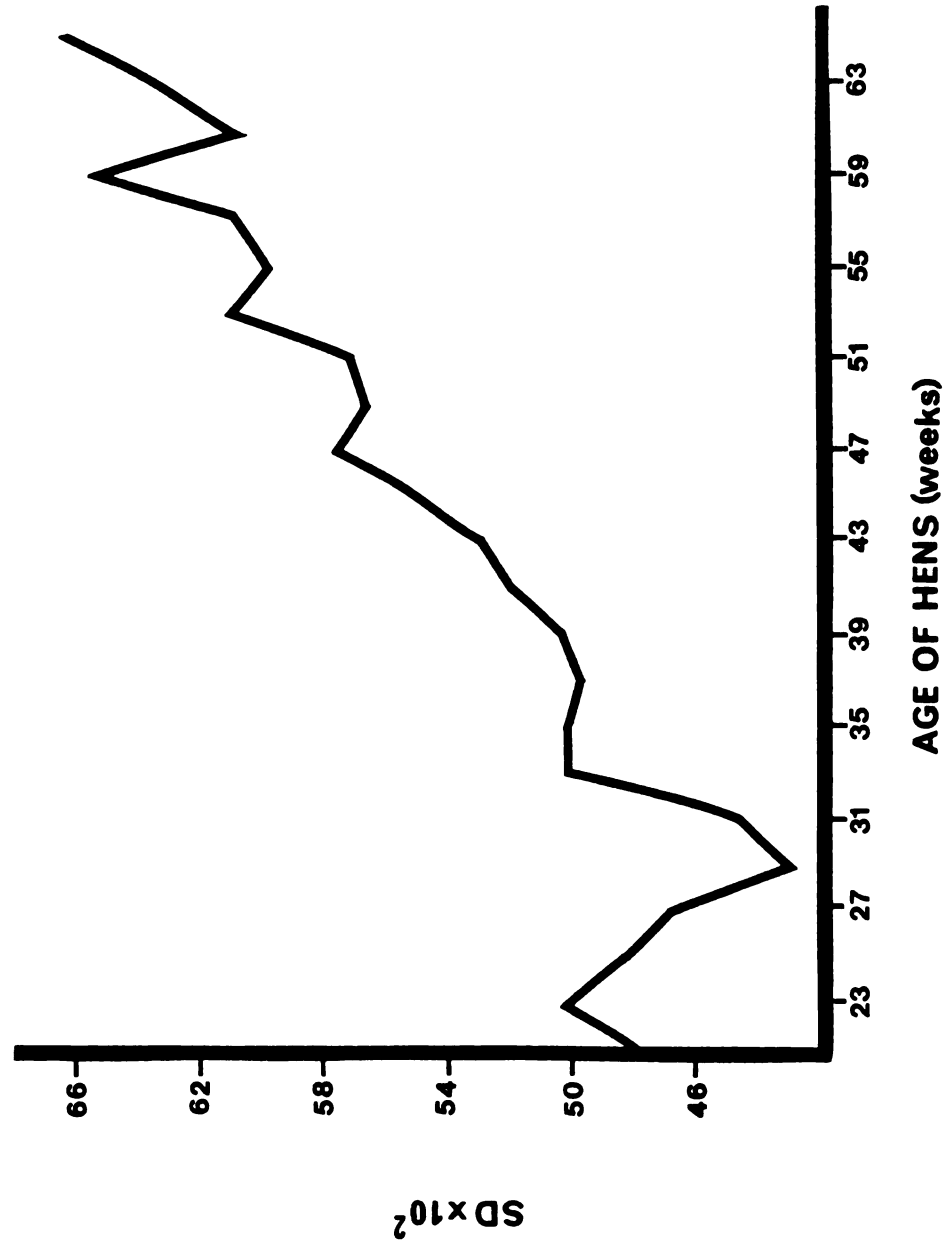


Figure 5. Relationship between SG standard deviation and age (pullet).

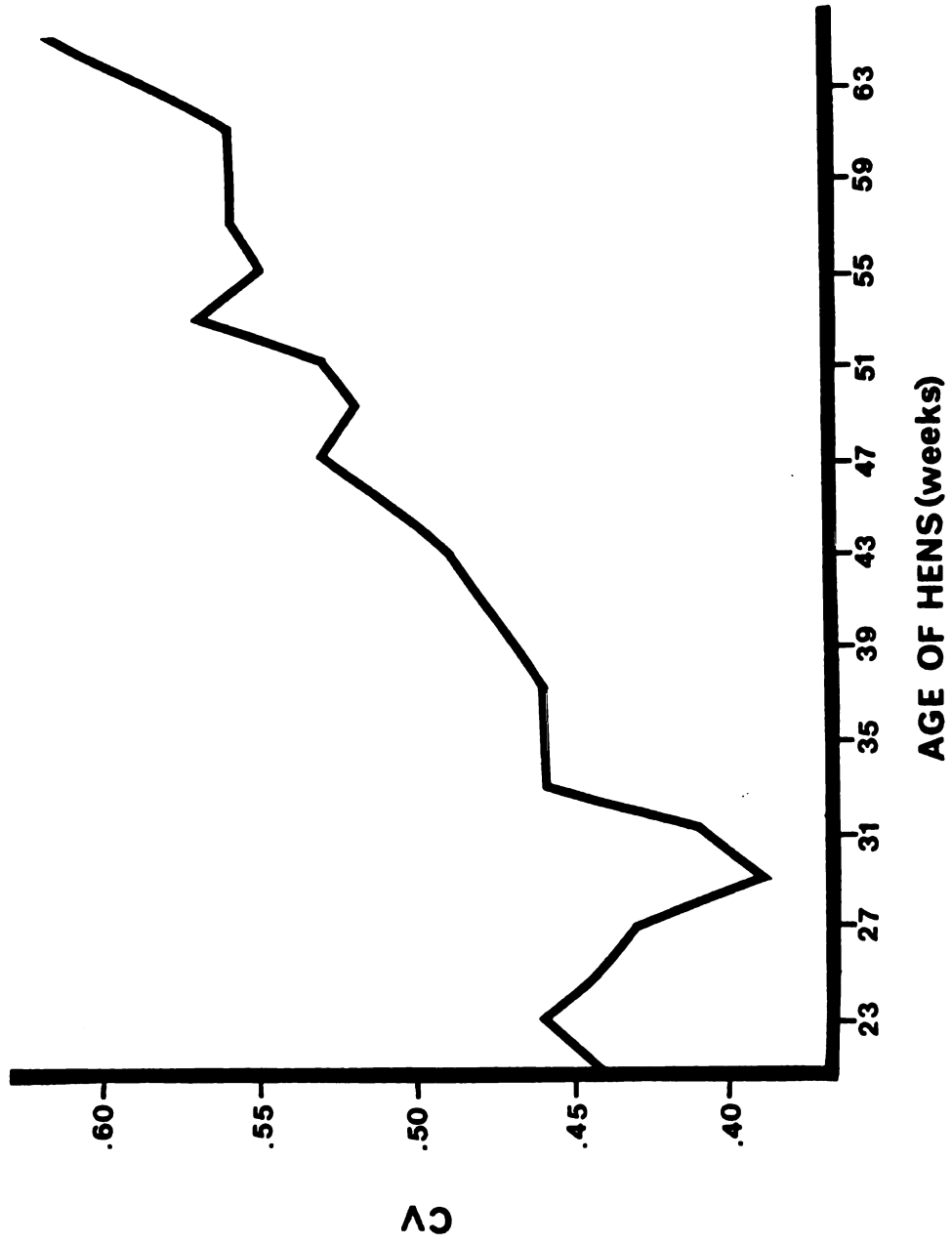


Figure 6. Relationship between SG coefficient of variation and age (pullet).

residual mean square errors for each of the four solution alternatives. The solution 1.080 produced the highest R^2 and the lowest mean square error. Age and age² were added to this selected base model to see if they could contribute to the model. These results are shown in Appendix A.1., section a. Statistically, both age and age² significantly improved the model.

