Dynamic stiffness measurements with the "crack detector": a new method to improve egg shell strength

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Introduction

For the egg industry and consumers, an intact shell is the first and most important egg quality criterion. Unless the egg has an intact shell, it is downgraded and not saleable as quality shell egg. Various sources of variation in shell quality have been reported in the extensive literature, including strain, age of hen, nutrition, health, cage design and other mechanical stress factors from oviposition to the consumer. It is common knowledge that egg shells become more susceptible to breakage as hens get older and the eggs larger, but the percentage of shell defects varies between strains and depends on nutrition and management (SCHOLTYSSEK, 1994).

Primary breeders of egg-type chickens have always included shell strength in their breeding goals and improved shell strength at given age, but the problem remains that the incidence of defective shells increases toward the end of the laying period and is often the main reason for terminating a flock when production is still above 80%. Data to predict egg breakage later in life are usually collected before one year of age, when the main selection on part records is due. At this early age, most eggs have good shells and the accuracy of predicting the rate of breakage depends on the method used to evaluate shell quality.

CARTER (1971) concluded from pilot experiments that most cracks occuring in battery cages at oviposition are produced when the eggs drop on the cage floor. Variables affecting the probability of breakage at this point include intrinsic shell characteristics, but also the mass of the cage floor, egg mass and the drop height, for which the author documented breed differences in another paper (CARTER, 1975).

A multiple regression analysis of strain differences in random sample tests showed that shell colour, shell thickness, egg production and egg weight had significant effects on the incidence of cracks and other defects (CARTER (1975), from which the author concluded that "breeders who wish to exercise indirect selection for low crack incidence should consider selecting for dark shell colour rather than high shell thickness".

This idea is not helpful for the improvement of shell strength in White Leghorns, but as shown by BONITZ and FLOCK (1992) it is only a question of selection intensity to increase breaking strength in white-egg strains, even above the level of brown-egg strains. The question remains: what are the most useful indirect shell quality criteria for a breeding program to reduce shell breakage under commercial conditions? In this paper, we will review different criteria of shell quality and present new estimates of genetic parameters, with special attention to dynamic stiffness.

Shell quality criteria

Direct selection against defective eggs cannot be very effective, because the incidence of shell defects is too low to exert significant selection pressure at the time of the main selection, when the hens are less than one year of age. A simple way to support adequate shell quality is to include only eggs with apparently normal shells in the egg count, which can change the correlation between egg production and shell strength from slightly negative to zero or even slightly positive (FLOCK, 1990).

Indirect selection for shell strength is being practiced by primary poultry breeders, using a variety of destructive and non-destructive methods. The latter have the advantage that the eggs can still be used after measurement, but in view of the low price per egg and EU food safety regulations, this argument carries less weight than speed and accuracy of measurement, heritability and genetic correlation with shell damage under commercial conditions. The following indirect methods differentiate between eggs with apparently normal shells.

1. Shell percentage: Eggs with intact shells have about 10-11% shell, which can be measured by weighing first the whole egg, then breaking it to remove the contents, weighing the shell and expressing it as percentage of egg weight. Depending on the purpose of measurement, it may be sufficient for routine evaluation to remove residues of egg white with a tissue; for more precise measurements, the shell is dried in an oven before weighing.
2. Shell thickness: This trait is highly correlated with shell percentage and may be measured in different regions. Measurement in the equatorial region is preferred, where thickness is more uniform than in the pole regions. To withstand the stress of handling from point of lay to the consumer, eggs should have a uniform shell of about 0.35-0.40 mm thickness.
3. Specific gravity: Shell percentage and shell thickness can be estimated from the specific gravity of eggs, because the shell has about twice the specific gravity of the egg contents, yolk and albumen. The method is simple and non-destructive, but has the disadvantage that the specific gravity of an egg can decrease considerably during 24 hours, depending on holding temperature. We have found unsatisfactory correlations between specific gravity and the incidence of cracked and otherwise damaged shells (VON HAAREN-KISO et al., 1985) and therefore changed to shell breaking strength as the main selection criterion.
4. Shell breaking strength: To determine their breaking strength, eggs are placed between two plates and subjected to increasing pressure until the shell breaks. The force necessary to break the shell is expressed in Newton. Measurements can be made between the poles or at the equator, simulating different risks of breakage under field conditions. Measurements between the poles, as practiced e.g. in German random sample tests for many years (PREISINGER et al., 1998), have a higher repeatability (SCHOLTYSSEK, 1994). Breaking strength is lower at the small end, but the variation is unaffected by the position during measurement (CORDTS et al., 2001).
5. Structural properties: A classical paper on the structure of egg shells with older literature is the dissertation of SIMONS (1971). Since then, a research group in Glasgow has published extensively on structural properties of the eggshell (BAIN, 2004), confirming that thicker shells are not necessarily stronger. More important is the uniformity of shell formation, which can be analysed by microscopic inspection. For routine genetic analyses, these techniques would be too time-consuming.
6. Dynamic stiffness - K_{dyn}: A promising new method to describe egg shell stability is dynamic stiffness (DUNN et al., 2005a), measured as Kdyn value. The machine is called „Crack Detector" and uses the same physical principles as large commercial egg graders which sort out eggs with hair cracks and other defects. The dynamic force is a little hammer, which hits the egg to generate shell vibrations. During the measurements the egg is turned around its equatorial axis and hit four times. The frequency of vibrations is recorded by a laterally positioned microphone. The method was first described by COUCKE et al. (1999). DUNN et al. (2005a,b) reported the first heritability estimates and concluded that a large part of the total variance is genetically determined. Moderately high genetic correlations were found between K_{dyn} and shell breaking strength (r_g=0.49), somewhat lower with shell thickness (r_g =0.34).

