# EDUCATION AND PRODUCTION

# The Relationships Among Measures of Egg Albumen Height, pH, and Whipping Volume[1]

F. G. Silversides*,†,[2] and K. Budgell†

*Crops and Livestock Research Centre, Charlottetown, Prince Edward Island, Canada C1A 7M8; and †Nova Scotia Agricultural College, Truro, Nova Scotia, Canada B2N 5E3

**ABSTRACT** A total of 2,123 eggs obtained from Brown Leghorn hens (unselected since 1965, ISA Brown, commercial brown egg layer) and Babcock hens (commercial white egg layer) at 32, 50, and 68 wk of age were used to investigate relationships among measures of albumen quality and a functional property of albumen. The eggs were sampled fresh and after storage for 5 and 10 d. At sampling, eggs were weighed and broken, and albumen height, pH, and volume after whipping for 80 s were measured. Also, yolks were weighed, dried shells were weighed, and albumen weight was determined by difference. Egg weight and the weights of the 3 principal components of the egg all increased with increasing age of the hen, with yolk weights increasing proportionately more. With storage, egg and albumen weights decreased, whereas yolk weight increased. Eggs from Brown Leghorn hens were smallest but had proportionately the largest yolks. Albumen height decreased with time in storage, and albumen pH and whipping volume increased. Differences between lines suggested that selection has changed the proportion of the yolk, albumen, and shell and has increased albumen height. Albumen height and whipping volume were negatively correlated, and differences between lines suggest that selection could have decreased the foaming ability of albumen, a principal reason for including eggs in many processed food products.

(*Key words*: egg quality, layer strain, storage, whipping volume, egg component)

2004 Poultry Science 83:1619–1623

## INTRODUCTION

The chicken egg is a high quality food (Robinson, 1987), but after elimination of eggs that are abnormal or cracked and those that contain large meat or egg spots, defining of quality has been difficult. Yolk color is used as a quality determination factor but is nearly entirely dependent on the diet and is easily manipulated (Hunton, 1995). The height of the inner thick albumen when the egg is broken onto a flat surface has largely defined the quality of sound eggs for many years because it is easily measured and relates well to the freshness of the egg. The Haugh unit (Haugh, 1937) exemplifies measures of albumen height; it adjusts the height according to the weight of the egg, and it uses a log scale because albumen height declines with storage in a logarithmic fashion.

The adjustment for egg weight implicit in the Haugh unit adds a bias to the calculation and has been shown to be incorrect (Silversides et al., 1993; Silversides and Villeneuve, 1994; Silversides, 1994). Whereas the Haugh unit has likely always had this bias, albumen height can be measured anywhere with little equipment. Defining egg quality by albumen height was likely reasonable when "quality" almost surely meant "freshness" because time in storage is linked to a steady decline in albumen height. However, Scott and Silversides (2000) and Silversides and Scott (2001) showed that albumen height is biased by the age and strain of hen, and they suggested using the pH of albumen to measure freshness because it lacked this bias.

The determinants of albumen height are not completely understood (Williams, 1992) although the components of the albumen and their chemical and functional characteristics have been described (Robinson, 1987; Li-Chan and Nakai, 1989). The content and nature of ovomucin appear to be primarily responsible for determining albumen height, but the chemical changes in storage that cause the reduction in albumen height are less clear. Reduced albumen height has been variously attributed to proteolysis of ovomucin, cleavage of disulfide bonds, interactions with lysozyme, and changes in the interaction between $\alpha$ and $\beta$ ovomucins with no clear favorite (Stevens, 1996).

Albumen height is easily observed by consumers when the egg is broken open, but the egg processing industry is concerned about the functional characteristics of eggs. Those functional properties relating to albumen (emulsi-

©2004 Poultry Science Association, Inc.
Received for publication April 21, 2004.
Accepted for publication June 22, 2004.
[1]Agriculture and Agri-Food Canada Contribution Number 698.
[2]To whom correspondence should be addressed: silversidesf@agr.gc.ca. Present address: PARC (Agassiz), PO Box 1000, Agassiz, British Columbia V0M 1A0.