The three models that contained the information obtainable from the solution 1.080 all showed a strong relationship to the SGM. Ninety-five percent confidence intervals were calculated for each of these models to test the precision of the predictions. The confidence intervals from the base model using 1.080 are presented in Table 2. Appendix A.1., section b. contains the confidence intervals for the regression models containing age and age². Confidence intervals are always narrowest at the regressor variable means, therefore, the 95 percent confidence intervals were calculated at the mean values, and at each variable's extreme values (the other variables at this time were at their mean).

The next step toward simplifying SG procedures was to analyze the relationships between information obtainable from two SG solutions versus the SG mean. Three solution sets were analyzed: 1.070 and 1.080; 1.075 and 1.080 and; 1.075 and 1.085. These provided three SG categories which included the major proportion of eggs. The regressor variables for the linear regression models were the percent of eggs floating in the lowest solution and the percent of eggs floating in the highest solution. The two-solution set, 1.070 and 1.080, produced the highest R^2 and the lowest mean square error. Age was then added to this base model to try to improve it. Statistically, it significantly improved the

Table 1. Relationship between the five-solution SG mean and one SG solution (pullet).

Regressor	Coefficient of Determination	Mean Square Error
One solution=1.075 % in 1.075	.859	18.51×10^{-3}
One solution=1.080 % in 1.080	.938	7.97×10^{-3}
One solution=1.085 % in 1.085	.769	26.34×10^{-3}
One solution=1.085 to week 30 =1.080 after week 31 % in 1.085 / % in 1.080	.707	37.86×10^{-3}

Table 2. Ninety-five percent confidence intervals for the SG mean predictions from the SG solution 1.080 (pullet).

Regression Model: SGM = constant + % in 1.080			
Regressor Value	Prediction Estimate	Lower-Upper	Crude Range
Mean	1.0813	1.0762-1.0863	.009861
Minimum % at 1.080	1.0887	1.0767-1.1008	.019940
Maximum % at 1.080	1.0751	1.0650-1.0853	.023541

Table 3. Relationship between the five-solution SG mean and two SG solutions (pullet).

Regressors	Coefficient of Determination	Mean Square Error
Two solutions=1.070, 1.080 % in 1.070 % in 1.080	.911	1.24×10^{-6}
Two solutions=1.075, 1.080 % in 1.075 % in 1.080	.906	1.30×10^{-6}
Two solutions=1.075, 1.085 % in 1.075 % in 1.085	.909	1.26×10^{-6}

Table 4. Ninety-five percent confidence intervals for the SG mean predictions from the SG solutions 1.070 and 1.080 (pullet).

Regression Model: $SGM = \text{constant} + \% \text{ in } 1.070 + \% \text{ in } 1.080$			
Regressor Value	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0883	1.0883-1.0884	.000124
Minimum % at 1.070	1.0883	1.0882-1.0884	.000183
Maximum % at 1.070	1.0882	1.0878-1.0886	.000837
Minimum % at 1.080	1.0884	1.0882-1.0885	.000327
Maximum % at 1.080	1.0883	1.0881-1.0884	.000301

Table 5. Relationship between the five-solution SG mean and three SG solutions (pullet).

Regressors	Coefficient of Determination	Mean Square Error
Solutions=1.065, 1.075, 1.085 % in 1.065 % in 1.075 % in 1.085	.917	1.16×10^{-6}
Solutions=1.070, 1.075, 1.080 % in 1.070 % in 1.075 % in 1.080	.914	1.19×10^{-6}
Solutions=1.075, 1.080, 1.085 % in 1.075 % in 1.080 % in 1.085	.921	1.10×10^{-6}

Table 6. Ninety-five percent confidence intervals for the SG mean predictions from the SG solutions 1.075, 1.080 and 1.085 (pullet).

Regression Model: $SGM = \text{Constant} + \% \text{ in } 1.075 + \% \text{ in } 1.080 + \% \text{ in } 1.085$			
Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0900	1.0900-1.0901	.000117
Minimum % at 1.075	1.0901	1.0899-1.0902	.000237
Maximum % at 1.075	1.0899	1.0896-1.0902	.000508
Minimum % at 1.080	1.0900	1.0899-1.0902	.000286
Maximum % at 1.080	1.0900	1.0898-1.0902	.000408
Minimum % at 1.085	1.0900	1.0899-1.0902	.000343
Maximum % at 1.085	1.0900	1.0897-1.0903	.000562

model. The regression results for the base model are displayed in Table 3 and the regression results for the models containing age are presented in Appendix A.2., section a. Ninety-five percent confidence intervals were calculated for the two models containing information from the two-solution set 1.070 and 1.080. The confidence intervals for the base model are presented in Table 4. Appendix A.2, section b. contains the 95 percent confidence intervals for the regression model containing age.

The next step to simplifying SG procedures was to determine if three solutions provided sufficient information to precisely predict the SG mean. Three three-solution sets were analyzed: 1.065, 1.075 and 1.085; 1.070, 1.075 and 1.080 and; 1.075, 1.080 and 1.085. The results are shown in Table 5. The set 1.075, 1.080 and 1.085 produced the highest R^2 and lowest residual mean square error. Ninety-five percent confidence intervals were calculated and are presented in Table 6.

MOLTED CYCLE

SG Trends:

The frequency distributions from the molted flock at 75, 85 and 95 weeks of age are displayed in Figure 7. Again, the test of multinomial goodness of fit was used to test the hypothesis of normality. The hypothesis of normality was not rejected. The distribution shifted to the left as age increased following the pattern exhibited by the pullet cycle.

The SGM, SD and CV also showed the same trends exhibited by the pullet cycle. The SGM decreased as age increased at a faster rate of decline than that occurring in the pullet cycle with a linear regression

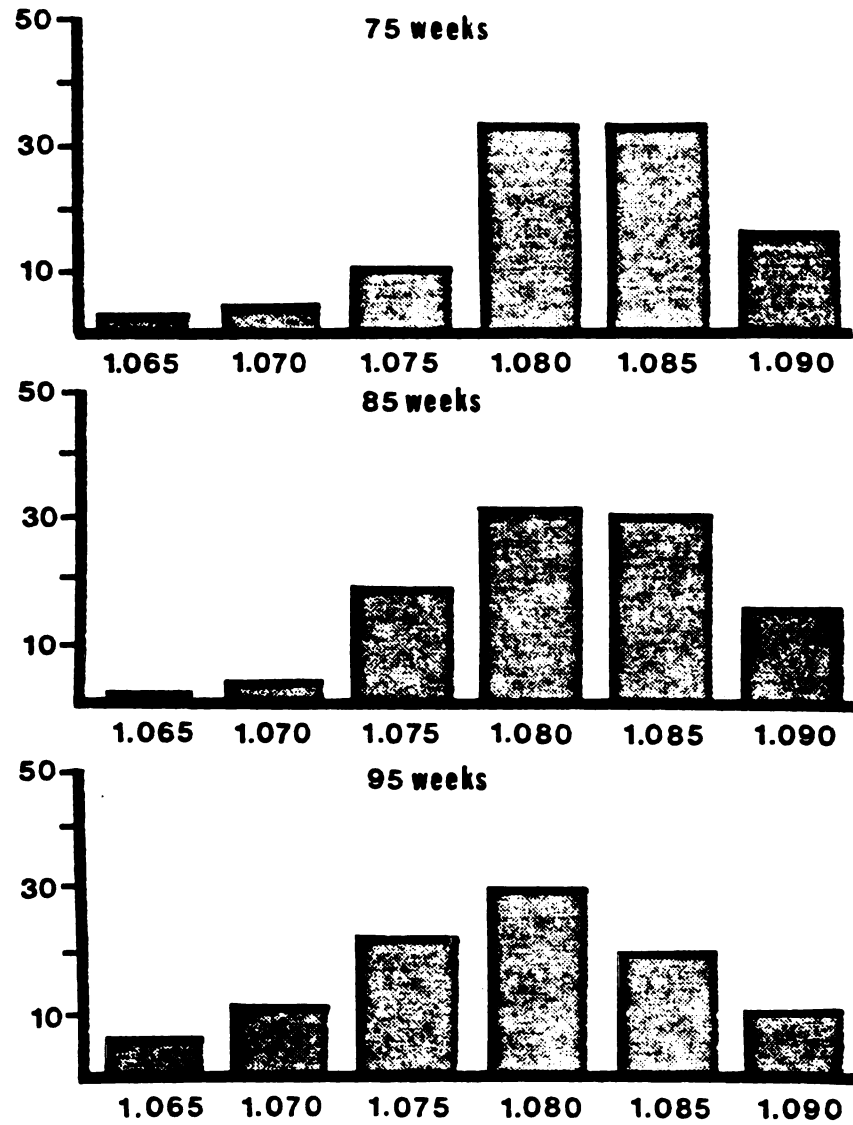


Figure 7. SG frequency distributions from 75, 85 and 95 weeks of age. SG solutions represented on X-axis; percent of eggs represented on Y-axis.

