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استخدام الاهتزازات الصوتية في تقييم خواص الجودة للبيض

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الملخص العربي

أجريت هذه الدراسة بمعمل اختبار المواد البيولوجية بقسم الهندسة الزراعية بكلية الزراعة – جامعة المنوفية وتمثلت في عمل القياسات الخاصة بدراسة جودة البيض عن طريق استخدام الموجات الصوتية الناتجة عن قشرة البيض نتيجة التصادم واستخدامها في فرز البيض المكسور والمشروخ عن البيض السليم.

وقد تم اختبار طريقة غير متلفة لتحديد خواص الجودة الفيزيائية للبيض، حيث أنه يوجد ٦% إلي ٨% من البيض المنتج مكسور أو به شروخ، وكان اختبار قوة الكسر لقشرة البيضة من الاختبارات المتلفة والمرتبطة جداً بخواص البيض المكسور ولكن الاختبارات غير المتلفة لم تكن واضحة. وللوصول إلي ذلك تم دراسة العلاقة بين الاهتزازات الصوتية والصلابة الديناميكية من ناحية وقوة الكسر من ناحية أخري كدليل غير متلف لجودة البيض. وأجريت التجارب علي عينات من بيض أربع سلالات من الدجاج ممثلة في عينتين، وكان عدد العينات الكلية (٤٣٧ بيضة) حيث أخذت العينة الأولي من مزرعة كلية الزراعة – جامعة المنوفية (نورفا وسينا ١٢٩ و٦٨ بيضة علي الترتيب) والعينة الثانية من شركة الوادي لإنتاج الدواجن (هاي لنين ولوهمان ١٢٠ بيضة لكل منهما).

وقد استخدم في هذه الدراسة جهاز مكتشف الشروخ وجهاز قياس قوة الكسر و تم حساب الصلابة الديناميكية لتحديد خواص البيض بطريقة غير متلفة مع دراسة خواص الجودة الفيزيائية. وأظهرت النتائج أنه كانت هناك فروق معنوية للتفاعل بين السلالات وحالة البيض (سليم – مكسور) لكل من الصلابة الديناميكية ووزن القشرة الجاف وقوة الكسر وسمك القشرة ونسبة القشرة عند مستوي معنوية ٠.٠١، وكذلك دليل الشكل عند مستوي معنوية ٠.٠٥، وهذا الاختلاف راجع للعوامل الوراثية بين السلالات.

وجد أيضاً أن هناك علاقة شديدة بين التردد الصوتي وقوة الكسر وسمك القشرة، كما أمكن التنبؤ بقوة الكسر عن طريق الصلابة الديناميكية ووزن القشرة الجاف وسمك القشرة ونسبة القشرة ودليل الشكل. وتتلخص أهم النتائج فيما يلي:

١- معامل الارتباط بين الصلابة الديناميكية وأبعاد البيضة (الطول والقطر) معنوياً علي مستوي ٠.٠١ (٠.٥٣٣، ٠.٦١٠ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

٢- معامل الارتباط بين الصلابة الديناميكية ووزن وحجم البيضة معنوياً علي مستوي ٠.٠١ كان (٠.٦١٨، ٠.٦٢٥ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

٣- معامل الارتباط بين الصلابة الديناميكية ودليل القشرة معنوياً علي مستوي ٠.٠١ كان (٠.٦١٤) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

٤- معامل الارتباط بين الاهتزازات الصوتية ووزن وحجم البيضة معنوياً علي مستوي ٠.٠١ (٠.٣٨٦، ٠.٣٩٢ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

٥- معامل الارتباط بين الاهتزازات الصوتية وأبعاد البيضة (الطول والقطر) معنوياً علي مستوي ٠.٠١ كانا (٠.٣٥٨، ٠.٣٧٧ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

٦- كما وجد أنه عندما تتعرض قشرة البيضة لصدمة غير متلفة، يكون لقشرة البيضة رد فعل بموجة صوتية. بالنسبة للقشرة السليمة تكون نبضة الصوت متماثلة عند كل النقط علي محيط البيضة، بينما القشرة المشروخة تظهر نبضات مختلفة في مواضع علي محيط البيضة.

٧- وجد أن الاهتزازات الصوتية للبيضة السليمة تراوحت من ٤٣٠ إلي ٨٦١٣ هرتز أما بالنسبة للبيضة المشروخة فقد وجد أن الاهتزازات الصوتية تراوحت بين ١٤٢٠ و ١٢٢٧٣ هرتز .

USING ACOUSTIC RESONANCE FREQUENCY IN EVALUATION FOR EGGS QUALITY PROPERTIES

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ABSTRACT: *The incidence percent of broken and cracked eggs ranged from 6% to 8% of all produced eggs. Breaking force strength has proven to be closely related to the proportion of broken eggs but the relationship with non-destructive measurements is not yet clear. Therefore, the relationship of resonance frequency and the dynamic stiffness with breaking force strength was measured as a non-destructive alternative. It seems to be necessary, to develop other measurements for estimating eggshell quality without destroying the egg shell. Four samples of 437 eggs, collected from the poultry farm, Faculty of Agriculture, Minoufiya University, first sample consisted of Norva and Sina, (129 and 68 eggs, respectively), second was collected from El Wady Company for poultry production, Hie-linen and Lohman (120 for each strain) and were used for analysis, acoustic impulse (using an acoustic crack detection device), besides measuring the breaking force strength. Calculations from dynamic stiffness have stronger influences on breaking force strength. Shell breakage strength, shell thickness, dynamic stiffness and shell mass had the best coefficients of correlation. Also it was the best assessment for practical large scale uses, because the characteristics of egg shell quality changes from strain to another. Intact eggs produced sound signals mainly exhibiting a single dominant peak in the frequency range of 430 and 8613Hz with signal duration of about 112 ms. The cracked eggs showed frequency spectra in relatively wider frequency range of 1420 to 12,273Hz and shorter signal duration of about 5ms. It was concluded that, the influence of the material strength (breakage force) upon total eggshell strength (crack detector) is limited. The commercial egg measurements showed that, dynamic stiffness accurately predicted which eggs would crack as they passed through the gathering and processing system. Thus the method could be used to sort out eggs likely to crack and remove them prior to cartooning.*

