Eggshell Qualities as Indicative of Eggshell Strength for Layer Selection

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ABSTRACT

The study aimed at investigating which of four traits is the most representative of eggshell strength (destructive eggshell thickness measurement, eggshell weight, egg specific gravity, ultrasonic measurement of eggshell thickness) and could be used for selection purposes. To date, investigations focused mostly on pairwise (eggshell strength vs. another eggshell feature) analyses, resulting in two-, maybe three-trait, models when eggshell traits are considered. Since the covariance estimates are also model dependent, we collected five eggshell traits within one analysis, which better reflects what occurs in nature. The eggs were collected from 4571 Rhode Island White and 2426 Rhode Island Red hens. A multiple-trait animal model and the REML method were employed to compute variance components for calculation of heritabilities and genetic correlations between the traits. On average, the highest correlations were found between the destructive measurement and the other quality traits. It is concluded, however, that the ultrasonic eggshell thickness measurement, also with high genetic correlations with the other traits and leaving an egg intact for further handling, can suit best, as an indirect criterion, the selection for eggshell strength.

INTRODUCTION

Eggshell is a structure of major importance in layer breeding, influencing two economically vital aspects in commercial egg production – the eggshell protects the embryo, while enabling its development, and has an impact on the level of losses in the production of consumption or hatching eggs (Mertens *et al.*, 2006).

Eggshell quality has long been subjected to genetic selection, and considerable improvement of eggshell quality has been reported (Hocking *et al.*, 2003). Some main features of the eggshell are its strength expressed as the force needed to crack it, thickness, and weight. Before the emergence of non-destructive measurement devices (Kibala *et al.*, 2015), destructive methods, leaving the egg unsuitable for further handling, were employed to evaluate eggshell quality. In order to avoid egg destruction, other traits genetically correlated with the eggshell strength, such as the ultrasonic measurement of eggshell thickness (ibid) and egg specific gravity (Rozempolska-Rucinska *et al.*, 2011), were proposed as indicative of eggshell strength.

Any of the above egg traits may be employed as criterion for the selection for eggshell strength; however, only ultrasonic eggshell thickness measurement and egg specific gravity leaves the egg intact.

Although eggshell breaking strength is the ultimate measurement of eggshell strength, this study aimed at investigating which of the four other traits reflecting eggshell strength (destructive eggshell thickness

measurement, eggshell weight, egg specific gravity, and ultrasonic measurement of eggshell thickness) is most representative of them all and could eventually be used for selection purposes.

MATERIAL AND METHODS

Since the performance data were obtained from the routine performance records of a commercial farm, Animal Care and Use Committee approval was not warranted.

Eggs of two layer populations, Rhode Island Red (RIR) and Rhode Island White (RIW), were collected on a single day of the 33rd week of egg laying on the farm. Laying performance was evaluated based on an individual recording system. Altogether, eggs were collected from

4571 Rhode Island White (RIW) and 2426 Rhode Island Red (RIR) hens. The traits measured to evaluate eggshell quality were: egg specific gravity (ESG – calculated from the Archimedes' principle), eggshell strength (ES – measured with a device recording breaking strength with the accuracy of 0.01N at a constant velocity of the measuring head shift equal to 50 mm/min), eggshell weight (ESW – measured on an electronic scale with accuracy of 0.1g), destructive eggshell thickness (DET – taken with an electronic micrometer at random points over the egg's equator towards the wide end, and ultrasonic eggshell thickness measurement (UET – using a commercially available device for measuring the thickness of different materials).

The basic characteristics of the material are shown in Table 1.