**TABLE 1. Sample sizes for statistical analyses of egg measurements[1]**

| | | Line of hen | | | |
|---|---|---|---|---|---|
| Age (wk) | Storage (d) | Brown Leghorn | ISA Brown | Babcock | Total |
| 32 | 0 | 88 to 95 | 98 to 108 | 108 to 109 | |
| | 5 | 80 to 82 | 106 to 109 | 107 to 109 | |
| | 10 | 93 to 95 | 106 to 108 | 110 to 111 | |
| | | | | | 899 to 926 |
| 50 | 0 | 45 to 46 | 75 | 75 to 77 | |
| | 5 | 61 to 63 | 78 | 80 to 81 | |
| | 10 | 58 to 59 | 78 to 80 | 84 to 86 | |
| | | | | | 635 to 644 |
| | 0 | 47 | 66 | 74 to 75 | |
| | 5 | 49 to 51 | 60 to 63 | 72 | |
| | 10 | 45 to 50 | 50 to 56 | 69 to 72 | 532 to 552 |
| Total | | 569 to 588 | 719 to 743 | 781 to 791 | 2,067 to 2,123 |

[1]Sample sizes varied slightly for the different measures.

fication is related to the yolk) are heat coagulation and the ability to form stable foams when whipped and are the reason that eggs are used widely in the food industry (Robinson, 1987). The project reported here investigated the importance of genetic strain and age of hen and storage on albumen height, pH, and whipping volume of the albumen.

## MATERIALS AND METHODS

Eggs were collected from commercial ISA Brown and Babcock B300 hens and from hens of a line of Brown Leghorns that had been unselected since 1965 (Crawford, 1981). The hens had been randomly housed in the laying facilities at Nova Scotia Agricultural College, and sampling occurred when they were approximately 32, 50, and 68 wk of age, representing early, mid, and late production. At each sampling time, eggs were measured within 2 h of being laid (fresh) and after storage at room temperature (approximately 21°C) for 5 and 10 d. Cracked, soft-shelled, and double-yolked eggs were not used. Samples varying from 45 to 111 for each strain, age, and storage period totaled 2,123 eggs (Table 1).

At the time of sampling, each egg was weighed and then broken onto a flat surface. The albumen height was measured with an electronic tripod micrometer.[3] The yolk was separated and weighed, and the albumen was collected into a recalibrated graduated beaker. The albumen collected in the beaker was weighed, and the pH was measured with an Accumet 950 pH/ion meter.[4] The albumen was whipped for 80 s using a 200 W White-Westinghouse[5] 6-speed hand mixer set at a speed of 4 with only 1 beater in place. After beating, the foam was pressed into the beaker with a plunger, and the volume was read from the graduations on the side. The albumen volume was calculated as the volume in milliliters per gram of albumen whipped. The shell was washed with water, dried at room temperature and then dried at 100°C for 4 h, and weighed. The weight of the albumen was determined by the difference between the egg weight and the yolk and shell weights.

### Statistical Analysis

Data on egg, yolk, shell, and albumen weights and albumen height, pH, and volume were analyzed using the SAS statistical package (Littell et al., 1991). An ANOVA using PROC GLM included the main effects of age, storage time, and strain of hen and the 2- and 3-way interactions between these factors. Although many interactions were significant, a further ANOVA used only main effects. When main effects were significant, means were separated using Duncan's test.

Correlation coefficients (r) were calculated using PROC CORR of SAS for each combination of age of hen, storage time, and strain of hen to determine the relative importance of the 3 egg components in determining egg weight. The PROC CORR was also used to investigate the statistical relationship among albumen height, pH, and whipping volume, both overall and for each combination of age, storage, and strain. Finally, for each of the 3 strains, PROC REG was used to calculate simple regression coefficients of the age of the hen and the time in storage on albumen height, albumen pH, and whipping volume. Probabilities of less than 0.05 were considered significant for all analyses.

