Dynamic stiffness (K_{dyn}) as a predictor of eggshell damage and its potential for genetic selection

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Abstract

Genetic progress in reducing eggshell damage depends on having a measurement that can both predict if an egg will crack during routine handling and whose variance contains a substantial genetic component. We have demonstrated that the measurement of dynamic stiffness, derived from the acoustic resonance of the egg and its mass, fulfils both of these criteria. The heritability of dynamic stiffness is high (0.53) which indicates that a large component of its variance is genetically determined. Furthermore, it has been possible to demonstrate that dynamic stiffness of the egg can predict the probability that it will crack during its journey through a packing plant. The lower the value of dynamic stiffness, the greater the probability that the egg will crack in the packing plant. We believe this is the first demonstration of the relationship between a measurement of quality and actual damage.

The measurement of dynamic stiffness, therefore offers an excellent method to improve eggshell quality and reduce the incidence of cracked eggs by its incorporation in to breeding programmes.

Introduction

Damage to eggshells causes economic loss and provides a route for pathogenic organisms to contaminate eggs contents. As eggshells are a biological material both environmental and genetic factors determine their structure and influence the likelihood of cracking during normal processing. Environmental factors such as diet and the processing machinery can be improved but genetics remains an important way to improve eggshell quality. Genetic improvement is both permanent and cumulative. Breeders have been selecting for many years to improve lifetime eggshell quality and continue to strive to improve quality (Preisinger and Flock, 2000). However there can be impediments to making genetic progress, notably finding measurements that truly reflect the trait that is being addressed. In this case the trait to be addressed is the susceptibility of the eggshell to cracking. If such a measurement can be found then a significant component of its variation must be genetically determined to allow genetic selection to be effective. This can be assessed by the estimation of a measurement's heritability.

One problem of reducing the incidence of eggshell damage by genetic selection has been that the measurements used in selection have only been correlative. Because methods such as breaking strength are destructive, no direct relationship can be established between the measure used and the incidence of shell damage in packing and transportation. In the studies described here we examined the genetic contribution to a non-destructive method to determine eggshell quality which, because of its non-destructive nature, we have been able to use to predict the likelihood an egg will crack.

In 1998 Coucke proposed an alternative method of detecting cracks based on the observation that when an egg is subjected to a non-destructive impact it oscillates at a natural or resonant frequency (RF). The RF of an intact egg is repeatable at different locations around the equator whilst cracked eggs display a greater variation in their RF values. In addition to identifying cracked eggs Coucke proposed that acoustic resonance frequency analysis could also measure the mechanical stiffness of intact eggs (Coucke, 1998; Coucke *et al.* 1999) and the authors defined a novel eggshell parameter, dynamic stiffness (K_{dyn}). De Ketelaere *et al.,* (2003) found the measurement correlated well with other

measures of eggshell quality including static stiffness and thickness and proposed that K_{dyn} may provide a better indicator of an eggs ability to withstand insult than the static measures. Also K_{dyn} could provide a useful tool for selecting hens with superior eggshell characteristics (Cordts *et al.*, 2002; De Ketelaere *et al*., 2002).

If the measurement is to be successfully used for selection a number of criteria must be met. Firstly the measurement must have a large genetic component of its variability; secondly it must not have a detrimental effect on other production traits; thirdly the measurement must relate directly to the trait that is being improved. This last criterion is perhaps the hardest to prove in the case of eggshell quality.

In this study we have estimated the heritability of the K_{dyn} measurement to determine if it contains a significant genetic component and we have estimated its genetic correlation with established methods for determining eggshell quality and with other production traits. Finally we have determined if K_{dyn} can predict the likelihood that an egg will be damaged in an integrated production and packaging unit.

Materials and methods

STUDY 1: GENETIC ESTIMATES

a) Animals and egg collection

The population used to estimate genetic parameters comprised 32 Rhode Island Red sires and 240 dams and their offspring. The offspring (1501 hens) had measurements made on 2 eggs laid between 38 and 42 weeks of age. The hens were housed in individual cages on 16 hours of light per day and eggs were sampled in batches from a quarter of the population on each occasion. Full details on the population and calculation of parameters are described by Dunn *et al.* (2005).

b) Eggshell quality measurements

The following measurements were carried out on each egg: egg weight (g), shape index (derived from measuring length/breadth in mm), dynamic stiffness, static stiffness, breaking strength, total thickness, effective thickness and thickness of the mammillary layer. The determination of dynamic stiffness (K_{dyn}) was made using the lab-scale test arrangement described by De Ketelaere *et al.* (2000). This consists of a lightweight hammer, which delivers a non-destructive impact to the equator of the egg as the egg rotates about its mid axis, and a small microphone which records the resulting vibrational response of the egg. Details relating to the calculation of K_{dyn} can be found in De Ketelaere *et al*. (2000). Only intact eggs were included in our analysis. Breaking strength (N) and static stiffness were measured by quasi static compression using an LR50 material-testing machine (Lloyd, Fareham, Hants, England) and a compression speed of 20mm/min. The breaking strength was measured as the maximum force (F), the static stiffness (N/mm) was calculated from the maximum force (N) and deformation at fracture (mm). Each egg was then emptied and the eggshells prepared for assessment by scanning electron microscopy of the total, effective (palisade layer) and mammillary thickness as described by Bain, (1992).