of:

$$1.0811 = 1.1021 - 0.000243 \times \text{age} \\ (1080.08) \quad (-20.70)$$

The extremely low SGM from age 73 to approximately age 76 could have been caused by problems that occurred in the feed system and would not normally be this low for a molted flock in the first four weeks of production following molt.

The SD and CV also show the same trends exhibited by the pullet flock, as SD and the CV increased as age increased. The regression equations, respectively, are:

$$.005490 = -.000215 + 0.000066 \times \text{age} \\ (-.57) \quad (15.14)$$

$$.508 = -.030 + 0.0062 \times \text{age} \\ (-.84) \quad (15.34)$$

Both slopes were greater during the molted cycle than during the pullet cycle.

Procedure Simplification:

The molted cycle data was analyzed using the same steps that were used for the pullet cycle. Linear regression models were used to assess the strength of the relationships between one, two and three solutions versus the SGM. The single solutions and the two- and three-solution sets analyzed were the same as those of the pullet cycle, and the results were very similar. Again, 1.080 and 1.070 and 1.080 were the single and two solutions that produced the strongest relationship to the SGM. The three solutions selected this time were 1.070, 1.075 and 1.080. Age and age² were again added to the one, two and three solution base models and the 95 percent confidence intervals calculated. The

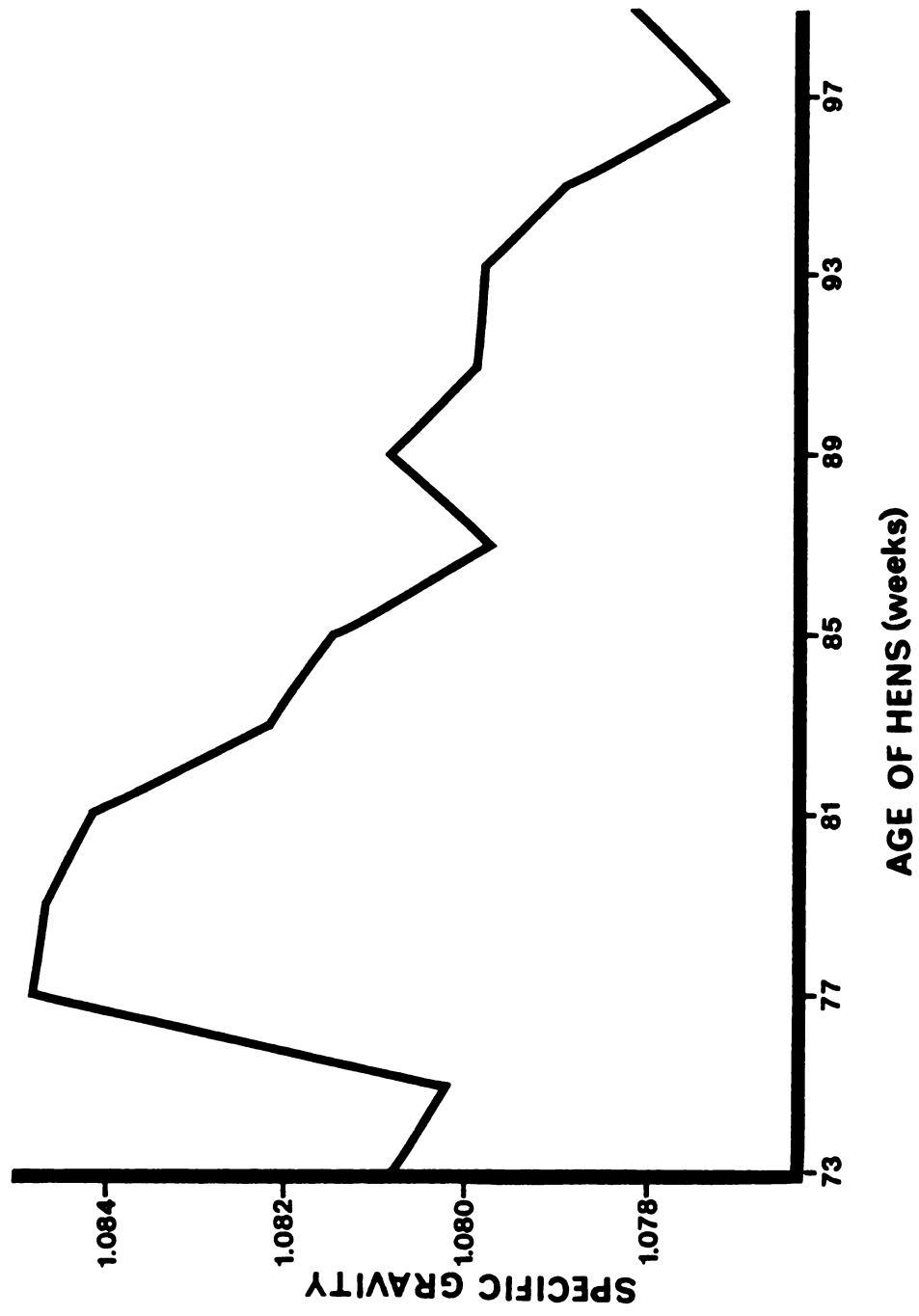


Figure 8. Relationship between five-solution SG mean and age (molted).