Key words: *Egg quality, physical egg quality parameters, acoustic resonance frequency, breaking force strength and dynamic stiffness.*

INTRODUCTION

High value agricultural products must be carefully handled in order to correspond to the customers demands and quality standards. Many methods are available for quality detection and sorting of agroproduct based on external properties such as size, shape, and external defects. One of these methods is dynamics excitation and response analysis, (Wang and Jiang, 2004). Economically the egg strength is of great importance since cracked eggs cause a major financial loss. In addition, people are at high risk when eating eggs, which might be contaminated after being damaged (Bain, 1990). Better knowledge of shell strength should led to a better understanding of eggshell fracture which, in turn, influences the design of egg-processing equipment and research in strengthening of the shell. In fact, total shell strength is influenced by both material and structural strength. Material strength concerns the strength of the building stones of a material and is described by the elastic modulus (E). for eggs, this depends on the association of the mineral and the organic components of the shell. Structural strength, on the other hand, is related to the interaction between the building stones and depends on several variables namely size, shape, thickness and distribution of the shell components. These variables fluctuate in time and place and are the major source of variation in eggshell strength (Govaerts *et al*., 2001). The detection of eggshell cracks, usually done manually in the poultry industry. It has become a bottleneck for the automation of egg sorting and packaging due to the increasing throughput of modern egg grading machines. Also considerable effort has therefore gone into the development of methods of replacing the manual inspection with a highly effective and automatic detection, which has important significance both in economy and food safety to those involved in the production and marketing of eggs, including producers and consumers. (De Ketelaere *et al.,* 2004). Coucke (1998) presented a fast, objective, and nondestructive method for the determination of the eggshell strength, based on acoustic resonance analysis. This technique measured the resonant frequency (RF) of the egg and its damping ratio. Based on the (RF) and the egg weight, the dynamic shell stiffness (K_{dyn}) was defined. This technique can also be used to detect cracks in the eggshell (Coucke, 1998; Coucke *et al*., 1999; De Ketelaere *et al*., 2000; Wang *et al*., 2004). Several authors have since shown that, the (K_{dyn}) is a useful eggshell quality measurement. De Ketelaere *et al*. (2002), for example, investigated the variation of this strength parameter in relation to certain production parameters. Coucke *et al*., (1999), De Ketelaere *et al*., (2002) and Wang *et al*., (2004) also found an acceptable correlation between the measurement of (K_{dyn}) and other measures of eggshell quality., Bain *et al*., (2006) showed that, (K_{dyn}) provides a good estimation of eggshell strength in relation to the likelihood of breakage in practice. In this research, eggs were excited by small hummer on the equator, and the response signals were detected by flexible piezoelectric film sensors on the different sides, respectively. The response wave signals were then transformed from time to frequency domain and the frequency spectrum was analyzed. The specific objectives of the this research were to:

1. Study the use of new technology to facilitate the discovery of cracks and facilitate the process of sorting eggs;
2. Study the relationship between acoustic resonance frequency and physical properties of the eggs;
3. Study the relationship between dynamic stiffness and physical properties of the eggs.

MATERIALS AND METHODS

1. Experimental procedure

Eggs were collected from a commercial packing station. A number of 450 eggs were used in this test originated from four genetically different strains which were Lohmann, Heil Linen, Norva and Sina. The feed for the birds was as in commercial diet. All eggs were carefully transported to the laboratory of quality measurements, and consequently all the required measurements can be obtained. First, eggs were handled and those with shell defects, (i.e. hairline cracks), obviously thin shells and misshapen eggs or irregularly shaped eggs were discarded. After discarding (437) sound eggs remained. Shell thickness (T_m, mm) was measured with a vice caliper to the nearest 0.01 mm. The average thickness was calculated from three measurements at the equatorial region of the egg (two in the poles and one in the middle part) were taken after the shell was dried and expressed in mm. The whole egg weight (EW) and shell weight (SW) was measured with an electronic weighing balance with an accuracy of (0.01 g). The methods of the non-destructive evaluating shell quality were: (1) resonant frequency; and (2) dynamic stiffness, while the methods of destructive evaluating shell quality was breakage force strength.

The surface area of the egg was estimated from the geometric relationship, in which area is divided into square centimeters, from the formula of Ahmed *et al*., (2005).

$$S.S.A. = 4.67(EW)^{2/3} \qquad (1)$$

where :

S.S.A = Shell surface area in (cm^2); and
E.W = Fresh egg mass in (g).

Eggshell index (I) can be calculated using the following equation (Bain 1990):

$$Shell \quad index(I) = \frac{WSW}{S.S.A} \times 100 \qquad (2)$$

where:

WSW = Shell wet weight in (g).

Shell thickness (mm) was calculated taking into account shell density as follows (Bain 1990):

$$T = \frac{I}{23.5} \qquad (3)$$

where:

I = the eggshell index; and
23.5 = egg shell density (g/cm^3).

2. Direct measurement of egg shell strength *(Shell breakage strength).*

The eggs were tested in a test apparatus [Breakage force tester, BMG 1.2] which compressed each egg between two flat plates to measure breakage force as presented. The force acting on the egg during compression was recorded over the range (1 to 147 N) by a force transducer and electronic recording digital system. This procedure was carried out on 200 eggs with the major axis parallel to the compression surfaces (force applied at equator). The shells were dried before test to a constant mass. Shell thickness measurements were taken at three random locations around the equator of the egg.