The following additional data was provided from the pedigree population used in this study: body weight at 33 weeks; total numbers of eggs produced per bird (26 - 50 and 58 - 74 weeks of age.

STUDY 2: CRACK PREDICTION

a) Animals and egg collection

Over two separate occasions towards the end of a laying cycle 1637 eggs were collected by hand from the front of cages housing Hy-line brown hens in a commercial battery unit containing 135,000 birds. Each egg was clearly labelled with reference to its origin (battery, tier) then acoustically tested to determine its K_{dyn} value as described above. Cracked eggs were eliminated from the test sample. The intact eggs were then replaced in front of the cages then passed through the collection, grading and packing machinery along with a representative volume of unmarked eggs. The acoustic test was then repeated after the test eggs had been retrieved from the packing plant to determine which eggs had cracked.

b) Analysis

A logistic regression of the probability of cracking versus the dynamic stiffness was fitted to assess the possible use of dynamic stiffness as a predictor of cracking. Additional variables found to influence the prediction were also fitted to improve precision; the date of the measurement, the position the eggs started from in the housing system and their weight. K_{dyn} was transformed to $10^{12}/ K_{dyn}^3$ to improve its predictive power while fitting only a single parameter.

Results

The estimate of heritability for the novel measurement of K_{dyn} was high (0.53) (Table 1) and only a little less than the estimates for egg and body weight that are commonly considered as being high. This compared with a relatively low value (0.18) for breaking strength on the same eggs, the measure currently used for selection in our pedigree population. Values for the heritability of mean thickness and effective thickness of the eggshell were moderate while mammillary thickness was lower.

Table 1 Estimates of heritability (h2) (n=1501). Estimates were made using the animal model with the exception of the SEM measurements, which were made using the sire model and are therefore lower than if made by the animal model. Values used in the calculation for eggs were the mean of observations from 2 eggs per hen.

Trait		h2
Dynamic stiffness	Dynamic stiffness (K_{dyn})	0.53
Egg weight and shape	Egg Weight	0.60
	Shape Index	0.30
Quasi-static compression	Breaking strength	0.18
	Static stiffness	0.21
SEM thickness	Total thickness	0.30
	Mammillary thickness	0.18
	Effective thickness	0.29
Related production data	Body Weight at 33 wks	0.77
	Total egg production from week 26-50	0.25
	Total egg production from week 58-74	0.03

Genetic correlation values were relatively high for K_{dyn} and breaking strength (0.49) and for K_{dyn} and static stiffness measurements (0.57) made on the same egg (Table 2). The K_{dyn} value also correlated well with total eggshell thickness and effective thickness measurements. Genetic correlations of K_{dyn} with egg production were negative (Table 2) as was K_{dyn} and body weight. There was no indication of a genetic correlation with egg weight or shape.

Table 2 Estimates of genetic correlation for K_{dyn} with other traits in a pedigree Rhode Island Red population (n=1501).

Trait		Genetic correlation ±SE
Egg weight and shape	Egg Weight	-0.06±0.25
	Shape Index	0.01±0.24
Quasi-static compression	Breaking strength	0.49±0.22
	Static Stiffness	0.57±0.21
SEM thickness	Total thickness	0.34±0.23
	Effective thickness	0.43±0.21
Related production data	Total egg production from week 26-50	-0.19±0.35
	Total egg production from week 58-74	-0.36±0.24
	Body Weight at 33 wks	-0.27±0.23

As initial K_{dyn} of the egg measured at the cage front decreases, the probability of it cracking on its passage through the processing plant increases (Figure 1). The graph shown is for data taken on the second visit and is for battery levels 1 and 2 (Figure 1). A very similar pattern was observed for all 4 combinations of visit and battery level, but the probability of cracking was slightly greater on the

second visit than the first, and for levels 3 and 4, over levels 1 and 2. Heavier eggs increased the probability of cracking slightly but the estimates were relatively poor.