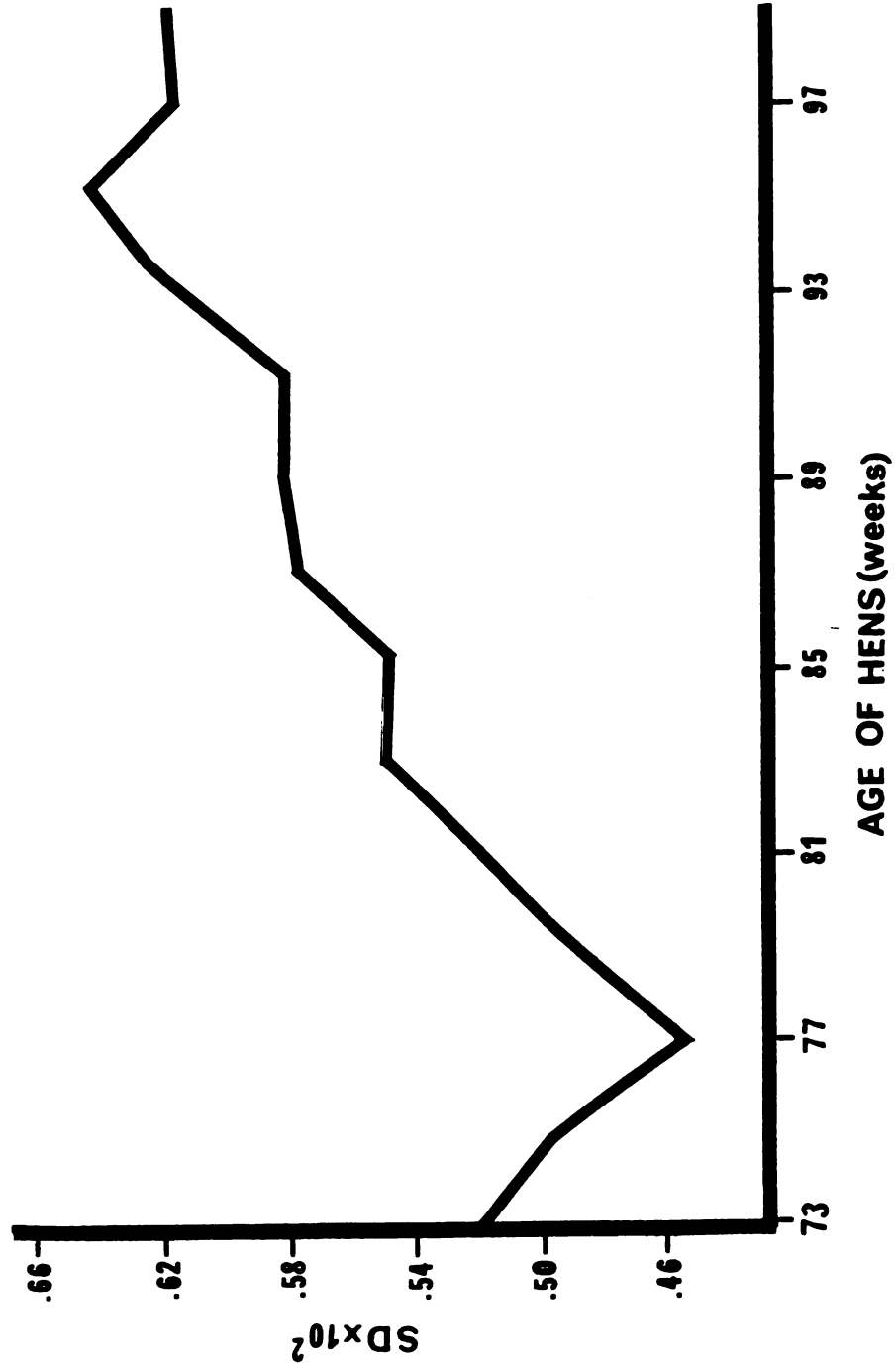


Figure 9. Relationship between SG standard deviation and age (molted).

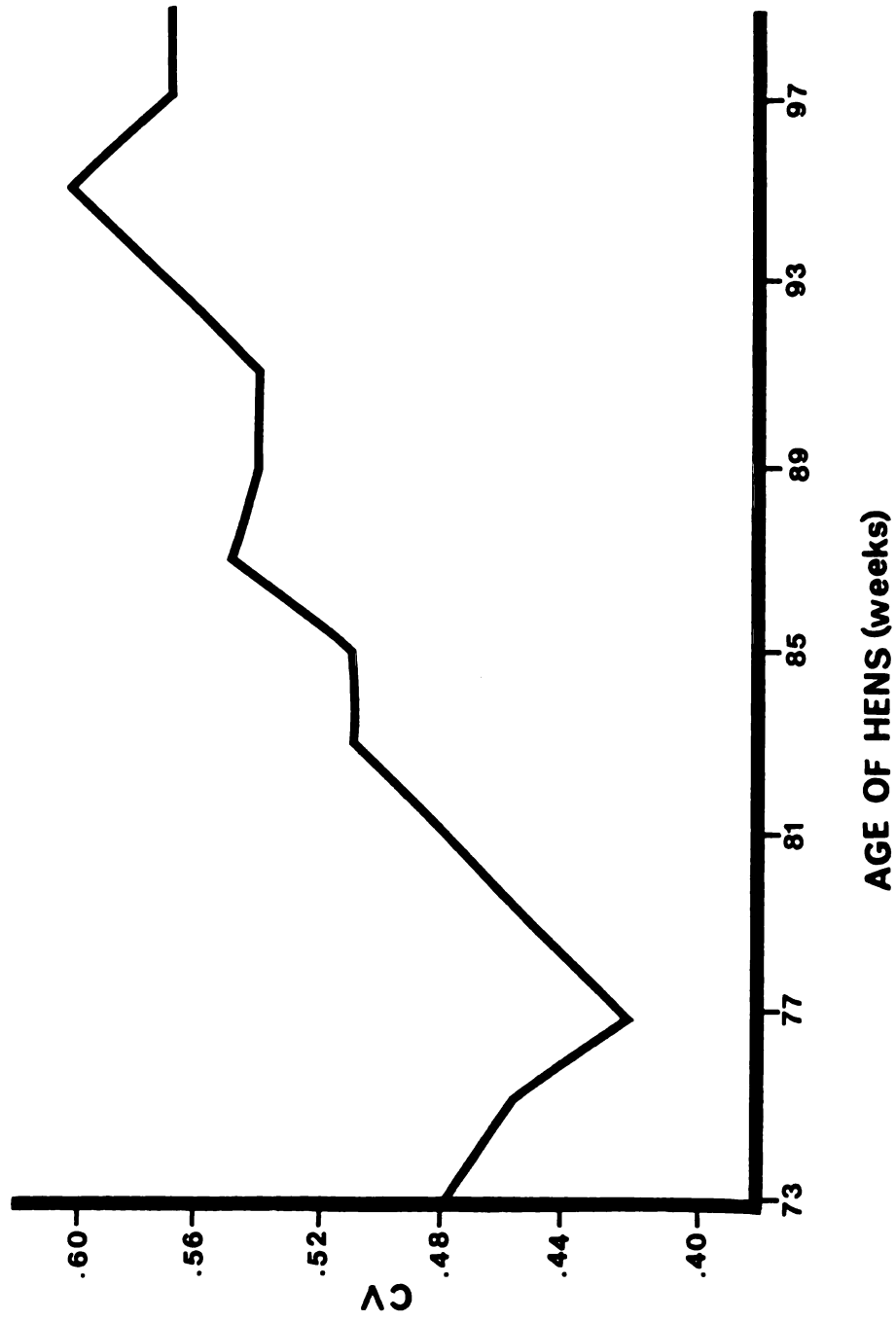


Figure 10. Relationship between SG coefficient of variation and age (molted).

Table 7. Relationship between the five-solution SG mean and one SG solution (molted).

Regressor	Coefficient of Determination	Mean Square Error
Solution=1.075 % in 1.075	.891	10.76×10^{-3}
Solution=1.080 % in 1.080	.896	10.23×10^{-3}
Solution=1.085 % in 1.085	.711	28.54×10^{-3}

Table 8. Ninty-five percent confidence intervals for the SG mean predictions from the SG solution 1.080 (molted).

Regression Model: SGM = Constant + % in 1.080			
Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0811	1.0727-1.0895	.016542
Minimum % at 1.080	1.0881	1.0663-1.1100	.042807
Maximum % at 1.080	0.9513	0.6268-1.2758	.635985

Table 9. Relationship between the five-solution SG mean and two SG solutions (molted).

Regressor	Coefficient of Determination	Mean Square Error
Solutions=1.070, 1.080 % in 1.070 % in 1.080	.968	0.316×10^{-6}
Solutions=1.075, 1.080 % in 1.075 % in 1.080	.957	0.430×10^{-6}
Solutions=1.075, 1.085 % in 1.075 % in 1.085	.952	0.479×10^{-6}

Table 10. Ninety-five percent confidence intervals for the SG mean predictions from the SG solutions 1.070 and 1.080 (molted).

Regression Model: $SGM = \text{Constant} + \% \text{ in } 1.070 + \% \text{ in } 1.080$			
Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0812	1.0814-1.0812	.000092
Minimum % at 1.070	1.0832	1.0831-1.0833	.000127
Maximum % at 1.070	1.0619	1.0615-1.0623	.000809
Minimum % at 1.080	1.0857	1.0855-1.0858	.000284
Maximum % at 1.080	1.0778	1.0777-1.0780	.000218

Table 11. Relationship between the five-solution SG mean and three SG solutions (molted).