Material and Methods

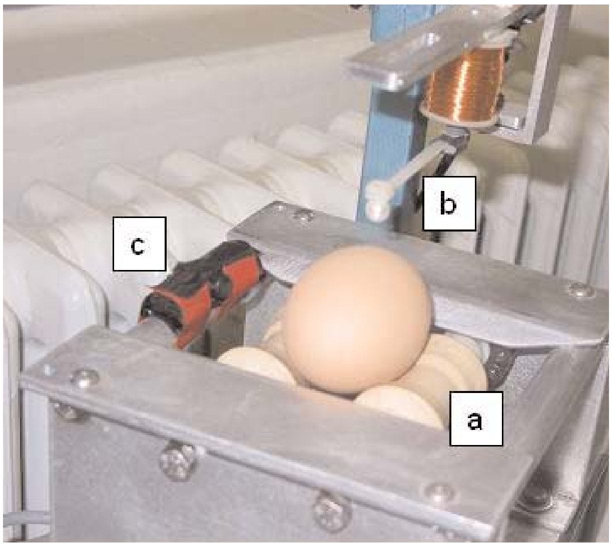
For the present study we used a total of 2520 eggs from 1000 pedigreed pureline hens from the same commercial Red Island Red line as used in the earlier analyses by DUNN et al., three generations later (data collected in 2005). The hens were daughters of 385 dams and 60 sires, hatched on the same day and kept under the same management conditions from hatch to the time of egg collection. When the hens were 37, 38 and 39 weeks of age, one day's production was marked with the individual cage number.

Data collection started with a test run over the "crack detector" to eliminate eggs with hair cracks and other defects. In the first week, 6 % of the eggs were sorted out by the machine, but this apparently included some "false positives". In the second and third week, this percentage was reduced to 4 and 2 %, respectively, by closer inspection of the rejected eggs and repeated measurement before elimination.

The eggs with apparently intact shells were then measured as follows:

(1) length and width to calculate the shape index (100*width/length),
(2) egg mass and frequency of vibrations to calculate dynamic stiffness
$K_{dyn} = 4\pi^2$ * Egg mass [kg] * Resonant frequency $[Hz]^2$
(3) shell breaking strength (between the poles)
(4) shell weight (after drying) to calculate shell percentage
(5) shell thickness (at the equator).

The "crack detector" used for measurement of the resonance frequency is shown in figure 1.



a: rollers
b: impact hammer
c: microphone

Results and Discussion

Means and standard deviations for 8 traits measured or calculated are shown in table 1 for each of the three samples.

