Monitoring of egg shell strength and egg shell breakage in different production chains of consumption eggs

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Summary

In consumption eggs the quality of the shell is of major importance. Therefore it is of great interest to obtain high shell strength in order to resist all impacts an egg is subjected to in the production chain. The research had 3 goals: 1. monitoring of the critical points for eggshell breakage in different logistic chains; 2. investigate differences in eggshell strength (K_{dyn} & damping) between eggs produced in different housing systems; 3. developing a model to investigate the relation between the initial shell strength (K_{dyn} & damping), and the likelihood of the egg to break during handling and grading. Four logistic chains were investigated: cages, furnished cages, aviary and free-range system. In all systems Bovans Goldline © chickens in their mid lay were housed. In every system, a randomised set of 1500 eggs was taken, numbered and strength of the intact eggs was measured. In this way the percentage of broken eggs directly after laying was defined. Then all the intact eggs were placed back into the cages and they continued their normal way throughout the logistic chain. At every critical point in the logistic chain, the eggs were examined for breakage to define the percentage of breakage. Firstly the traditional and furnished cage system showed high breakage directly after lay (6.73% resp. 10.72%) while the other systems showed about 2% of breakage. There was no difference in breakage between the other control points of the logistic chains. Secondly, there was a significant difference between the eggshell strength of eggs from chickens in different housing systems. Thirdly, there was a significant correlation between the measured shell strength and the likelihood of breakage. In conclusion, it was shown that measurement of K_{dyn} and damping provides a good predictive value for egg shell breakage.

Introduction

Since the eggshell is the natural packing material for the egg contents, it is of great interest to obtain a high shell strength in order to resist all impacts an egg is subjected to during the production chain (Bain, 1990). There are several methods to measure the eggshell quality. The most commonly used are specific gravity, eggshell thickness, breaking strength and non-destructive deformation (Voisey and Hunt, 1974; Hamilton, 1982).

Coucke (1998) presented a fast, objective and non-destructive method for determination of the eggshell strength, based on acoustic resonance analysis. This technique measures the resonance frequency (RF) of the egg and its damping. Based on the RF and the egg weight, the dynamic shell stiffness (K_{dyn}) is defined. Simultaneously, this technique can be used to detect cracks in the eggshell (De Ketelaere *et al.,* 2000).

There have been several researches demonstrating the use of the dynamic shell stiffness. First, both Coucke *et al.* (1999) and De Ketelaere *et al.* (2002) found an acceptable correlation between the measurement of K_{dyn} and the static stiffness (resp. 0.84 and 0.76) and shell thickness (resp. 0.78 and 0.75). Second, recent work of Dunn *et al.* (2005) pointed out that the dynamic stiffness shows a high heritability (0.53) and a high genetic correlation with eggshell breaking strength (0.49). Since numerous studies have been conducted on improving eggshell strength through selection but few of them dealt with selection responses in terms of actual egg breakage (Saito *et al.*, 1988), this result shows that the dynamic stiffness might be of interest to incorporate in breeding programs. And although the feed has a major impact on the eggshell strength, De Ketelaere *et al.* (2000) proved that differences in dynamic stiffness between different commercial layer lines are at least as important. Third, research by Bain *et al.* (2005) and Dunn *et al.*(2005) proved that K_{dyn} provides a good

estimation of the eggshell strength in relation to the likelihood of break in practice. And fourth, a small-scale experiment of Lin *et al.* (2004) showed a declining of the dynamic stiffness as a result of heat-stress.

Besides Wells (1967) and Bowman and Challender (1963), mainly Charles and Strong (1988) investigated the relationship between some measures of shell quality and egg-breakage in a commercial processing plant. They found that eggshell strength defined by specific gravity and percentage of shell was correlated with percentage of cracks. Also, Britton (1987) investigated the relationship between shell quality, determined by the shell deformation method, to breakage on filler flats. He reported a much higher breakage with high shell deformation (poor shell).

Monitoring eggshell breakage in the complete production chain includes breakage in the hen house. Amongst others, Leyendecker *et al.* (2001), Abrahamsson & Tauson (1995, 1998), Abrahamsson *et al.* (1995), Guesdon & Faure (2004) and Wall & Tauson (2002) presented differences in egg quality and proportion broken eggs for different housing systems (battery cages, furnished cages, aviary). Furthermore, Thompson and Hamilton (1986) stated that most eggs are broken during transportation, rather than any other step during processing and distribution. However, no results were available on possible difference in initial shell strength of eggs produced in these systems and their incidence on breakage in the rest of the production chain.