## RESULTS

Characteristics of the eggs studied are shown in Table 2. Egg, yolk, and albumen weights increased as the hens aged. Storage reduced egg weight and albumen weight, increased yolk weight, and had no effect on shell weight. Eggs from Brown Leghorn hens were smaller than those from the commercial lines, which was reflected by less yolk, shell, and albumen. However, yolk made up a larger percentage of the eggs from Brown Leghorns (29.7% vs. 25.5 and 26.8% for ISA Brown and Babcock), with the shell (9.1% vs. 10.0 and 9.4% for ISA Brown and Babcock)

[3]Queensboro Instruments, Ottawa, ON, Canada.
[4]Fisher Scientific, Montreal, PQ, Canada.
[5]www.frigidaire.com/white_westinghouse.asp.

**TABLE 2. Means of egg weight, egg component weights and albumen quality measures**

| Parameter | Egg weight | Yolk weight (g) | Shell weight (g) | Albumen weight (g) | Albumen height (mm) | pH | Albumen volume (mL/g albumen) |
|---|---|---|---|---|---|---|---|
| Age | | | | | | | |
| 32 wk | 59.62[c] | 15.16[c] | 5.86 | 38.68[c] | 6.47[a] | 8.71[b] | 5.68[b] |
| 50 wk | 62.72[b] | 17.50[b] | 5.94 | 39.29[b] | 5.76[b] | 8.64[c] | 5.70[b] |
| 68 wk | 64.82[a] | 18.35[a] | 5.90 | 40.63[a] | 4.76[c] | 8.85[a] | 5.89[a] |
| Storage | | | | | | | |
| 0 d | 62.70[a] | 16.32[b] | 5.91 | 40.57[a] | 8.45[a] | 7.78[c] | 5.15[c] |
| 5 d | 62.05[b] | 16.86[a] | 5.90 | 39.36[b] | 4.96[b] | 9.12[b] | 5.89[b] |
| 10 d | 61.01[c] | 16.91[a] | 5.88 | 38.22[c] | 4.10[c] | 9.26[a] | 6.17[a] |
| Line | | | | | | | |
| Brown Leghorn | 52.45[c] | 15.56[c] | 4.75[c] | 32.20[c] | 4.81[c] | 8.84[a] | 6.03[a] |
| ISA Brown | 66.69[a] | 17.00[b] | 6.65[a] | 43.08[a] | 5.55[b] | 8.67[c] | 5.67[b] |
| Babcock | 64.46[b] | 17.26[a] | 6.04[b] | 41.18[b] | 6.77[a] | 8.70[b] | 5.60[c] |
| SEM | 0.18 | 0.06 | 0.02 | 0.17 | 0.06 | 0.01 | 0.02 |
| ANOVA | | | | $P$ | | | |
| Age | <0.01 | <0.01 | NS | <0.01 | <0.01 | <0.01 | <0.01 |
| Storage | <0.01 | <0.01 | NS | <0.01 | <0.01 | <0.01 | <0.01 |
| Line | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

[a–c]Means within a main effect with different superscripts are different at $P < 0.05$ using Duncan's multiple range test.

and albumen (61.4% vs. 64.6 and 63.9% for ISA Brown and Babcock) making up smaller percentages. The 3 measures of albumen quality (height, pH, and whipping volume) were all affected by age, storage, and line of hen (Table 2). Albumen height decreased with the age of the hen and with storage and was lowest for eggs from Brown Leghorns and highest for those from Babcock hens. The pH of the albumen differed slightly according to age of the hen but not in a consistent direction, whereas the increase in pH with storage was clear. Differences in albumen pH between lines were significant but small. Whipping volume increased slightly with increasing age of the hen and more so with increasing storage, with eggs from Brown Leghorns having the greatest whipping volume.

An ANOVA that included all 2- and 3-way interactions (not shown) demonstrated significant age-by-storage interactions for egg and yolk weights and significant age-by-line interactions for egg weight and weights of the 3 components. All 2-way interactions were significant for albumen quality measurements (albumen height, pH, albumen whipping volume) except that for age by storage for albumen height, for which the 3-way interaction was significant. Interactions were not explored further because the primary aim of this study was to investigate relationships among albumen quality variables.