3. Shell elastic modulus or Young's modulus (E_{shell})

The shell elastic modulus or Young's modulus (E_{shell}) in N/mm^2 was calculated for each egg using formula developed by Bain (1990). The elastic modulus describes the contribution made by the shell material to the overall stiffness of the shell:

$$E_{shell} = C\left[\frac{F_s \times R}{T^2}\right] \qquad (4)$$

Where:

F_s = breakage stiffness; and
R = radius of curvature (width/2) (mm).
C = A × [0.408 + (5.052 × T/width]
Where: A = [(0.153 × L^3) – (0.907 × L^2) + (1.866 × L) – 0.666]/0.444

Shell fracture toughness (K_c)

Shell fracture toughness (K_c) in N/mm$^{3/2}$ were calculated for each egg using the formula developed by Bain (1990).

$$K_c = K_{nd}\left[\frac{F}{T^{3/2}}\right] \qquad (5)$$

where:

K_{nd} = constant = 0.777 [2.388 + (359.208 /width)]$^{1/2}$
and F breaking force value (N)

Figure (1): Breakage force tester in operation

4. Acoustic resonance analysis (dynamic stiffness).

The strength is determined according to the properties of the material of the eggshell. Measuring the eggshell strength in a dynamical way, nondestructively and fast. Katholieke University at Leuven, Belgium and Lohmann Breeding Company of Cuxhaven, Germany, newly developed measuring system-to measure the dynamic stiffness (K_{dyn}). It is assessed using acoustic resonance, following a non-destructive impact applied to the shell and predict shell damage. This device operates under the same physical principle as the great commercial egg graders which sort out eggs with hairline cracks and other shell damage, on the other hand the grading based on eggshell strength becomes possible. The surface of the egg is cautiously knocked on four times with a small hammer has a 1g ball on its equatorial axis so that the egg does not get damaged. Each and every strike leads to minimal oscillation of the eggshell, which is recorded by a microphone situated nearby as shown in Fig. (2). These which so called oscillation frequencies are similar with eggs which are intact, whereas the frequencies in defected eggs show a large part of total variance. Four knocks or impacts in addition to there and mean were calculated, respectively. The frequency of each egg suffices to calculate the parameter dynamic stiffness (K_{dyn}), which determines the shell stability.

Dynamic stiffness (K_{dyn}) was measured on a lap-scale test arrangement, as shown in Fig. 2. The eggs were struck with a light rod, and a small microphone recorded the resulting egg vibration. Modeling the egg as a mass-spring system, the dynamic stiffness (K_{dyn}) was obtained from the following equation (De Ketelaere *et al*., 2002):

$$k_{dyn} = c \times EW \times R_f^{\ 2} \qquad (6)$$

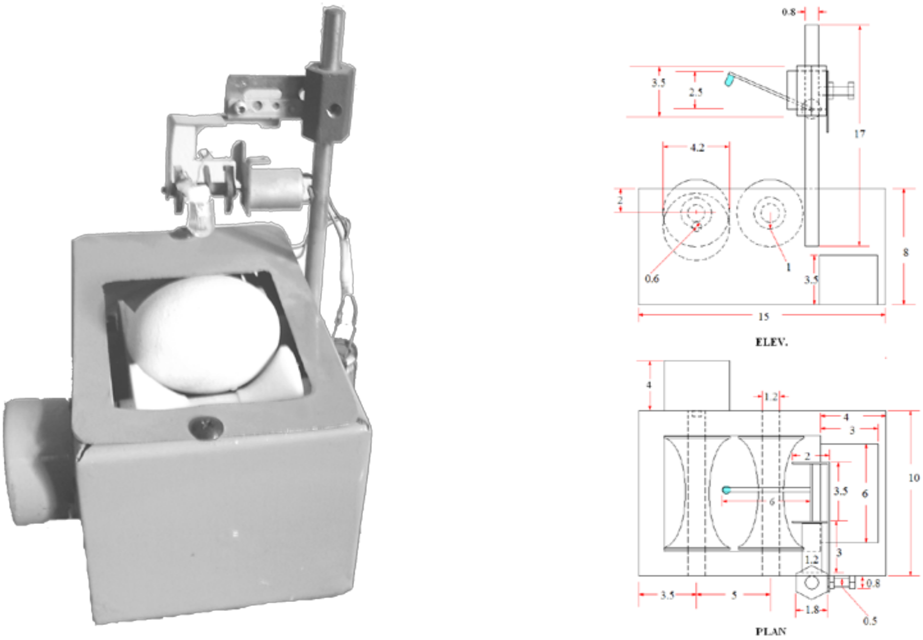
Where:

EW= egg mass in (g);

c = constant (set to 1), and

R_f = resonant frequency of the vibration in (Hz).

A detailed description of the vibration analysis of eggs and its application can be found in reports by Coucke (1998), De Ketelaere *et al*., (2002) and Kemps *et al*., (2006).



(DIMS. in: cm)

Fig. (2). Crack detector for single eggshell evaluation.

5. Data analysis

FFT (Fast Fourier Transformation) properties V5 was used in analyzing sound for each case. It gave the trends of amplitude and frequency.

For statistical analysis, (SPSS, V13) was used in driving the analysis of variance that was obtained from the following equation:

$$y_{ijk} = \mu + A_i + B_j + AB_{ij} + e_{ijk} \qquad (7)$$

where:

- y_{ijk} = individual observation for each parameter;
- μ = overall mean for each parameter;
- A_i = effect of i^{th} strains (i.e., i = 4 for all tested strains Hie linen, Lohmann Sina and Norva strains);
- B_j = effect due to egg status j^{th} = intact and cracked
- $(AB)_{ij}$ = effect due to interaction of i^{th} strains with the j^{th} status; and
- e_{ijk} = random effect

RESULTS AND DISCUSSION

1. Egg shell stability as affected by egg strain

Mean values of the measured and the calculated variables and the analysis of variance are presented in tables (1a, b and c). The strain had a significant effect on some egg shell characteristics with the exception of resonance frequency.

The mean values and standard error for dynamic stiffness, egg weight, egg length, egg diameter, egg shell wet and dry weight, breakage force, albumen height, yolk height, yolk diameter, yolk color, Albumen weight, yolk weight, egg shell thickness, volume, density, specific gravity, Haugh unit, surface area, shell index, modulus of elasticity and fracture stiffness are presented as follow: The mean values for dynamic stiffness (k_{dyn}) ranged from 2400.6±106.88 N/m for the Lohmann strain to 1198.2±145.30 N/m for the Norva strain. Eggs from Lohman strain were higher in egg mass (P<0.01). The mean egg length and diameter values ranged from 57.66±0.25 mm for the Hei Lenin strain to 51.54±0.37 mm for the Norva strain in length, and ranged from 44.94±0.18mm for the Lohman strain to 38.35±0.24 mm for the Norva strain in diameter, respectively, at a significant different (P<0.01). Egg shell wet and dry weight also the same significant, and ranged from 8.36±0.09g for Hei Linen strain to 5.31±0.13g for Norva strain in wet weight, and 6.65±0.08g for Lohman strain to