Regressor	Coefficient of Determination	Mean Square Error
Solutions=1.065, 1.075, 1.085 % in 1.065 % in 1.075 % in 1.085	.970	0.300×10^{-6}
Solutions=1.070, 1.075, 1.080 % in 1.070 % in 1.075 % in 1.080	.976	0.237×10^{-6}
Solutions=1.075, 1.080, 1.085 % in 1.075 % in 1.080 % in 1.085	.967	0.236×10^{-6}

Table 12. Ninty-five percent confidence intervals for the SG mean predictions from the SG solutions 1.070, 1.075 and 1.080 (molted).

Regression Model: $SGM = \text{Constant} + \% \text{ in } 1.070 + \% \text{ in } 1.075 + \% \text{ in } 1.080$			
Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0812	1.0811-1.0812	.000080
Minimum % at 1.070	1.0831	1.0831-1.0832	.000113
Maximum % at 1.070	1.0628	1.0625-1.0632	.000751
Minimum % at 1.075	1.0831	1.0830-1.0832	.000156
Maximum % at 1.075	1.0769	1.0768-1.0771	.000310
Minimum % at 1.080	1.0836	1.0835-1.0838	.000230
Maximum % at 1.080	1.0783	1.0781-1.0784	.000268

linear regression results and 95 percent confidence intervals for the molted cycle base models are presented in tables 7 through 12. The models containing age and age are presented in Appendices A.3. and A.4..

SG VERSUS BREAKAGE

Linear regressions were used to investigate the relationship between the weighted average SGM and breakage which was defined as the percentage checks plus the percentage leakers listed on the gradeout sheet. This relationship is illustrated by the scatter plot in Figure 11.

The regressand of the linear regression models was the percentage breakage. Four regressions were analyzed using the regressor variables 1) the SGM, 2) the SGM plus SD, 3) the inverse of the SGM and 4) the SGM plus the SGM. The R^2 , mean square errors and two-tailed P values for each regressor variable are presented in Table 13.

The first model only produced a R^2 of .527, but the P value for the SGM coefficient indicated that the SGM was a significant regressor variable. When the SD was added, the R^2 increased to .542, but the P value indicated that the SD coefficient was only significantly different from zero at the .157 level. The third model produced results very similar to the first model with an R^2 of .527, a very similar mean square error and a significant P value for the regressor, the SGM inverse. The fourth model produced a R^2 of .528, but both SGM and SGM were insignificant regressors.

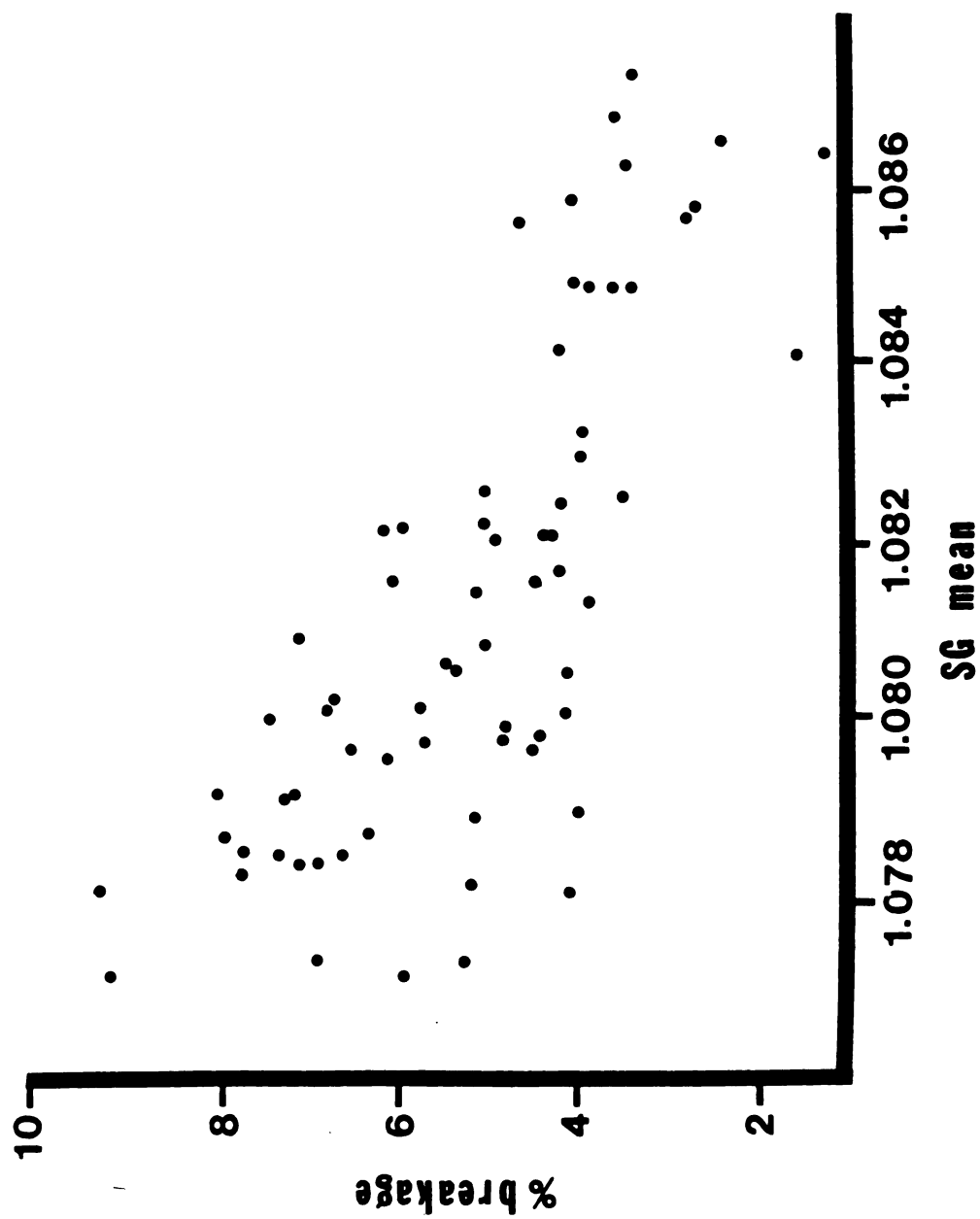


Table 13. The relationship of breakage to the weighted average specific gravity mean of all egg samples.

Regression Variables	coefficient of determination	Mean square error	Two-tailed P value
SGM	.527	1.361	SGM=.000
SGM+SD	.542	1.340	SGM=.000 SD=.157
1/SGM	.527	1.361	1/SGM=.000
SGM+SGM ²	.528	1.380	SGM=.781 SGM ² =.789

DISCUSSION

SG TRENDS

The egg SG trends of decreasing SGM and increasing SD and CV over age reflect declining egg shell strength. Roland (1975) hypothesized that the decline in egg shell strength as a hen ages is due to the increase in egg size without a relative increase in the amount of shell deposited around the egg. This appears to be supported by the decline in the SGM which is highly correlated to percentage shell. The increase in SD indicates more variability is expressed by the birds as they age. Further research to study whether the increased variability is due to an increase in variability within the hen or among the hens, would enhance knowledge about egg SG trends and about shell strength trends.

The SD trend also may reflect that percent breakage is deteriorating more rapidly than suggested by the decline in SGM alone. Because of the curvilinear relationship (i.e. cracks decrease at a decreasing rate as SG increases) between SG and percentage cracks (Wells, 1967a), an egg sample with a SG mean of 1.0775 may yield fewer cracks than an egg sample with a larger SD but the same mean. This concept is illustrated in Table 14 where the sample with the largest variability showed greater percentage cracks which were estimated using data from Wells (1967a).

Table 14. Prediction of percentage cracks from two hypothetical egg samples.

Solution	% Cracks ¹			% Cracks ²	
		Sample 1	Sample 2	Sample 1	Sample 2
1.065	21.3	0	4	0.0	0.852
1.070	13.8	5	5	0.69	0.690
1.075	10.1	10	6	1.01	0.606
1.080	5.7	10	6	0.57	0.342
1.085	4.4	5	5	0.22	0.220
1.090	0.0	0	4	0.0	0.0
				2.49	2.710

¹Wells (1967a)

²Predicted cracks calculated by multiplying percentage cracks for each solution by number of eggs floating in that solution and summing products across all solutions.