Correlation coefficients between the 3 major egg components and egg weight (Table 3) showed that variation in yolk and shell weight was associated to a lesser degree with egg weight as the age of the hen increased (r for yolk and egg weight decreased from 0.79 to 0.50 and that for shell and egg weight from 0.91 to 0.73). The association between albumen and egg weight was very high at all 3 ages. Storage did not affect the relationships between egg components and egg weight. Among eggs from Brown Leghorns, the yolk weight was more closely associated with egg weight than among eggs from ISA Brown or Babcock hens. Shell weight was most closely associated with egg weight in eggs from ISA Brown hens, and albumen weight was closely associated with egg weight in all 3 lines.

Correlation coefficients for the entire sample of eggs (Table 4) showed that albumen height was negatively associated with pH and whipping volume (high albumen was associated with lower pH and whipping volume). Albumen pH and whipping volume were associated in a positive manner. These relationships remained true in the subsamples, except that within each storage time the associations of albumen whipping volume with height and pH were very low.

The regression coefficients and $R^2$ values for age of hen and storage time on albumen height, pH, and whipping volume are shown in Table 5. Very low $R^2$ values showed that the age of ISA Brown and Babcock hens had little effect on any measure of egg quality (although most regressions were significant) and higher $R^2$ values showed that the age of Brown Leghorn hens had some effect on

**TABLE 3. Correlation coefficients (r) of 3 egg weight components (g) with total egg weight (g) at 3 storage times from 3 lines of hens at 3 ages (all are signficant at $P < 0.01$)**

| Parameter | Yolk weight | Shell weight | Albumen weight |
|---|---|---|---|
| All | 0.66 | 0.81 | 0.97 |
| Age | | | |
| 32 wk | 0.79 | 0.91 | 0.99 |
| 50 wk | 0.59 | 0.81 | 0.97 |
| 68 wk | 0.50 | 0.73 | 0.96 |
| Storage | | | |
| 0 d | 0.69 | 0.82 | 0.97 |
| 5 d | 0.66 | 0.83 | 0.97 |
| 10 d | 0.68 | 0.80 | 0.96 |
| Line | | | |
| Brown Leghorn | 0.84 | 0.55 | 0.91 |
| ISA Brown | 0.56 | 0.65 | 0.94 |
| Babcock | 0.67 | 0.48 | 0.91 |

**TABLE 4. Correlation coefficients (r) between albumen height (mm), pH, and whipping volume (mL/g) for eggs from 3 lines of hens at 3 ages and stored for 3 different periods (all correlation coefficients are signficant at $P < 0.01$ unless followed by NS)**

| Parameter | Height:pH | Height:volume | pH:volume |
|---|---|---|---|
| All | –0.73 | –0.29 | 0.35 |
| Age | | | |
| 32 wk | –0.85 | –0.23 | 0.30 |
| 50 wk | –0.61 | –0.25 | 0.42 |
| 68 wk | –0.85 | –0.33 | 0.33 |
| Storage | | | |
| 0 d | –0.32 | –0.11 | –0.05 (NS) |
| 5 d | –0.48 | –0.02 (NS) | 0.07 (NS) |
| 10 d | –0.52 | –0.02 (NS) | 0.11 |
| Line | | | |
| Brown Leghorn | –0.83 | –0.50 | 0.33 |
| ISA Brown | –0.62 | –0.35 | 0.51 |
| Babcock | –0.88 | –0.58 | 0.56 |

albumen height (negative) and whipping volume (positive). Storage had a relatively large effect on albumen height (negative) and pH (positive) with a moderately positive effect on whipping volume in all 3 lines and overall.

## DISCUSSION

Changes observed in egg, yolk, shell, and albumen weights with age of the hen were consistent with those reported in the literature (Hill and Hall, 1980; Silversides and Scott, 2001). Egg size increased with age of the hen with a proportionately larger increase in yolk weight than albumen weight. Increasing periods of storage decreased egg weight, likely due to water loss through the shell, with a decrease in albumen weight and an increase in yolk weight as protein was transferred through the yolk membrane from the albumen (Heath, 1977; Ahn et al., 1999; Silversides and Scott, 2001).