3.63±0.11g for Norva strain in dry weight, respectively. The mean values for the breakage force ranged from 38.88±1.47N for the Lohmann strain to 16.74±2.19N for the Sina strain, at (P<0.01). The mean albumen height, yolk height and yolk diameter values ranged from 6.76±0.11 mm for the Hei Linen strain to 5.08±0.18 mm for the Sina strain in mean albumen height and 16.64±0.17 mm for Norva Strain to 14.30±0.18 mm for Sina strain in yolk height, and 41.00±0.23 mm for Hei Linen strain to 36.46±0.34 mm for Norva strain in yolk diameter, respectively, at (P<0.01). The mean shell thickness values ranged from 0.37±0.01 mm for the Lohman strain to 0.26±0.01mm for the Norva strain. The mean egg volume values ranged from 60.53±0.56 cm^3 for Lohman strain to 39.71±0.76 cm^3 for Sina strain. The mean egg density values ranged from 1065.83±10.69 kg/m^3 for Norva strain to 1014.65±11.68 kg/m^3 for Sina strain. The mean Haugh unit values ranged from 93.25±0.60 for Hei Linen strain to 83.69±0.97 for Sina strain. The mean surface area values ranged from 76.40±0.50 cm^2 for Hei Lohman strain to 57.70±0.68 for Norva strain. The mean resonant frequency ranged from (5904.8±200.77 Hz) for the Hei Linen strain to (5055.6±299.22 Hz) for the Norva. The mean Modulus of elasticity ranged from (0.099±0.011, N/mm^2) for the Sina strain to (0.150±0.007, N/mm^2) for the Norva at (P<0.01). The mean Fracture toughness ranged from (10.97±1.23, $N/mm^{3/2}$) for the Sina strain to (19.42±0.83, $N/mm^{3/2}$) for the Norva at (P<0.01). However, the average egg weight, shell weight, breaking strength, modulus of elasticity and fracture toughness for the foreign egg strain was higher than the average value of the local egg strain, which indicated that although they had thicker shells, they had stronger shells. This would suggest that more than one method of shell strength assessment should be used and that factors other than shell thickness are important, and must influence this change in elasticity. There are also differences in eggshell properties between different breed lines and from breed to breed (Amer Eissa, 2009).

2. Egg shell stability as affected by interaction

Strain by status (intact and cracked egg) interaction, being significantly different with dynamic stiffness, shell dry weight, breakage force, shell thickness, and shell ratio (P<0.01), and shape index (P<0.05) as shown in tables (1a, 1b and 1c). This is caused by the different genetic factors between strains. The results of these experiments demonstrated that, resonance frequency have greater relationship to both shell breakage force, and shell thickness. These results indicated that, although dynamic stiffness, shell dry weight, breakage force, shell thickness, shell ratio and shape index is a useful predictor of shell breaking strength; the relationship is affected by strain of hen and status, these findings in agreement with Amer Eissa (2009).

Table (1a): Analysis of variance for strains and there interaction with status

Items	Mean square						
	Resonance frequency (Hz)	Dynamic stiffness K_{dyn} (N/m)	Egg Weight (g)	Egg length (mm)	Egg diameter (mm)	Shell wet weight (g)	Shell dry weight (g)
Strain	5764360.6	13552241.9	5410.4	424.8	414.8	110.0	91.5
Status	124689523.8	47288983.9	77.7	2.5	3.9	4.0	10.2
Strain × status	2195604.8	3258286.9	1.8	10.7	0.4	1.2	1.2
Error	2687292.7	633664.8	19.6	4.2	1.4	0.5	0.4
	Calculated F value, and signifcancy.						
Strain	2.15	21.39	275.63	100.77	292.51	208.71	237.22
	N.S.	**	**	**	**	**	**
Status	46.40	74.63	3.96	0.59	2.77	7.66	26.52
	**	**	*	N.S.	N.S.	**	**

Strain × status	0.82	5.14	0.09	2.54	0.28	2.32	3.18
	N.S.	**	N.S.	N.S.	N.S.	N.S.	*
(**), Significant at level P ≤ 0.01, (*), significant at level P≤ 0.05, (N.S.) non significant.							

Table (1b): Analysis of variance for strains and there interaction with status

Items	Mean square						
	Breakage force (N)	Albumen height (mm)	Yolk height (mm)	Yolk diameter (mm)	Yolk color	Albumen weight (g)	Yolk weight (g)
Strain	3926.1	20.5	28.8	166.2	375.4	2956.79	114.82
Status	14322.3	0.0	1.2	0.5	0.5	25.42	9.75
Strain × status	672.5	0.3	0.2	0.6	3.2	1.84	0.59
Error	120.5	0.8	0.8	3.5	2.0	10.29	2.67
	Calculated F value, and signifcancy.						
Strain	32.59	25.69	34.78	47.60	189.16	287.36	42.93
	**	**	**	**	**	**	**
Status	118.90	0.01	1.39	0.16	0.24	2.47	3.64
	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Strain × status	5.58	0.41	0.27	0.16	1.62	0.18	0.22
	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
(**), Significant at level P ≤ 0.01, (*), significant at level P ≤ 0.05, (N.S.) non significant.							