The relationship of SGM to breakage in this experiment, however, did not appear to support this concept. When SD was added to SGM as a regressor of the percentage breakage, the resulting P value for this variable was .157, a value large enough to indicate that SD is not an important variable in describing breakage.

PROCEDURE SIMPLIFICATION:

In order to better describe the relationships between simplified SG testing procedures and the more universal five-solution testing procedures, all analyses were performed on the flock for both its pullet and molted cycle. The molted cycle data were expected to validate or invalidate the optimal number of solutions that were found for the pullet cycle, and many of the same results were replicated.

The R^2 presented in this experiment show strong relationships between one, two and three solutions and the SGM. The single solution 1.080 actually produced the highest R^2 from the pullet cycle, and the three solutions 1.070, 1.075 and 1.080 produced the highest R^2 from the molted cycle. However, the R^2 is not an exact measure of the precision of the predictions. It is possible to obtain better precision from a set of data with a somewhat lower R^2 than from a set of data with a higher R^2 . This occurred here when the 95 percent confidence intervals were calculated for selected models for each simplified procedure. The R^2 was only used to compare models from the same data sets to obtain the best single solution, the best two-solution set and the best three-solution set.

Precision estimates in the form of 95 percent confidence intervals provided additional information. Although the 1.080 base model for a single solution produced a high R^2 , the confidence intervals from both cycles were not good enough for practical use. Even when the base model was improved statistically by adding age and age², the resulting intervals were too wide. Actually, the intervals were even wider after adding age and age². Larimore and Mehra (1985) showed that while model error may be decreased when more, significant regressors are added to a model, the prediction error may actually start increasing after it reaches a minimum. This appears to have happened here.

Two reasons occur which suggest that the confidence intervals from the single solution 1.080 were too wide. One, the crude range at the mean values alone was almost twice as wide as the solution increment of 0.005, and of course this was wider when calculated at the regressor's extreme values. Two, according to Wells (1967a), the slope of the relationship between the percentage cracks and SG is steep enough that an interval of 1.076 to 1.086 could include a difference of 10.1 percent to 4.4 percent cracks. Therefore, the SGM predictions obtained from the single solution linear regression equation are not able to predict the SGM with enough precision.

The two-solution set of 1.070 and 1.080 was the best of the three analyzed for both the pullet and molted cycle. The 95 percent confidence intervals were markedly improved over those from the single solution and were very similar across the pullet and molted cycle. In both cases, the intervals at the mean values from the base model were only about one-fiftieth as wide as the solution increment, and the widest intervals

were still only about one-fifth of the solution increment. The addition of age to the base model did not improve precision although it improved the model statistically.

The two-solution set of 1.070 and 1.080 gives enough information to predict the SGM precisely enough for practical use for both pullet and molted flocks. Also, the information can easily be set up in tables, so the SG tester would be able to quickly and readily interpret his/her SG scores.

However, could more precision be obtained from procedures utilizing three SG solutions, and would the increased precision offset the added burden of using one more solution? The results indicate very little, if any, improvement in precision. The only evident improvement is obtained from the pullet cycle. The largest interval from the two-solution procedure is almost twice that of the largest interval from the three-solution procedure. No practical difference existed between the two procedures for the molted cycle.

To summarize the results of simplifying SG testing procedures, the two-solution procedure using 1.070 and 1.080 provides enough information to precisely predict the SGM and is still simple and quick to use. One solution is inadequate to precisely predict the SGM, and three solutions do not improve precision enough to warrant the third solution.

SG VERSUS BREAKAGE:

The rate of breakage, in this study, was highly related to the overall SGM. The scatter plot in Figure 11 shows a decrease in percentage breakage as the overall SGM increased. The relationship

may or may not be linear as this study revealed that both the overall SGM and the inverse of the overall SGM explained 52.7 percent of the variation in percentage breakage, and the coefficient P values indicated that the regressor coefficients in both models were significantly different from zero. It is possible that a curvilinear relationship such as that described by Wells (1967a) exists between percentage breakage and the SGM, but the range of values for the SGM was so narrow, 1.077 to 1.087, that the relationship in this study appeared linear.

The wide dispersion of data points around any one SGM in the scatter plot and the amount of variation still unexplained by any of the regression models suggests that many other factors have the potential to affect breakage rates. Some of these factors known to vary over the course of this study include 1) the height egg flats were stacked for transport to the egg grader/packer, 2) the steps involved between accumulating eggs from the collection belts and placing the eggs in flats, 3) machinery adjustments and 4) personnel changes. Many other factors influence breakage that we could not or did not attempt to control.

Many factors have the potential to influence breakage rates, and because the presence of these factors varies from house to house, farm to farm, company to company, etc., a general or universal prediction of percentage breakage given the SGM only is not possible. However, if these factors could be kept fairly constant in one certain house or location, past performance data and past SG records may be used to obtain a good estimate of breakage from that location. Also, the SGM can still be used to evaluate relative egg shell strength and can aid in business and farm management decision-making.

RECOMMENDATIONS FOR STANDARDIZING PROCEDURES

A set of standard SG testing procedures would be invaluable for business and farm management decision-making. Procedural steps that currently vary according to the opinion of the tester include 1) the inclusion of cracked eggs in the egg sample, 2) the sample size, 3) the storage of samples and solutions prior to testing, 4) the method of reporting test results and 5) the number of SG solutions. If these procedural steps were standardized, the SG information from one egg sample would consistently have the same meaning whether or not testing was performed on different farms, companies, strains, etc. Thus, managers could readily compare their own results to those available throughout the poultry industry and know that differences between one sample and another is due to differences in the eggs and not to testing procedures. The following are recommendations for standardizing the six procedural steps listed above.

Voisey and Hamilton (1977) reported that hairline cracks produced insignificant errors to SG measurements. Strong and Reynnells (1983) and Potts and Washburn (1974) candled all eggs and removed the cracked eggs before performing SG tests. Wells (1967a) included cracked eggs in his SG tests. It is recommended here that eggs with hairline cracks not be removed prior to SG testing. Candling all eggs to remove checks would be time consuming and could produce a bias as removing checks could mean removing a portion of weaker shelled eggs.

Doyon (1984) stated that a sample size of nine eggs was sufficient for estimating the SG mean from birds 197 to 490 days of age. However,

Doyon et al. (1985) observed no trend in SD, and this study did observe an increase in SD over the age of the flock. Because of the discrepancy between the two findings, a sample size of 30 eggs or one flat is recommended. A flat is also easy to collect and store, and since samples should be collected from any location (i.e. house, feed troughs, tier, etc.) where a different environment may have an impact on hen performance, a flat is also easy to label.

Egg samples and solutions should be stored together in an area where temperatures are constant over all seasons and similar across all testing sites. The recommended storage place is the egg cooler. Temperatures in egg coolers are usually held at a target temperature of 12.8 C (55 F) throughout the industry.

The recommended method of reporting test results is the SG mean. The mean is a single, concise number that can be readily compared to other means and can be easily benchmarked or displayed in a standard curve like those for bodyweight or egg production. One shortcoming of using a SG mean is that, under certain circumstances, a higher mean may not indicate better shell quality. This concept is illustrated in Table 15. A single egg sample was hypothetically tested using the three different solution sets shown. When the SG means were calculated, the eggs floating in the first solution were assigned the value of that solution even though there were eggs which actually had lower SG's. The eggs which sank in the highest solution were assigned the value of the next highest solution that would logically have been used. Because of these open-ended classes, different means can be calculated if different solution numbers are used. Another shortcoming to using the SG mean is

Table 15. Specific gravity means of the same egg sample obtained from three different solution sets.