**TABLE 5. The regression coefficients (b) of albumen height (mm), pH, and whipping volume on storage of eggs and age of the hen (all regression coefficients are significant at $P < 0.01$ unless followed by NS, n = 2,066)**

| | Age of hen | | Storage | |
|---|---|---|---|---|
| Dependent variable | b | $R^2$ | b | $R^2$ |
| All | | | | |
| Albumen height | –0.05 | 0.06 | –0.43 | 0.41 |
| Albumen pH | 0.003 | 0.005 | 0.15 | 0.72 |
| Whipping volume | 0.47 | 0.045 | 2.68 | 0.11 |
| Brown Leghorn | | | | |
| Albumen height | –0.06 | 0.20 | –0.36 | 0.50 |
| Albumen pH | 0.006 | 0.02 | 0.13 | 0.67 |
| Whipping volume | 1.04 | 0.26 | 1.96 | 0.07 |
| ISA Brown | | | | |
| Albumen height | –0.04 | 0.04 | –0.43 | 0.29 |
| Albumen pH | 0.0003 (NS) | 0.004 | 0.15 | 0.75 |
| Whipping volume | 0.19 | 0.016 | 2.31 | 0.19 |
| Babcock | | | | |
| Albumen height | –0.04 | 0.07 | –0.49 | 0.68 |
| Albumen pH | 0.002 (NS) | 0.002 | 0.15 | 0.74 |
| Whipping volume | 0.26 | 0.016 | 3.72 | 0.25 |

Eggs from Brown Leghorn hens were much smaller than those from the commercial lines, but the yolk was proportionately larger, and the proportion of shell was smaller. It appears that the selection that increased egg size and egg number favored smaller yolks, a suggestion that has been made previously (Scott and Silversides, 2000) and shown in selected lines (Akbar et al., 1983) and in a comparison between modern and historic lines (Tharrington et al., 1999). Washburn (1990) cited studies showing that the albumen is the major contributor to egg size and suggested that selection for increased egg size should increase the relative amount of albumen. The very high correlation between albumen weight and egg weight confirm that variation in albumen weight is the principal determinant of egg weight, and the greater relative weight of albumen for eggs from the 2 selected lines compared with that of Brown Leghorns suggests that Washburn (1990) was right. That eggs from ISA Brown hens had heavier shells suggests that an effort has been made to select for increased shell strength, likely because brown egg layers have had thin shells in the past (Hunton, 1982).

These eggs provided a diverse sample that differed in important egg quality characteristics, and the data confirm that albumen height is biased by the age and strain of hen (Silversides, 1994). Albumen height decreased with increasing age of the hen, and eggs from the unselected Brown Leghorn hens had substantially lower albumen than those of the commercially selected hens. Silversides and Scott (2001) suggested that pH provides a better measure of egg freshness than albumen height; the minor importance of age or strain on albumen pH and the large effect of storage support this conclusion. Albumen whipping volume increased slightly with increasing age of the hen and substantially with time in storage. Brown Leghorns, which had the lowest albumen height, and would therefore be considered to have the worst egg quality, had the highest whipping volume. For eggs from Brown Leghorn hens, the age of the hen was more important for whipping volume than time in storage, in sharp contrast to eggs from ISA Brown or Babcock hens.

Correlation coefficients between albumen height and pH were high and negative because storage decreased the albumen height and increased the pH. However, at each storage time the statistical association between albumen height and pH was moderate, suggesting that factors other than storage were important for one of the measures. Silversides and Scott (2001) have already shown that albumen pH is determined almost entirely by storage time and may be more useful than albumen height for measuring egg quality. The association between albumen height and albumen whipping volume was negative so that eggs considered to have good quality, measured as albumen height, had poor whipping characteristics. Overall, a higher pH was associated with higher whipping volume, but whipping volume at each storage time was unrelated to either albumen height or pH, which suggested that correlations within ages or lines were related to corresponding changes in storage that affected all 3 measures.