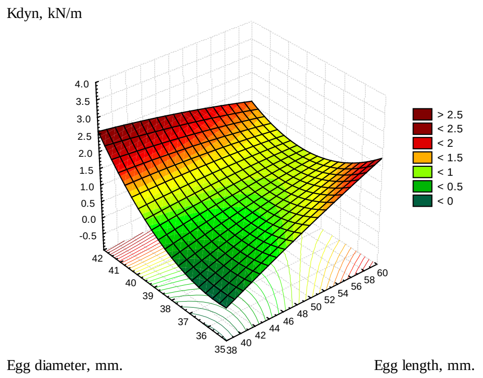
Table (1c): Analysis of variance for strains and there interaction with status

Items	Mean square						
	Measured shell thickness, T_m (mm)	Volume (cm^3)	Density (kg/m^3)	Huagh Unit	Surface area (cm^2)	Modulus of elasticity, E. ($N.mm^{-2}$)	Fracture toughness, FT. ($N.mm^{-3/2}$)
Strain	0.11	4465.35	15466.96	653.09	3895.74	0.018	521.14
Status	0.05	16.87	13304.38	1.76	55.74	0.355	4896.15
Strain × status	0.01	6.66	5024.39	12.86	1.47	0.022	272.44
Error	0.00	16.50	1468.54	23.74	13.69	0.003	38.12
	Calculated F value, and signifcancy.						
Strain	70.18	270.64	10.53	27.51	284.51	6.382	13.67
	**	**	**	**	**	**	**
Status	36.41	1.02	9.06	0.07	4.07	126.58	128.42
	**	N.S.	**	N.S.	*	**	**
Strain × status	7.33	0.40	3.42	0.54	0.11	7.989	7.15
	**	N.S.	*	N.S.	N.S.	**	**
(**), Significant at level P ≤ 0.01, (*), significant at level P ≤ 0.05, (N.S.) non significant.							

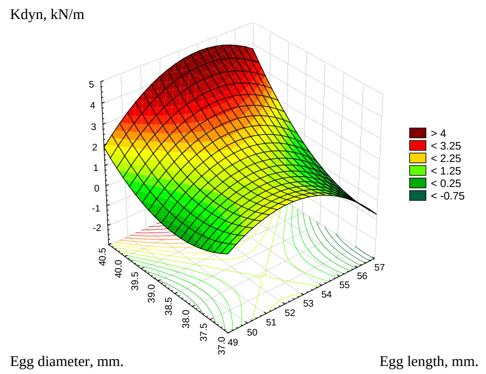
3.Relationships between dynamic stiffness (k_{dyn}) and physical characteristics

The correlation between the dynamic stiffness and egg dimensions (length and diameter, mm) was significant, where they were 0.533 and 0.610 at P<0.01, respectively. For local strains, indicating that increasing dimensions was associated with increasing dynamic stiffness. On the other hand, the correlation between the dynamic stiffness and both egg length and egg diameter were non significant for foreign strains. Pairs of values for egg length (L) and egg diameter (D) represented in specific contour line dark red on the horizontal plane shows the highest values for the dynamic stiffness as shown in Fig. (3a and 3b) was >2.5kN/m for intact local egg strains and was > 4kN/m for cracked local egg strains.

Also, the correlation between the dynamic stiffness (K_{dyn}) and the egg weight (EW) and volume (V), were significant, where they were 0.618 and 0.625 at P<0.01, respectively. Pairs of values for egg weight (EW) and egg volume (V) represented in specific contour line dark red on the horizontal plane shows the highest values for the dynamic stiffness as shown in Fig. (4a and 4b) was > 2kN/m for intact local egg strains and was > 5kN/m for cracked local egg strains.

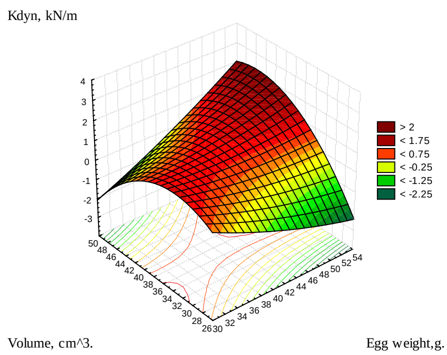


a (intact eggs)

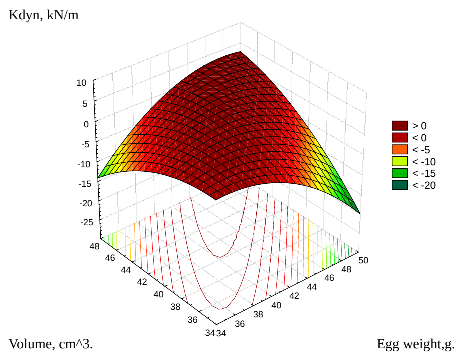


b (cracked eggs)

Fig (3a and 3b): Relationship between dynamic stiffness (K_{dyn}) and both egg length and egg diameter for local strains in case of intact and cracked eggs.



a (intact eggs)



b (cracked eggs)

Fig (4a and 4b): Relationship between dynamic stiffness (K_{dyn}) and both egg weight and egg volume for local strains in case of intact and cracked eggs.

Furthermore, dynamic stiffness was correlated with shell index (I) where it was 0.614 at P<0.01 for intact and cracked local strains, and was non significant for foreign strains, as shown in Fig. 5 (a and b). Pairs of values for shell index (I) and breakage force (BF) specific contour line dark red on the horizontal plane shows the highest values for the dynamic stiffness as shown in Fig. (5a and 5b) was > 2.5kN/m for intact local egg strains and was > 3N/m for cracked local egg strains.

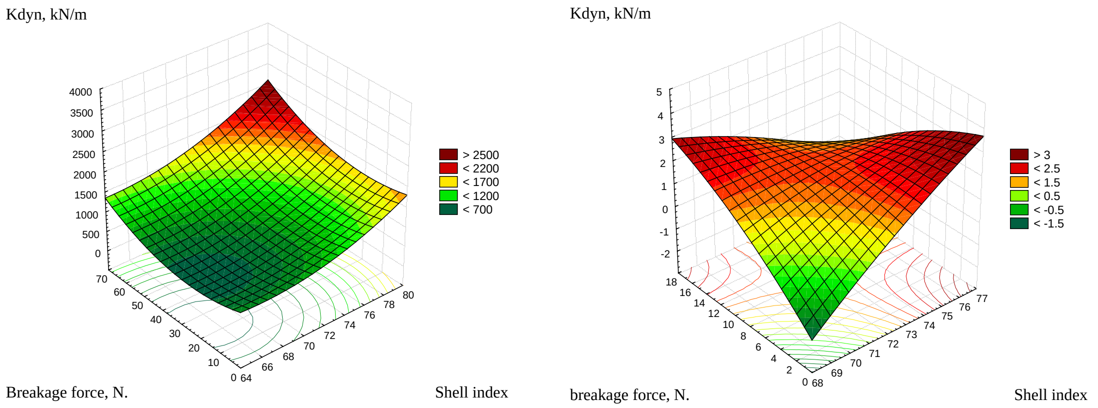
Dynamic stiffness was correlated with shell wet weight (P<0.01, 0.593) and was correlated with shell dry weight (P<0.01, 0.578), for intact and cracked local strains. This indicated that, increasing both of wet and dry weight was associated with increasing dynamic stiffness as shown in Fig. (6a and 6b). Pairs of values for shell wet weight (WSW) and shell dry weight (WSD) represented in specific contour line dark red on the horizontal plane shows the highest values for the dynamic stiffness as shown in Fig. (6a and 6b) was >2kN/m for intact local egg strains and was >14N/m for cracked local egg strains.