Table 1: Means ($\bar{x}$) and standard deviations (s) of egg quality traits measured

Age of hens	37 weeks n=816		38 weeks n=836		39 weeks n=868	
Trait	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Egg weight (g)	64.3	4.8	64.8	4.8	65.4	4.8
Shell weight (g)	6.5	0.6	6.7	0.6	6.7	0.5
Shell percentage (%)	10.3	0.9	10.4	0.8	10.3	0.7
Shell thickness (mm)	0.39	0.03	0.40	0.03	0.41	0.03
Breaking strength (N)	56.2	12.2	57.3	12.6	58.2	11.3
Shape Index (100*W/L)	78.4	2.9	77.9	3.0	77.8	2.6
Res. Frequency (Hz)/100	47.89	3.41	48.29	3.34	48.21	3.15
Dyn. stiffness (K_{dyn})/100[1)]	14.75	1.87	15.10	1.78	15.19	1.69

[1)] $K_{dyn}=m*RF^2$ with m=Egg mass in kg; RF=Resonant frequency;
Note that we did not use the constant $4\pi^2$ here and divided the original figures for RF and K_{dyn} by 100 for more convenient presentation

Estimates of heritabilities and genetic correlations are shown in table 2 for six traits of major interest. These estimates are based on averages of up to three eggs per hen.

Table 2: Estimates of heritabilities (diagonal) and genetic correlations (off-diagonal) among different egg quality traits

	Egg weight	Stiffness K_{dyn}	Breaking strength	Shape Index	Shell thickness	Shell percentage
Egg wt.	**0.54**	-0.14	-0.57	-0.09	+0.10	-0.49
K_{dyn}		**0.40**	+0.57	+0.41	+0.20	+0.39
Break.Str.			**0.10**	+0.42	+0.39	+0.73
Shape				**0.38**	+0.14	+0.09
Thickness.					**0.19**	+0.75
Shell pct.						**0.32**

The heritability estimate for the new trait K_{dyn} (h^2 = 0.40) is of similar magnitude as for shape index and higher than for the other shell quality criteria, especially breaking strength. The low heritability of breaking strength compared to estimates reported in the literature is due to the fact that we calculated h^2 on the basis of a single egg, whereas previous estimates are based on the average of several eggs per hen. Breaking strength has a lower repeatability than the other shell quality criteria, i.e. the heritability can be increased significantly by evaluating more eggs for breaking strength.

Intensive selection for shell quality on the basis of breaking strength during many generations may have used up some of the useful variation in this trait, whereas the new trait varies in a dimension of shell quality which has not been selected on so far. The genetic correlation of +0.57 between the K_{dyn} value and breaking strength is significantly below 1.0, indicating that these two traits have a common basis, but measure different aspects of shell strength. Desirable from a breeder's point of view is the lower genetic correlation between K_{dyn} and egg weight, compared to breaking strength.

Index selection for multiple objectives takes the heritabilities and genetic correlations among all traits into account. The combination of optimal egg weight with adequate shell strength is obviously easier to achieve if the correlation is less strongly negative than for breaking strength. Desirable from a breeder's point of view are also the lower genetic correlations of K_{dyn} with shell thickness and shell percentage (0.20 and 0.39), compared to breaking strength (0.39 and 0.73). If shell strength can be further improved without increasing shell percentage, this would also be of special interest for the egg breaking industry, for which shell mass is an undesired by-product.

The results of this study confirm estimates by DUNN et al. (2005a,b) who reported h^2 values for K_{dyn} between 0.33 and 0.53, depending on the statistical model used. The genetic correlations around 0.50 among different measures of shell quality agree well with the publications by BAIN (2004) and DUNN et al. (2005a,b). Contrary to our findings, DUNN et al. (2005) found essentially no correlation between egg weight and shell strength and a slightly negative correlation with egg production. As shown earlier by VON HAAREN-KISO et al. (1985), the negative correlation between shell quality and egg production disappears if only eggs with intact shells are included in the egg count.

To demonstrate the effect of a moderate „selection" on the basis of shell breaking strength vs. dynamic stiffness, we calculated the phenotypic averages per hen (corrected for week of measurement and missing values) and sorted on breaking strength and Kdyn, respectively. In table 3, the upper and lower 25% are shown for the primary selection trait (in fat print) and the correlated response in other traits. The differences are also expressed in phenotypic standard deviations.

Table 3: Characteristics of upper and lower 25% hens phenotypically “selected” on K_{dyn} compared to breaking strength