The first goal of this research was to monitor the critical points for eggshell breakage in different logistic chains, from laying to final destination. Secondly, it was investigated whether there was a difference in eggshell strength (K_{dyn}) and damping between eggs produced in different housing systems. And thirdly, a model was developed to assess the relation between the initial shell strength, defined by the dynamical shell stiffness (K_{dyn}) and the damping, and the incidence of the egg to break during handling and grading.

Material and methods

LOGISTIC CHAINS

In the experiment carried out, four different logistic chains for the production of consumption eggs were investigated. The main difference between these chains was the housing system of the production unit: classical battery cages, furnished cages, aviary and free-range system. In order to exclude differences in genetics and age of the layers, only farms with Bovans Goldline® hens from the same age were chosen. The effect of different feeds could not be excluded, but it can be assumed that the basic formulation of different commercial feeds is comparable. Moreover, also effects of other parameters, like management, climate, health status of the hens, could not be excluded. It was stated that all these parameters were taken together under one general parameter, namely, housing system. Table 1 is giving a survey of the links every logistic chain contains.

At the start of the first chain, in total 28.800 hens were housed in a Specht ® battery cage system. The eggs were transported out of the hen house on a rubber conveyor belt, there after collected by a belt consisting of coated iron bars, rolling in a direction perpendicular at the rubber belt. In this way the eggs were conveyed into the egg storage room, which bordered to the hen house. In this room the eggs were automatically collected with a Moba Farmpacker®. The hens were fed with feed A.

Table 1 Survey of the different links from which each logistic chain consists. "X" indicates the absence of the link in the chain. The measurements performed in each link are noted between brackets [ ].

	Chain 1	**Chain 2**	**Chain 3**	**Chain 4**
Housing	Battery cages [K_{dyn}- %crack]	Furnished cages [K_{dyn}- %crack]	Aviary	Free-range
Egg-collecting	[%crack]	[%crack]	[K_{dyn}- %crack]	[K_{dyn}- %crack]
Transport to packing station	[%crack]	[%crack]	[%crack]	[%crack]
Grading & packing	[%crack]	[%crack]	[%crack]	[%crack]
Transport to warehouse depot	X	X	X	[%crack]
Transport to retail	[%crack]	[%crack]	[%crack]	[%crack]

In the second chain, the housing system consisted of furnished cages, equipped with perches, a laying nest (with Astroturf XPNP laying nest material) and scratching area for improvement of animal welfare. Dimensions and bird density (for in total 2.460 hens) of the cages met the European standards. The eggs were transported into the egg storage room by a standard Specht ® conveyor belt and elevator.

The aviary, the first link of the third chain, was divided into 4 pens each housing 500 hens. The laying nests (with Astroturf XPNP laying nest material) were located on the two lateral sides of the compartments. The eggs were transported into the egg storage room by a perforated conveyor belt, which minimizes the egg rolling and hence inter-egg clashes.

The furnished cage system and the aviary were situated at the same location, furthermore they were in the same building. The hens in the furnished cages and half of the hens in the aviary were fed the same feed (feed B), yet for the other half of the hens in the aviary, a supplement of CCM was added to feed B (feed C).

The last chain started off with a free-range housing system with 13.500 layers. Two rows of laying nests (with Astroturf XPNP laying nest material) were placed in the middle of the house at a height of 67 cm. The back of the laying nests came out on the conveyor belt that transported the eggs out of the hen house into the egg storage room. This conveyor belt was perforated with small holes of Ø1cm to minimize the egg rolling and hence inter-egg clashes. Also, every day from 11.00u till dusk the hens had access to an outside free-range meadow. The hens were fed with feed D.

MEASUREMENT POINTS

For every chain, there were 5 measuring points, except for chain 3 which had 4. At the first measurement point (as early as possible in the chain) of each chain a sample of 1500 eggs was taken. As shown in Table 1, this point differs for the different logistic chains. In both the classical and furnished cage system this point is situated directly after laying (risk for breakage due to inter-egg contact, egg-cage contact or caused by the hens). While in the aviary and free-range system the first critical point is situated after collecting of the eggs (additional risk for breakage caused by the collecting system). The reason for this difference in initial measurement point was the fact that it was practically impossible to take the eggs out of the laying nests in the last two systems. For every system, the sample of eggs was taken equally spread in respect to their origin (battery, stage, cage number, pen, …). Subsequently, measurements were carried out in each following link of every chain, as shown in Table 1.

MEASURING METHOD

After collecting, the eggs were numbered (with reference to their origin) and tested with the crack detector, described by De Ketelaere *et al.* (2000). This first measurement defines the percentage of cracked eggs in this first point. Subsequently, the eggshell strength K_{dyn} and the damping of the intact eggs were measured as described by Coucke (1998) and Coucke *et al.* (1999). Afterwards, these eggs were placed back in this first measurement point from where they would follow the rest of the chain as usual. In each measurement point (Table 1) the percentage of cracked eggs is defined by use of the crack detector.