4.Relationships between resonance frequency (RF) and physical characteristics of eggshell

The correlation between the resonance frequency (RF) and both of egg weight (EW) and egg volume (V) were significant, where there values were 0.386 and 0.392, at P<0.01, respectively. This indicated that, increasing egg weight and egg volume were associated with increasing resonance frequency as shown in Fig. (7a and 7b) for local strains. But, there is no significant correlation for foreign strains. From Fig. (7a and 7b), represents pairs of values for egg weight (EW) and egg volume (V) specific contour line dark red on the horizontal plane shows the highest values for the dynamic stiffness, was > 6kHz for intact local egg strains and was >5kHz for cracked local egg strains.

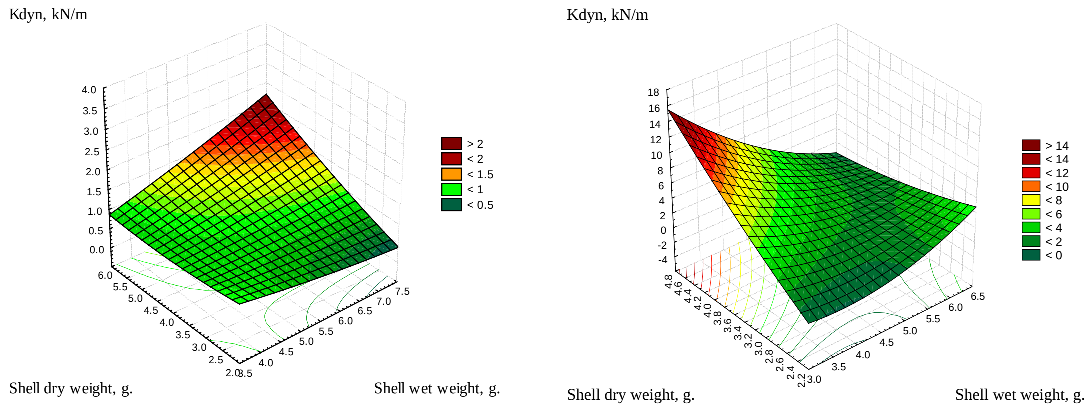
Resonance frequency was correlated with egg dimensions (length and diameter) for local strains, where it was (0.358 and 0.377 at P<0.01, respectively). Figs. (8a and 8b) represented that, pairs of values for both egg length (L) and egg diameter (D) specific contour line dark red on the horizontal plane shows the highest values for the dynamic stiffness and it was > 8kHz for intact local egg strains and was > 10kHz for cracked local egg strains.

The correlation between the resonance frequency and shell wet weight was significant where it was 0.397 at P<0.01, and the correlation between the resonance frequency and shell dry weight was significant where it was 0.377 at P<0.01, for local strains these values indicated that, increasing shell thickness was associated with increasing resonance frequency, as shown in Fig. (9a and 9b), pairs of values for both wet and dry shell weight specific contour line dark red on the horizontal plane shows the highest values for the dynamic stiffness, and it was >7kHz for intact local egg strains and was >35kHz for cracked local egg strains.



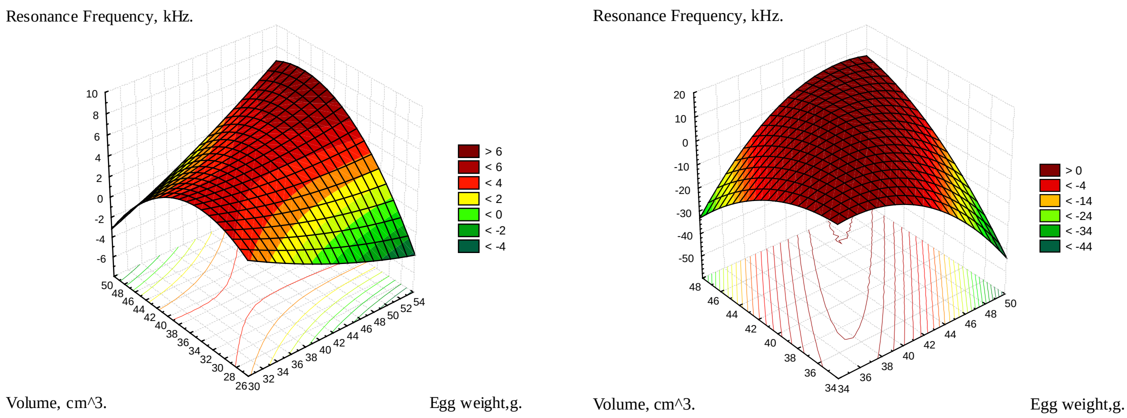
a (intact eggs) b (cracked eggs)

Fig (5a and 5b): Relationship between dynamic stiffness (K_{dyn}) and both shell index and breakage force for local strains in case of intact and cracked eggs.