Table 1 – Basic statistics of eggshell quality traits in Rhode Island Red (RIR) and Rhode Island White (RIW) hens

Breed	Variable	Number of hens	Mean	SD	Min	Max
RIW	Specific gravity (g/cm ³)	4468	1.072	0.008	1.020	1.100
	Shell strength (N)	4431	40.2	9.0	10.0	71.5
	Shell weight (g)	4462	7.4	0.7	4.9	9.9
	Destructive shell thickness (µm)	4447	315	31	178	399
	Ultrasonic shell thickness (µm)	4472	412	35	269	609
RIR	Specific gravity (g/cm ³)	2407	1.071	0.009	1.020	1.100
	Shell strength (N)	2369	40.0	10.2	10.5	82.8
	Shell weight (g)	2400	7.3	0.6	4.9	9.7
	Destructive shell thickness (µm)	2397	312	31	192	398
	Ultrasonic shell thickness (µm)	2403	403	33	257	635

Variance components required computing the genetic correlations among eggshell quality traits, and their heritabilities were estimated by the REML method using the following multiple-trait model:

$$y_{ij} = \mu + YH_i + a_j + e_{ij}$$

where:

y_{ij} – vector of 5 observations on j^{th} bird in i^{th} contemporary group (ESG, ES, ESW, DET, UET);

μ – vector of 5 means of the traits;

YH_i – vector of fixed solutions due to the combined effect of year of hatch and hatch no. within year of hatch;

a_j – vector of random animal additive genetic solutions, pedigrees three generations deep;

e_{ij} – vector of random residuals.

The computations were performed using the AIREMLF90 software of Misztal *et al.* (2002).

RESULTS

The additive genetic variability of the studied traits accounted for 16 to 22% of the total variability in the

RIW breed and for 26 to 42% in RIR (Table 2). In both breeds, ESW and UET presented the highest heritability estimates.

Table 2 – Heritabilities and their standard errors of eggshell strength quality traits in Rhode Island White (RIW) and Rhode Island Red (RIR) breeds

Breed Trait	RIW		RIR	
	h ²	se	h ²	se
Specific gravity	0.16	0.03	0.26	0.05
Shell strength	0.16	0.03	0.24	0.04
Shell weight	0.21	0.03	0.42	0.05
Destructive shell thickness	0.16	0.03	0.30	0.05
Ultrasonic shell thickness	0.22	0.03	0.37	0.05

Table 3 presents the genetic correlations among the traits. The correlations proved to be moderate to very high, and of small standard errors. In both breeds, on average, the highest correlations were found between DET and the other quality traits. Somewhat lower genetic correlations, still with small standard errors, were recorded for UET. In addition, the genetic correlation between DET and UET was very high in both breeds, of 0.82 and 0.95 in RIW and RIR, respectively.

Table 3 – Genetic correlations and their standard errors amongst the eggshell quality traits in Rhode Island White (beneath diagonal) and Rhode Island Red (above diagonal)

	Specific gravity		Shell strength		Shell weight		Destructive shell thickness		Ultrasonic shell thickness	
Specific gravity			0.89	0.06	0.40	0.11	0.87	0.05	0.81	0.06
Shell strength	0.67	0.08			0.50	0.10	0.84	0.07	0.83	0.06
Shell weight	0.31	0.11	0.32	0.11			0.64	0.08	0.61	0.08
Destructive shell thickness	0.83	0.05	0.61	0.09	0.60	0.08			0.95	0.03
Ultrasonic shell thickness	0.75	0.07	0.73	0.07	0.53	0.09	0.82	0.06		

DISCUSSION

Eggshell quality, in its broad sense, largely depends on environmental factors, e.g. the age of the flock, moulting, nutrition, general stress, heat stress, diseases, production systems, and food supplements (Roberts, 2004). Nevertheless, the usefulness of a trait for genetic selection is determined by the genetic additive effects reflected by a sufficiently high heritability coefficient. The present analyses revealed that all traits were moderately or highly heritable, and had low heritability coefficient standard errors, while higher values were noted in the RIR breed. This difference may result from the different genetic structure of the breeds due to different selection pressures (maternal RIW vs. paternal RIR) for the traits included as selection criteria.