Set 1		Set 2		Set 3	
<u>Solution</u>	<u>Number of Eggs</u>	<u>Solution</u>	<u>Number of Eggs</u>	<u>Solution</u>	<u>Number of Eggs</u>
1.065	72				
1.070	36				
1.075	27	1.075	135		
1.080	9	1.080	9	1.080	144
1.085	9	1.085	9		36
1.090	9		27		
1.095	9				
SG					
Mean	1.074		1.078		1.081

* Park and Rahn (1984)

that calculations can be somewhat time consuming, although they are not difficult.

To solve the problems listed above, a standard number of two solutions is recommended for SG testing. These solutions are 1.070 and 1.080. The SG scores from these two solutions can easily be applied to a reference table such as that presented in Table 16. The prediction of the five-solution mean which was obtained from the linear regression prediction equation, is the cross reference of the percent of eggs floating in 1.070 and the percent of eggs floating in 1.080. Thus, the SG mean is standardized to a five-solution reference and precision is retained. Using two solutions also reduces calculations, labor time, storage space and materials and provides an inexpensive and easy method of monitoring egg shell strength.

Table 16. SG mean predictions for egg samples being tested using the solutions 1.070 and 1.080.^{1,2}

% eggs in 1.070	% eggs in 1.080																		
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95
0-5	1.0876	1.0870	1.0865	1.0859	1.0854	1.0848	1.0842	1.0837	1.0831	1.0826	1.0820	1.0815	1.0809	1.0803	1.0798	1.0792	1.0787	1.0781	1.0776
5-10	1.0865	1.0860	1.0854	1.0849	1.0843	1.0837	1.0832	1.0826	1.0821	1.0815	1.0810	1.0804	1.0798	1.0793	1.0787	1.0782	1.0776	1.0771	1.0765
10-15	1.0855	1.0849	1.0844	1.0838	1.0832	1.0827	1.0821	1.0816	1.0810	1.0805	1.0799	1.0793	1.0788	1.0782	1.0777	1.0771	1.0766	1.0760	1.0755
15-20	1.0844	1.0838	1.0833	1.0827	1.0821	1.0816	1.0810	1.0805	1.0799	1.0794	1.0788	1.0783	1.0777	1.0771	1.0766	1.0760	1.0756	1.0751	1.0745
20-25	1.0834	1.0828	1.0823	1.0817	1.0811	1.0806	1.0800	1.0795	1.0789	1.0784	1.0778	1.0772	1.0767	1.0761	1.0756	1.0750			
25-30	1.0823	1.0818	1.0812	1.0806	1.0801	1.0795	1.0790	1.0784	1.0779	1.0773	1.0767	1.0762	1.0756	1.0751	1.0745				
30-35	1.0813	1.0807	1.0801	1.0796	1.0790	1.0785	1.0779	1.0774	1.0768	1.0762	1.0757	1.0751	1.0746	1.0740					
35-40	1.0802	1.0796	1.0790	1.0785	1.0779	1.0774	1.0768	1.0763	1.0757	1.0751	1.0746	1.0740	1.0735						
40-45	1.0791	1.0786	1.0780	1.0775	1.0769	1.0764	1.0758	1.0752	1.0747	1.0741	1.0736	1.0730							
45-50	1.0781	1.0775	1.0770	1.0764	1.0759	1.0753	1.0747	1.0742	1.0736	1.0731	1.0725								
50-55	1.0770	1.0765	1.0759	1.0754	1.0748	1.0742	1.0737	1.0731	1.0726	1.0720									
55-60	1.0760	1.0754	1.0749	1.0743	1.0738	1.0732	1.0726	1.0721	1.0715										
60-65	1.0749	1.0744	1.0738	1.0733	1.0727	1.0721	1.0716	1.0710											
65-70	1.0739	1.0733	1.0728	1.0722	1.0716	1.0711	1.0705												
70-75	1.0728	1.0723	1.0717	1.0711	1.0706	1.0700													
75-80	1.0718	1.0712	1.0706	1.0701	1.0695														
80-85	1.0707	1.0701	1.0696	1.0690															
85-90	1.0696	1.0691	1.0685																
90-95	1.0686	1.0680																	
95-100	1.0675																		

¹SG mean predictions calculated from the linear regression equation relating the SG mean to 1.070 and 1.080.

²the predicted SG mean for a sample of eggs is obtained by reading down to the % eggs in 1.070 and then across to the % eggs in 1.080.

SUMMARY

The percent breakage is highly related to the SG mean and decreases linearly as the SG mean increases. The number of factors which have the potential to influence breakage makes accurately predicting breakage given an SG mean very difficult. An egg shell strength monitoring program using the SG flotation method is still recommended to aid in business and farm management decision-making. This program can provide information that can be compared to present and past performance at the farm, company and industry level. In the past, only SG performance records from the same farm or company have been referenced because of the lack of procedural standards which would enable managers to utilize SG information obtained anywhere throughout the whole industry.

The standards recommended by this study are:

1. include eggs with hairline cracks in the egg sample collected,
2. collect samples of 30 eggs or one flat from any location which may influence performance,
3. prior to testing, store samples and solutions overnight in the egg cooler at approximately 12.8 C (55 F) and
4. use two solutions of 1.070 and 1.080 for both pullet and molted flocks and obtain the estimate of the SG mean by using Table 16.

Universal acceptance of these procedures will provide a monitoring program that will enhance decision-making in the poultry industry.

FURTHER SUGGESTIONS

Further research is needed to relate percent breakage at each point in the egg channel to the SG and to determine whether or not the factors contributing to breakage are too variable across the industry to obtain such a prediction factor between percent breakage and SG. On individual farms, these factors may be held constant enough to obtain such a prediction. Careful monitoring using the SG flotation method and breakage data from each point in the system and good record keeping would be needed to establish an accurate information base. This research would have to be done at individual farms to obtain unique predictions. Extension services from the county to university level could aid in establishing data collection, record keeping systems and data analysis, however, each farm would be responsible for labor and materials.

Research is also needed to further substantiate the use of the solutions 1.070 and 1.080 for standard SG testing procedures. The feasibility of using two solutions is not questioned so much as using the specific solution of 1.070 and 1.080. The regression results obtained for the solutions 1.075 and 1.085 were very similar to those for 1.070 and 1.080, and perhaps may produce more precise predictions. Alternatively, the solutions 1.070 and 1.080 may produce more precise predictions of the SGM when the mean is quite low and shell quality is poor. In this case, it may be better to maintain precision when the SGM is low and forces management to make decisions influenced by the poor shell strength. The flock of DeKalb XL's used in this study have been replaced with Hyline W36's. It is suggested here that the same

regression analyses be applied to the data from the Hyline flock to see whether the preferred two solutions differ from 1.070 and 1.080.

APPENDIX

Appendix A.1. The results of adding age and age² to the single solution base regression model (pullet).

Regressors	Coefficient of Determination	Mean Square Error
Section a. Regression results		
% in 1.080 + Age	.945	7.08×10^{-3}
% in 1.080 + Age + Age	.946	6.96×10^{-3}

Section b. Ninety-five percent confidence intervals

Regression Model: SGM = Constant + % in 1.080 + Age

Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0813	1.0765-1.0860	.009292
Minimum % in 1.080	1.0880	1.0720-1.1040	.031346
Maximum % in 1.080	1.0757	1.0624-1.0890	.026033
Minimum Age	1.0820	1.0692-1.0959	.025202
Maximum Age	1.0805	1.0677-1.0934	.025244

Regression Model: SGM = Constant + % in 1.080 + Age + Age²

Regression Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0814	1.0753-1.0875	.011973
Minimum % in 1.080	1.0884	1.0677-1.1091	.040603
Maximum % in 1.080	1.0757	1.0633-1.0881	.024275
Minimum Age	1.0804	1.0145-1.1464	.129331
Maximum Age	1.0824	1.0045-1.1603	.152691
Minimum Age ²	1.0826	1.0273-1.1379	.108473
Maximum Age ²	1.0794	1.0027-1.1561	.150274

Appendix A.2. The results of adding age to the two-solution base regression model (pullet).