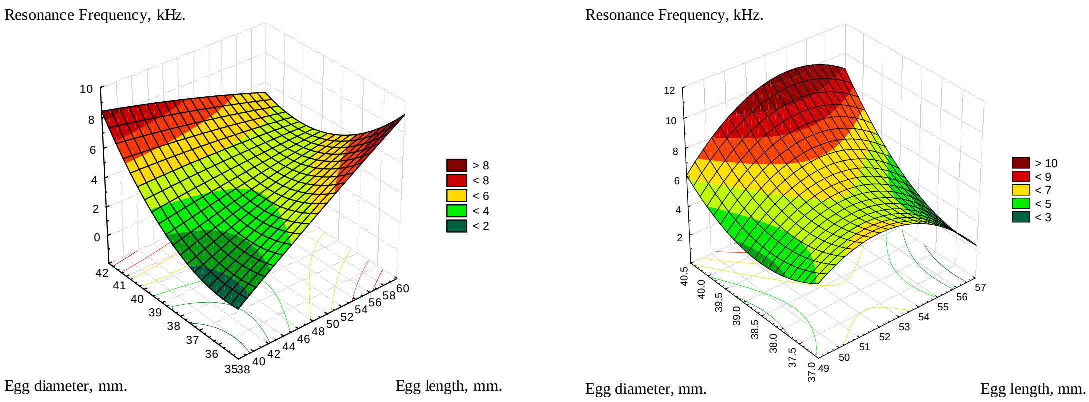
a (intact eggs) b (cracked eggs)

Fig (6a and 6b): Relationship between dynamic stiffness (K_{dyn}) and both wet and dry eggshell weight for local strains in case of intact and cracked eggs.



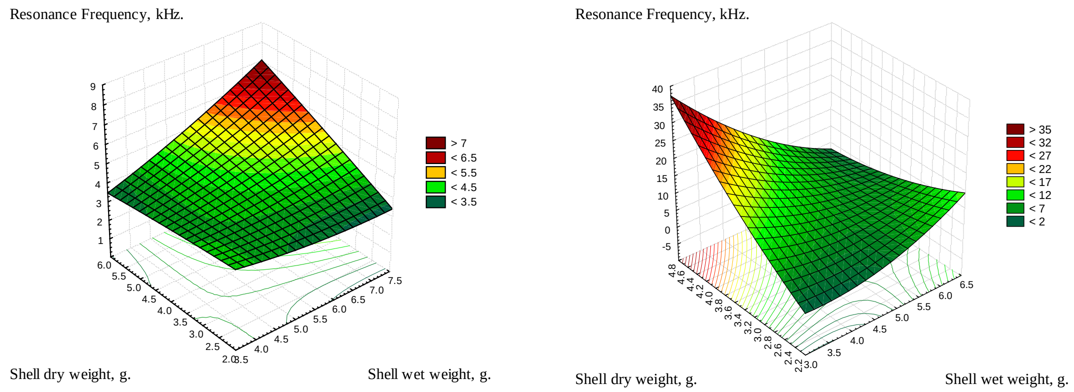
a (intact eggs) b (cracked eggs)

Fig. (7a and 7b): Relationship between resonance frequency (RF) and both egg weight and egg volume for local strains in case of intact and cracked eggs.



a (intact eggs) b (crackes eggs)

Fig. (8a and 8b): Relationship between resonance frequency and both egg length and egg diameter for local strains in case of intact and cracked eggs.



a (intact eggs) b (cracked eggs)

Fig. (9a and 9b): Relationship between resonance frequency and both wet and dry eggshell for local strains in case of intact and cracked eggs.

5.Relation between crack detection and eggshell stability

Different approachs were investigated by analyzing the response of the egg itself after being impacted rather than the behavior of the impactor after excitation. When an egg is subjected to a non-destructive impact excitation, the shell will react with an oscillation response. Figs. (10 and 11) illustrated that, eggs with cracked shells showed a higher number of resonant peaks than intact eggs. Also, for intact eggs, the impulse response was similar on every point on the equator, whereas eggs with a cracked shell show a different response on different locations of the equator. This finding led to the construction of a crack detection algorithm, which is based on the correlations between repeated measurements taken on the same egg. Only four measurements for each egg are needed, these findings were in agreement with Lin *et al*., (2004).

Typical acoustic signals obtained from intact and cracked eggs in time domain was presented in Figs. (10 and 11), respectively. The signals from cracked eggs had lower amplitudes in general as compared with those from intact eggs depending upon the location of cracks. The amplitude of sound signal emitted from cracked egg diminished faster than that of intact egg due to increased damping effect which was similar to the observation reported by Cho *et al*. (2000).

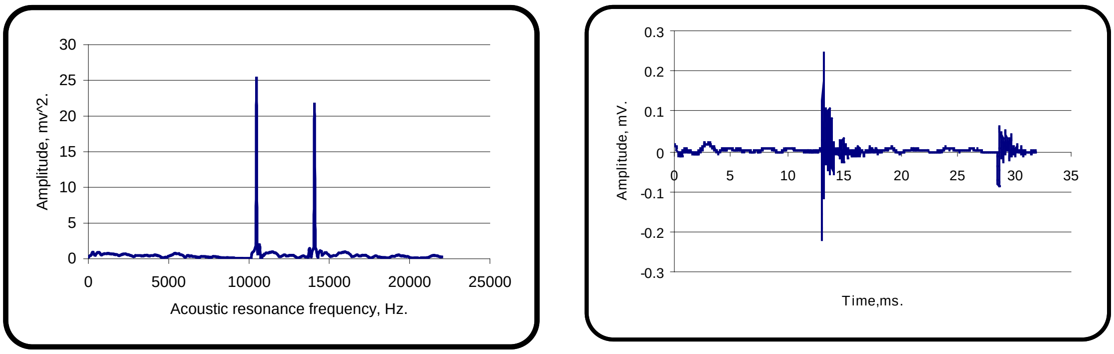


Fig. (10): Typical acoustic signals from an cracked eggshell in time domain and frequency domain.

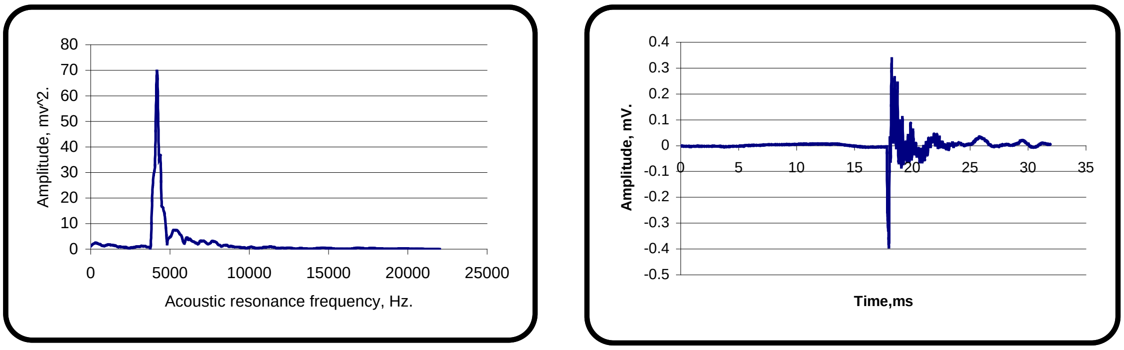


Fig. (11): Typical acoustic signals from an intact eggshell in time domain and frequency domain

The average durations of signals from cracked and intact eggs were about 12 and 5ms, respectively. However, there were instances when the signals from both cracked and intact eggs exhibited considerable overlapping and contradictory trends. As a result, the amplitude and duration of acoustic signals were not considered to have enough potential for classification. These findings were in agreement with Jindal and Former (2003).