Phenotypic selection on breaking strength						
			upper 25%		lower 25%	
Trait	Mean	s	Diff.	Diff/s	Diff.	Diff/s
Breaking strength	**57.2**	**10.1**	**+9.80**	**+0.97**	**-12,65**	**-1.25**
K_{dyn}	15.02	1.79	+0.52	+0.29	-0.62	-0.35
Egg weight	64.8	4.8	-0.67	-0.14	+1,86	+0.39
Shape index	78.0	2.8	+0.31	+0.11	-0,42	-0.15
Shell thickness	0.40	0.03	+0.01	+0.33	-0,01	-0.33
Shell percentage	10.2	0.7	+0.36	+0.46	-0,41	-0.52
Phenotypic selection on K_{dyn}						
K_{dyn}	**15.02**	**1.79**	**+2.05**	**+1.15**	**-1.98**	**-1.11**
Breaking strength	57.2	10.1	+3.26	+0.32	-2.59	-0.26
Egg weight	64.8	4.8	-0.06	-0.01	-0.37	-0.08
Shape index	78.0	2.8	+0.99	+0.35	-0.41	-0.14
Shell thickness	0.40	0.03	+0.01	+0.33	-0.01	-0.33
Shell percentage	10.2	0.7	+0.27	+0.34	-0.28	-0.35

The differences suggest that selection on dynamic stiffness would have less effect on egg weight, but lead to rounder egg shape, compared to selection on breaking strength. These relationships will be analyzed in more depth, based on breeding values for all traits of economic significance in different commercial lines while the crack detector is being used routinely in addition to breaking strength. Egg shape may need additional attention in future egg quality evaluation to maintain a desirable shape for commercial table eggs as well as hatching eggs.

Summary and conclusion

The „Crack-Detector“ is a device to measure the dynamic stiffness (K_{dyn}) of egg shells, using the same physical principles as large commercial egg grading stations to sort out eggs with defective shells. The important feature for application in genetic evaluation and selection is that the parameter K_{dyn} is a quantitative measure to predict the probability of breakage based on individual eggs with apparently intact shells from the frequency of vibrations (in response to being hit by a small hammer) and egg weight.

Estimates of genetic parameters summarized in table 2 confirm previous reports by DUNN et al., based on data from the same line three generations earlier. The higher heritability compared to breaking strength (h^2=0.40 vs. 0.10) and a genetic correlation of +0.57 between these two criteria of shell strength suggest that the introduction of Kdyn as additional trait in selection indexes should help to further reduce shell breakage under field conditions. The lower genetic correlation with egg weight

(-0.14 vs. -0.57) will enable breeders to maintain both shell quality and egg weight at a desirable level with less selection pressure compared to selection only on breaking strength.

Follow-up studies will investigate at which age Kdyn should be measured to predict the persistency of shell quality in cross-line progeny of sires selected on a combination of traditional breaking strength and dynamic stiffness.

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Zusammenfassung

Eischalenbeurteilung mit Hilfe des "Crack detector": eine neue Methode zur Verbesserung der Eischalenstabilität

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Ein Ziel der Legehennenzucht ist die Verminderung defekter Eischalen in der Praxis durch eine Verbesserung der Eischalenstabilität. Für die Messung dieses Selektionskriteriums wurde ein neues Gerät, der „Crack Detector" entwickelt, mit dem die Schalenstabilität eines Eies über den Messwert „dynamic stiffness" (K_{dyn}) bestimmt wird. Die Erfassung dieses quantitativen Merkmals erfolgt nach den gleichen physikalischen Prinzipien wie in großen kommerziellen Eiersortieranlagen, die Eier mit Haarrissen und anderen Schalendefekten aussortieren. Ein seitlich am Gerät angebrachtes Mikrofon zeichnet die Frequenz der Schalenvibrationen auf, die durch den Aufprall eines Hämmerchens erzeugt werden. In Verbindung mit dem jeweiligen Eigewicht kann hieraus der entsprechende K_{dyn}-Wert berechnet werden.

Schätzwerte genetischer Parameter sind in Tabelle 2 zusammengefasst. Die Heritabilität für das neue Merkmal der Schalenstabilität (K_{dyn}) ist überraschend hoch (h^2=0.40) im Vergleich zur Bruchfestigkeit (h^2=0.10). Die genetische Korrelation zur Bruchfestigkeit (+0.57) spricht dafür, K_{dyn} als zusätzliches Merkmal bei der Selektion zu berücksichtigen, um den Anteil defekter Eischalen weiter zu verringern. Die im Vergleich zur Bruchfestigkeit weniger enge Beziehung zum Eigewicht erleichtert es dem Züchter, Schalenstabilität und Eigewicht gleichzeitig zu optimieren.

In weiteren Untersuchungen soll gezeigt werden, in welchem Alter das Merkmal K_{dyn} erfasst werden muss, um eine gute Persistenz in der Eischalenqualität zu erreichen. Die Daten sollen von Kreuzungsnachkommen stammen, deren Väter nach einer Kombination aus traditionellen Bruchfestigkeits- und K_{dyn}-Werten selektiert wurden.