Albumen height is a heritable trait (Washburn, 1990) and is a concern for commercial breeders (Hunton, 1990). These data suggest that albumen height has formed part of the selection programs used by the primary breeder. The data also suggest that selection for albumen height may have decreased the foam-forming ability of the albumen. Most important is that the correlation coefficients between albumen height and whipping volume are negative. If high whipping volume is desired, then measuring albumen height may be counterproductive.

## ACKNOWLEDGMENTS

The authors would like to thank Rowena Currie for help in carrying out the experimental part of this research, Bruce Rathgeber and Nigel Firth for discussions relating to this project, the Poultry Industry Council and Agriculture and Agri-Food Canada for financial support, and George Ansah of ISA for the day old commercial chicks.

## REFERENCES

Ahn, D. U., J. L. Sell, C. Jo, M. Chamruspollert, and M. Jeffrey. 1999. Effect of dietary conjugated linoleic acid on the quality characteristics of chicken eggs during refrigerated storage. Poult. Sci. 78:922–928.

Akbar, M. K., J. S. Gavora, G. W. Friars, and R. S. Gowe. 1983. Composition of eggs by commercial size categories: Effects of genetic group, age, and diet. Poult. Sci. 62:925–933.

Crawford, R. D. 1981. Catalogue of Poultry Stocks Held at Research and Teaching Institutions in Canada. 14th ed. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Haugh, R. R. 1937. The Haugh unit for measuring egg quality. US Egg Poult. Mag. 43:522–555, 572–573.

Heath, J. L. 1977. Chemical and related osmotic changes in egg albumen during storage. Poult. Sci. 56:822–828.

Hill, A. T., and J. W. Hall. 1980. Effects of various combinations of oil spraying, washing, sanitizing, storage time, strain, and age upon albumen quality changes in storage and minimum sample sizes required for their measurement. Poult. Sci. 59:2237–2242.

Hunton, P. 1982. Genetic factors affecting egg shell quality. World's Poult. Sci. J. 38:75–84.

Hunton, P. 1990. Industrial breeding and selection. Pages 985–1028 in Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, New York.

Hunton, P. 1995. Egg production, processing and marketing. Pages 457–481 in Poultry Production. P. Hunton, ed. Elsevier, New York.

Li-Chan, E., and S. Nakai. 1989. Biochemical basis for the properties of egg white. Crit. Rev. Poult. Biol. 2:21–59.

Littell, R. C., R. J. Freund, and P. C. Spectot. 1991. SAS System for Linear Models. 3rd ed. SAS Series in Statistical Applications. SAS Institute Inc., Cary, NC.

Robinson, D. S. 1987. The chemical basis of albumen quality. Pages 171–191 in Egg Quality—Current Problems and Recent Advances. R. G. Wells and C. G. Belyavin, ed. Butterworths, London.

Scott, T. A., and F. G. Silversides. 2000. The effect of storage and strain of hen on egg quality. Poult. Sci. 79:1725–1729.

Silversides, F. G. 1994. The Haugh unit correction for egg weight is not adequate for comparing eggs from chickens of different lines and ages. J. Appl. Poult. Res. 3:120–126.

Silversides, F. G., and T. A. Scott. 2001. Effect of storage and layer age on quality of eggs from two lines of hens. Poult. Sci. 80:1240–1245.

Silversides, F. G., F. Twizeyimana, and P. Villeneuve. 1993. Research note: A study relating to the validity of the Haugh unit correction for egg weight in fresh eggs. Poult. Sci. 72:760–764.

Silversides, F. G., and P. Villeneuve. 1994. Is the Haugh unit correction for egg weight valid for eggs stored at room temperature? Poult. Sci. 73:50–55.

Stevens, L. 1996. Egg proteins: What are their functions. Sci. Prog. 79:65–87.

Tharrington, J. B., P. A. Curtis, F. T. Jones, and K. E. Anderson. 1999. Comparison of physical quality and composition of eggs from historic strains of single comb white leghorn chickens. Poult. Sci. 78:591–594.

Washburn, K. E. 1990. Genetic variation in egg production. Pages 781–804 in Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, New York.

Williams, K. C. 1992. Some factors affecting albumen quality with particular reference to Haugh unit score. World's Poult. Sci. J. 48:5–16.