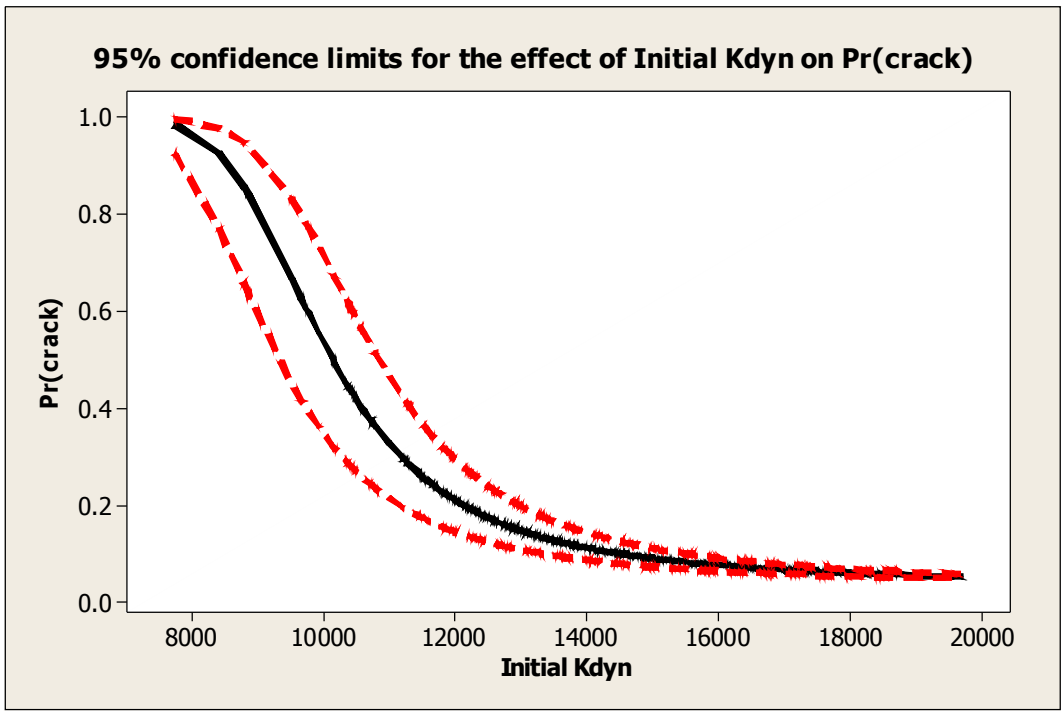


Figure 1 Graph of probability of cracking during passage through a packaging plant (Pr(crack)) versus the K_{dyn} value for an egg measured at the cage front (Initial Kdyn). The fit was produced by a logistic regression for data from visit 2, house level 1 & 2 and shows the 95% confidence limits of the prediction (broken lines).

Conclusion

The relatively high heritability estimates for dynamic stiffness (K_{dyn}) means that this measurement could be used effectively in a breeding programme. The high heritability value indicates that the variation in measurements between hens has a relatively large genetic contribution and that there may be alleles of genes that determine what is being measured segregating in the population. This suggests that K_{dyn} is about equally affected by genetic and environmental factors including measurement variance. Furthermore if the K_{dyn} measurement does predict the likelihood of an egg cracking it could be used to improve shell quality and could reduce the incidence of cracks in the packing plant and during transportation.

Our observations on individual eggs for which we had K_{dyn} values during their passage through the packaging plant, show that K_{dyn} does predict the likelihood of cracking. This was somewhat surprising given the many possible insults an egg might suffer as it passes through the collecting and packing machinery. As initial K_{dyn} decreases below 12000 there is a rapid increase in the probability that the egg will suffer damage during its transit through the packing plant conveyer belts and machinery. The relatively narrow confidence limits suggest that this "threshold" may be 1000 units lower or higher. The precision of the effects of the other variables is low in comparison.

Genetic correlations agree with previously observed phenotypic correlations (De Ketelaere *et al.*, 2003) that there is a relationship between K_{dyn} and other measurements of eggshell quality. These results suggest that selection for K_{dyn} would have positive effects on both breaking strength and static stiffness as well as effective and total thickness. The effective thickness comprises the palisade layer and is the component contributing most to the strength of the eggshell (Bain 1992).

Genetic correlations between K_{dyn} and egg production were negative but not very large. Measures of eggshell quality are generally negatively correlated with egg production (Van Tijen and Kuit, 1970; Nirasawa *et al.* 1998) and can be accommodated in selection programmes. Genetic correlation with body weight was also negative and in the same range as the estimated standard error, therefore confidence in these estimates is lower.

These results therefore strongly suggest that the measurement and selection of hens on the K_{dyn} value of their eggs will improve eggshell quality and reduce eggshell damage during automated egg collection, grading and packaging.

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