STATISTICAL ANALYSIS

After collecting the data, statistical analysis was performed using SAS version 8.2 (The SAS Institute Inc., Cary, NC, USA). To check whether the initial shell strength (K_{dyn}) and eventually damping had any predictive capacity for the egg breakage in the logistic chain, a logistic regression was used. A Hosmer and Lemeshow goodness-of-fit test was performed to assess model adequacy. To compare the percentages of cracked eggs in the different measurement points of the different chains, and to compare values for egg weight, K_{dyn} en damping, a general linear model was used.

Results

CRITICAL POINTS FOR BREAKAGE

When monitoring the egg breakage in the different chains, the cage systems (chain 1 & 2) showed a relative high breakage after lay, 6.73% and 10.72% respectively. Besides that, the collecting in chain 1 generated an extremely high percentage (36.85%) of broken eggs due to technical problems with the conveyor belt. Furthermore, regarding total breakage after collecting the eggs, the cage systems (chain 1 & 2) had a significantly higher value (43.58% and 14.55%) than the aviary and free-range system (chain 3 & 4) (1.94% and 1.99%). As shown in Table 2, grading and packing of the eggs is the second, next to laying and collecting, critical point in the logistic chain. Breakage due to transport varies from 0.21% to 2.65%. Following the higher breakage at laying, also total breakage is significantly higher for the chains with cage systems, especially for chain 1.

EGGSHELL STRENGTH

In Table 3 the average values of K_{dyn} and damping are compared for the eggs produced in the different housing systems. Compared to the other four groups, the free-range system displays a significant lower dynamical stiffness (11 403 N/m) and a higher damping (4.26%). The other groups are comparable, but still, eggs from hens in battery cages have a higher dynamic stiffness than the ones from furnished cages, but a lower value than the ones from the aviary. The same goes for the values of damping, but then the other way round. The values for the two groups in the aviary are equal. Remarkable is the difference between the values for both dynamic stiffness and damping for the furnished cages and part of the aviary that was fed the same feed (13 419 *vs.* 14 140 N/m and 3.99% *vs*. 3.48% respectively).

Table 2 Percentage of broken eggs given for the different links of the investigated production chains. Small letters compare the links of one production chain while capital letters compare the different production chains per link. Numbers with the same letter are equal (p < 0.05).

	LAYING	Collecting	Transport Packing Station	Grading & Packing	Transport Depot Warehouse	Transport Retail Store	TOTAL
Chain 1	6.73%^{Aa}	36.85%^{Ab}	2.65%^{Ac}	3.44%^{Ac}	-	0.25%^{Ad}	**44.63%**
Chain 2	10.72%^{Ba}	3.83%^{Bb}	1.25%^{Bc}	1.50%^{Bc}	-	0.16%^{Ad}	**16.61%**
Chain 3	1.94%^{Ca}		1.31%^{Ba}	2.17%^{ABa}	-	0.21%^{Ab}	**5.47%**
Chain 4	1.99%^{Ca}		0.28%^{Cbc}	2.11%^{ABa}	0.86%^{b}	0.22%^{Ac}	**5.36%**

Table 3 Average values and standard deviation for K_{dyn} and damping in the different housing systems and per different feed. Values with the same letter are equal (p<0.05).

Housing (feed)	K_{dyn} x 100 N/m	Damping%
Battery (A)	13474 ± 1779 ^{a}	3.68 ± 0.94 ^{a}
Furnished cages (B)	13419 ± 2083 ^{a}	3.99 ± 1.11 ^{b}
Aviary (B)	14140 ± 1915 ^{b}	3.48 ± 0.94 ^{a}
Aviary (C)	13998 ± 1876 ^{b}	3.60 ± 1.00 ^{a}
Free-range (D)	11404 ± 1765 ^{c}	4.26 ± 1.07 ^{c}

RELATION BETWEEN EGGSHELL STRENGTH AND BREAKAGE

Analyzing the data of the eggshell strength in function to the likelihood of the egg breaking during handling and grading pointed out that both K_{dyn} and damping possess a predictive capacity. For all models discussed, the Hosmer and Lemeshow goodness-of-fit statistic indicated no departure from the model assumptions (P>0.05). It was found that for the different chains, the probability of cracking was a function of K_{dyn} and/or damping. Table 4 is showing the different probability models and the Odd's Ratio's (O.R.) of the significant parameter(s) in the models. These O.R. indicate the increase or decrease of the probability of breakage with the decrease or the increase of the significant parameter with 1 unit. The only model that shows a significant predictive capacity for both strength parameters is

for the chain with battery cages. For the chains with furnished cages and free-range housing, only K_{dyn} shows significant capacity, while for the chain with the aviary system only damping is significantly predictive.