Regressors	Coefficient of Determination	Mean Square Error	
Section a. Regression results			
% in 1.070 + % in 1.080 + Age	.969	0.309 x 10 ⁻⁶	
Section b. Ninety-five percent confidence intervals			
Regression Model: SGM = Constant + % in 1.070 + % in 1.080 + Age			
Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0812	1.0811-1.0812	.000091
Minimum % in 1.070	1.0832	1.0831-1.0833	.000134
Maximum % in 1.070	1.0623	1.0618-1.0628	.000921
Minimum % in 1.080	1.0856	1.0855-1.0858	.000296
Maximum % in 1.080	1.0779	1.0778-1.0780	.000227
Minimum Age	1.0814	1.0813-1.0815	.000213
Maximum Age	1.0810	1.0809-1.0811	.000213

Appendix A.3. The results of adding age and age² to the one-solution base regression model (molted).

Section a. Regression results

Regressors	Coefficient of Determination	Mean Square Error
% in 1.080 + Age	.906	9.34×10^{-3}
% in 1.080 + Age + Age	.908	9.13×10^{-3}

Section b. Ninety-five percent confidence intervals

Regression Model: SGM = Constant + % in 1.080 + Age

Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0811	1.0730-1.0892	.015836
Minimum % in 1.080	1.0881	1.0615-1.1148	.052235
Maximum % in 1.080	1.0754	1.0537-1.0972	.042595
Minimum Age	1.0817	1.0633-1.1002	.036147
Maximum Age	1.0805	1.0621-1.0989	.036025

Regression Model: SGM = Constant + % in 1.080 + Age + Age²

Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0813	1.0569-1.1057	.047851
Minimum % in 1.080	1.0882	1.0543-1.1221	.066464
Maximum % in 1.080	1.0757	1.0426-1.1088	.064814
Minimum Age	1.0757	0.7596-1.3919	.619623
Maximum Age	1.0868	0.7491-1.4245	.661849
Minimum Age ²	1.0870	0.7737-1.4003	.614009
Maximum Age ²	1.0746	0.7315-1.4177	.672539

Appendix A.4. The results of adding age to the two-solution base regression model (molted).

Section a. Regression results

Regressor Variables	Coefficient of Determination	Mean Square Error
% in 1.070 + % in 1.080 + Age	.912	1.22×10^{-6}

Section b. Ninety-five percent confidence intervals

Regression Model: $SGM = \text{Constant} + \% \text{ in } 1.070 + \% \text{ in } 1.080 + \text{Age}$

Regressor Values	Prediction Estimate	Lower-Upper	Crude Range
Means	1.0887	1.0886-1.0888	.000123
Minimum % in 1.070	1.0887	1.0881-1.0891	.000201
Maximum % in 1.070	1.0886	1.0885-1.0889	.000982
Minimum % in 1.080	1.0887	1.0885-1.0888	.000379
Maximum % in 1.080	1.0886	1.0885-1.0889	.000347
Minimum Age	1.0887	1.0885-1.0889	.000344
Maximum Age	1.0887	1.0885-1.0889	.000344

BIBLIOGRAPHY

BIBLIOGRAPHY

- Anderson, G.B., T.C. Carter, and R. Morley Jones, 1974. Some factors affecting dynamic fracture of eggshells in battery cages. Pages 53-70 in Factors Affecting Egg Grading. B.M. Freeman and R.F. Gordon, ed. Oliver and Boyd, Edinburg, Scotland.
- Choi, J.H., R.D. Miles, A.S. Arafá, and R.H. Harms, 1981. The influence of oviposition time on egg weight, shell quality, and blood phosphorus. Poultry Sci. 60:824-828.
- Doyon, G., 1984. Determination of sample sizes for the estimation of several egg and shell quality variable means. Abstract. Poultry Sci. 63:93-94.
- Doyon, G., M. Bernier-Cardou, R.M.G. Hamilton, F. Castaigne, and H. MacLian, 1985. Egg quality. 1. Shell strength of eggs from five commercial strains of white leghorn hens during their first laying cycle. Poultry Sci. 64:1685-1695.
- Ernst, R.A., 1979. Specific gravity vs. percent cracks. California Poultry Letter, October 1979. University of Georgia, Berkeley, CA. p. 3.
- Hamilton, E.M.G., 1982. Methods and factors that affect the measurement of egg shell quality. Poultry Sci. 61:2022-2039.
- Hamilton, R.M.G. and B.K. Thompson, 1981. The effects of storage duration on nondestructive deformation, quasi-static compression strength, impact fracture strength, and specific gravity of eggs from white leghorn hens. Poultry Sci. 60:517-522.
- Hammerle, J.R., 1969. An engineering appraisal of egg shell strength evaluation techniques. Poultry Sci. 48:1708-1717.
- Holder, D.P. and M.V. Bradford, 1979. Relationship of specific gravity of chicken eggs to number of cracked eggs observed and percent shell. Poultry Sci. 58:250-251.
- Izat, A.L., F.A. Gardner, and D.B. Mellor, 1985. Effects of age of bird and season of the year on egg quality. 1. Shell quality. Poultry Sci. 64:1900-1906.
- Larimore, Wallace E. and Raman K. Mehra, 1985. The problem of overfitting data. Byte, October 1985, p. 167-180.

- McKeen, William D., 1983. Using specific gravity for eggshell quality control. Agricultural Cooperative Extension, University of California, San Bernadine, CA.
- Olsson, N., 1934. Studies on specific gravity of hen's eggs. A new method for determining the percentage shell on hen's eggs. Oho Harrassowitz, Leipzig.
- Park, K.S., and A.P. Rahn, 1984. Interpreting egg specific gravity scores, part 2. Poultry Digest, March-June, 1984. Animal Science Department, Michigan State University, East Lansing, MI. pp. 3-6.
- Potts, P.L. and K.W. Washburn, 1974. Shell evaluation of white and brown egg strains by deformation, breaking strength, shell thickness and specific gravity. 1. Relationship to egg characteristics. Poultry Sci. 53:1123-1128.
- Potts, P.L., K.W. Washburn, and K.K. Hale, 1974. Shell evaluation of white and brown egg strains by deformation, breaking strength, shell thickness and specific gravity. 2. Stepwise regression analysis of egg characteristics on methods of assessing shell strength. Poultry Sci. 53:2167-2174.
- Roland, D.A. Sr., D.R. Sloan, and R.H. Harms, 1973. Calcium metabolism in the laying hen. 6. Shell quality in relation to time of oviposition. Poultry Sci. 52:506-510.
- Roland, D.A. Sr., D.R. Sloan, and R.H. Harms, 1975. The ability of hens to maintain calcium deposition in the eggshell and egg yolk as the hen ages. Poultry Sci. 54:1720-1723.
- Strong, C.F. and Reynnells, R.D., 1983. Evaluation of egg specific gravity as a practical tool for monitoring eggshell quality. Special report #276. Extension Poultry Science Department, University of Georgia, Athens, GA.
- Swanson, M.H., 1979. Use the specific gravity test to monitor shell quality. Californis Poultry Letter, August 1979. University of California, Berkeley, CA. pp. 3-4.
- Thompson, B.K. and R.M.G. Hamilton, 1982. Comparison of the precision and accuracy of the flotation and Archimedes' methods for measuring the specific gravity of eggs. Poultry Sci. 61:1599-1605.
- Thompson, B.K., R.M.G. Hamilton, and A.A. Grunder, 1985. The relationship between laboratory measures of egg shell quality and breakage in commercial egg washing and candling equipment. Poultry Sci. 64:901-909.
- Voisey, P.W. and R.M.G. Hamilton, 1977. Sources of error in egg specific gravity measurements by the flotation method. Poultry Sci. 56:1457-1462.

- Wells, R.G., 1967a. Egg shell strength. 1. The relationship between egg breakage i the field and certain laboratory assessments of shell strength. Br. Poultry Sci. 8:131-139.
- Wells, R.G., 1967b. Egg shell strength. 2. The relationship between egg specific gravity and egg shell deformation and their reliability as indicators of shell strength. Br. Poultry Sci. 8:193-199.

MICHIGAN STATE UNIV. LIBRARIES



31293006498558