The range of genetic variability cannot be the sole determinant when deliberating the inclusion of a trait as selection criterion. The biological importance of a trait is also essential. In the current investigation, a total of five traits defining one broad indicator – eggshell quality – was analyzed. This complex trait is often associated with eggshell strength, which defines the resistance of the eggshell to damage by an external force (Hamilton, 1982). Eggshell strength can be regarded as a reflection of an egg's mechanical and physical properties (Hammerle, 1969). The heritability of eggshell strength, reported by other authors, ranged between 0.10 and 0.35 (Dunn *et al.*, 2005; Icken *et al.*, 2006; Begli *et al.*, 2010; Blanco *et al.*, 2014). The discrepancy between these values is related to both the analyzed birds' genetic origin and the computation method. It was shown in the present study, however, that eggshell strength was highly correlated with other eggshell quality traits, with the highest correlations recorded between eggshell strength and the ultrasonic measurement of eggshell thickness in RIW and, in RIR, also with the destructive eggshell thickness. This result should not be surprising as eggshell thickness is an indirect trait for determination of its strength (Hamilton, 1982). A great problem in the case of eggshell strength is the destructiveness of the measurement and the

impossibility of performing repeated measurements on the same egg. Hence, there may be differences among the results of crush tests applied on different areas of the eggshell (De Ketelaere, 2002). This is associated with the variable thickness of the eggshell, which in turn is highly correlated with eggshell crush strength (Yan *et al.*, 2014; Kibala *et al.*, 2015). Mechanical eggshell strength is determined by its thickness, which primarily reflects its structural properties (Bain, 2005) and it is highly responsible for the percentage of cracked eggs (Tyler and Geake, 1963). Thickness is one of the most important indirect measurements of eggshell strength; simultaneously, the magnitude of this trait is crucial in hatching eggs. Hatchability of eggs with thin shells is around 3-9% lower (Bennett, 1992) than that of eggs with normal shell thickness, i.e., between 0.35 and 0.40 mm (Icken *et al.*, 2006). Eggshell thickness is a trait of high genetic additive variability. Other authors reported higher heritability coefficient estimates than the present results, with values ranging from 0.19 to 0.57 (Icken *et al.*, 2006; Begli *et al.*, 2010).

Eggshell thickness can be measured via destructive analyses, which have been most frequently applied so far, but are inapplicable in commercial farms, or via non-destructive measurements, using, for example, the ultrasonic technology. It was shown in the present study that eggshell thickness, measured by either the destructive or non-destructive methods, is strongly correlated with the other traits, which confirms that eggshell thickness is indicative of the other traits of eggshell quality. Very high genetic correlations were recorded in both genetic strains between eggshell thickness and specific gravity (Table 3), which is another indicative trait used for eggshell strength assessment, as well as eggshell thickness.

Although the use of egg specific gravity for the genetic improvement of eggshell quality is sometimes controversial, the additive variability of egg specific gravity accounts for ca. 20%-45% of the total trait variability (Nirasawa *et al.*, 1998; Ledur *et al.*, 2003; Begli *et al.*, 2010; Rozempolska-Rucińska *et al.*, 2011), thereby making it a predictor candidate in effective

selection for eggshell quality. The objections against the use of egg specific gravity as a trait that defines eggshell quality in a broad sense are mainly related to the fact that the reliability of this measurement largely depends on environmental factors, e.g., the duration of egg storage or the lag of measurement time (Voisey and Hamilton, 1977; Sloan *et al.*, 2000). Despite these doubts, selection based on egg specific gravity has yielded positive results, as it reduced the number of eggs with thin shells by 3.4% in the study of McPhee *et al.* (1982).

Another indirect measure of eggshell strength is eggshell weight. This is, however, a destructive and labour-inefficient method, as it requires breaking the egg, washing the white out of the shell, as well as drying and weighing the shell. The genetic variability of this trait reported by other authors (Begli *et al.*, 2010) was similar to that presented in this paper.

To sum up the analyses performed, it may be claimed that non-destructive ultrasonic shell thickness measurement can be used as a criterion in hen selection for eggshell strength. This trait shows a sufficient level of additive genetic variability and very strong genetic correlations with the other eggshell traits. Hence, only one indicator needs be used for defining the general eggshell strength quality.

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