Table 4 Different (logistic) prediction models for the likelihood of breakage of an egg as a function of K_{dyn} and/or damping, with P-values and Odd's ratio's respectively per model.

Housing	MODEL P (breakage) = f (...)	P <		Odd's Ratio's	
		K_{dyn}	*Damping*	*K_{dyn}*	*damping*
Battery cages	P = f (K_{dyn}, damping)	0.0003	.0001	1.30%	32.30%
Furnished cages	P = f (K_{dyn})	0.0108	-	1.20%	-
Aviary	P = f (damping)	-	0.0417	-	32.90%
Free-range	P = f (K_{dyn})	.0001	-	5.60%	-
1 unit K_{dyn}	= 10000 N/m				
1 unit damping	= 1%				

Discussion

The relative high breakage generated by laying in both cage systems (6.73% in battery cages and 10.72% in furnished cages), is in agreement to the findings of Leyendecker *et al.* (2001) and Van Niekerk and Reuvekamp (1995, 1999). The higher percentage of breakage in furnished cages was also found by Abrahamsson *et al.* (1995) and Guesdon and Faure (2004). From the work of Wall and Tauson (2002) it was shown that devices to reduce this breakage, like egg savers and long nest curtains, are very effective in reducing cracks in furnished cages. However, even if such measures are taken, egg breakage in furnished cages is highly dependent on design of the cage and the nest.

The extreme high breakage after collecting of the eggs from the battery, is not really a representative measure, but does point out that the technique used can detect critical points in any logistic chain for egg production.

The 3.83% breakage caused by collecting of the eggs from the furnished cages is due to the fact that the eggs had to be collected from different heights (cages with 3 levels) and as a consequence had to pass the elevator which brought them to collecting level in the egg storage room. The low and comparable breakage after collecting in both aviary and free-range (1.94% *vs.* 1.99%) can be explained by the fact that both systems had the same laying nest material, and all nests were situated on the same level as the collecting platform.

Thompson and Hamilton (1986) stated that, from laying to final destination, most eggs are broken during transportation. This is in contrast with our findings, in which breakage true transportation varied from 0.21% to 2.65%, which is mostly lower than breakage in the other links. Besides packing material, a lot of factors are influencing transportation: truck suspension, traffic density, road conditions, location of the egg package on the truck and atmospheric conditions (Nethercote *et al.*, 1974), but possibly also driver attitude in both driving and handling of the egg packages.

Breakage during grading and packaging, which varied from 1.50% to 3.44%, is influenced by, amongst other factors, packing speed, filler flats speed and packing material (Britton, 1978).

Differences in shell strength (Table 3) from eggs originating from the different housing systems, are probably mainly caused by differences in feed. However, there was a difference in both stiffness parameters between eggs from furnished cages and from the part of the aviary that was given the same feed (1341900 N/m *vs.* 1414000 N/m, and 3.99% *vs.* 3.48%). Taken into account that the hens had the same age and that the systems were located in the same building (with the same climatization), an influence of the housing system can't be excluded. As hens housed in an aviary have more body movement, their feed intake is higher than hens housed in cages (Leyendecker *et al.*, 2001; Abrahamsson *et al.*, 1995), their overall intake of calcium is higher as well. Comparing the values of the strength parameters for both aviary divisions (feed B en C), it can be noted that adding CCM to the ration causes a lower, though not significant, strength.

From the relationship between the eggshell strength, defined by K_{dyn} and damping, and the incidence for breakage, it was shown that both strength parameters provide a predictive value and hence can be used to define shell quality. This result is in accordance with Bain *et al.* (2005) and Dunn *et al.* (2005). Charles and Strong (1988) found the specific gravity and the percentage of shell to possibly be of use to estimate shell quality. Britton (1987) presented shell deformation as a measure. Percentage of shell is a destructive method and needs two measurements (egg weight and shell weight) (Charles and Strong, 1988), specific gravity is strongly influenced by environmental and

operator effects (Voisey and Hamilton, 1976) and egg shell deformation is time consuming and needs multiple measurements (Voisey and Hunt, 1974). The acoustic resonance technique is a fast, objective and non-destructive method and so proves to be a better measure for eggshell quality and the likelihood to breakage during handling. Furthermore, based on these findings and the results of Dunn *et al.* (2005), it can be stated that K_{dyn} is a good parameter to use in breeding programs.

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