Typical frequency plots for intact eggs showed one dominant peak as presented in Fig. (10) where it varying between 430 and 8613 Hz. The signal amplitude at the resonance frequency of eggs showed considerable variation ranging approximately 25mV^2 most possibly due to the influence of factors such as size, shape and shell thickness. The frequency patterns obtained from the same egg in the presence of cracks were highly differed and not repetitive as shown in Fig. (11) depending upon the distance and location of crack from the excitation point. The signal amplitudes in the vicinity of resonance frequencies for cracked eggs were generally lower than in case of intact eggs, and the frequency spectra showed a great wider range where, it varied from about 1420 to 12,273 Hz. There wasn't any apparently relationship between the frequency patterns and various types of cracks. But there were another cases when the cracked and intact eggs exhibited similar frequency patterns. However, the acoustic patterns in frequency domain showed many important characteristics for developing classification criteria similar to the observation reported by De Ketelaere *et al*., (2000) and Jindal and Former (2003).

A fast and non-destructive quality assessment tool together with the modern information technology offers many advantages. In the packing house, crack detection allows the quality of an individual egg to be measured, instead of sampling from a large batch quality. These non-destructive measurements can be regarded as an important management tool. Compared to other eggshell quality measurements, dynamic stiffness and compression cone hardness, as the benefit of being a non-destructive measurements which can be rapidly, performed using a mobile and inexpensive piece of equipment. Therefore, in direct test, the possibility that the dynamic stiffness measurement can predict solidity of the eggshell and whether an egg will crack during routine egg handling procedures, and thus confirm the potential benefits of this measurement as a means of improving eggshell quality and reducing the incidence of cracked eggs by breeding.

Conclusions

- Using the dynamic stiffness will accurately predicted which eggs would crack as they passed through the gathering and processing system. Thus the method could be used to sort out eggs likely to crack and remove them prior to cartooning.
- After excitation, intact eggs emitted sound signals with relatively longer duration of about 12 ms in general as compared to 5

ms in case of cracked eggs. The frequency spectra of intact eggs were approximately distributed over the range 430 and 8613 Hz showing only one dominant peak. In contrast, the frequency spectra of cracked eggs showed heterogeneous patterns without any distinct trends in a much broader frequency range of 1420 to 12,273 Hz. Also there is a potential for developing online eggshell crack detection system.

- The breakage force measurement can predict structural strength and whether an egg will crack during routine egg handling procedures, and thus confirm the potential benefits of this measurement as a means of improving eggshell solidity and reducing the incidence of cracked eggs by breeding.

- To develop other measurements for estimating shell quality without destroying the egg shell, shell breakage strength, shell thickness, static stiffness, dynamic stiffness and shell mass revealed the best coefficients of correlation. Also, they were proven as the best predictors for practical large scale assessment, because the characteristics of the egg shell quality changes over time within the laying period. Finally, it can be concluded that the influence of material strength (breakage force) upon total eggshell strength (crack detector) is limited.

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استخدام الاهتزازات الصوتية في تقييم خواص الجودة للبيض

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الملخص العربي

أجريت هذه الدراسة بمعمل اختبار المواد البيولوجية بقسم الهندسة الزراعية بكلية الزراعة – جامعة المنوفية وتمثلت في عمل القياسات الخاصة بدراسة جودة البيض عن طريق استخدام الموجات الصوتية الناتجة عن قشرة البيض نتيجة التصادم واستخدامها في فرز البيض المكسور والمشروخ عن البيض السليم.

وقد تم اختبار طريقة غير متلفة لتحديد خواص الجودة الفيزيائية للبيض، حيث أنه يوجد ٦% إلي ٨% من البيض المنتج مكسور أو به شروخ، وكان اختبار قوة الكسر لقشرة البيضة من الاختبارات المتلفة والمرتبطة جداً بخواص البيض المكسور ولكن الاختبارات غير المتلفة لم تكن واضحة. وللوصول إلي ذلك تم دراسة العلاقة بين الاهتزازات الصوتية والصلابة الديناميكية من ناحية وقوة الكسر من ناحية أخري كدليل غير متلف لجودة البيض. وأجريت التجارب علي عينات من بيض أربع سلالات من الدجاج ممثلة في عينتين، وكان عدد العينات الكلية (٤٣٧ بيضة) حيث أخذت العينة الأولي من مزرعة كلية الزراعة – جامعة المنوفية (نورفا وسينا ١٢٩ و٦٨ بيضة علي الترتيب) والعينة الثانية من شركة الوادي لإنتاج الدواجن (هاي لنين ولوهمان ١٢٠ بيضة لكل منهما).

وقد استخدم في هذه الدراسة جهاز مكتشف الشروخ وجهاز قياس قوة الكسر و تم حساب الصلابة الديناميكية لتحديد خواص البيض بطريقة غير متلفة مع دراسة خواص الجودة الفيزيائية. وأظهرت النتائج أنه كانت هناك فروق معنوية للتفاعل بين السلالات وحالة البيض (سليم – مكسور) لكل من الصلابة الديناميكية ووزن القشرة الجاف وقوة الكسر

وسمك القشرة ونسبة القشرة عند مستوي معنوية ٠.٠٠١، وكذلك دليل الشكل عند مستوي معنوية ٠.٠٠٥، وهذا الاختلاف راجع للعوامل الوراثية بين السلالات.

وجد أيضاً أن هناك علاقة شديدة بين التردد الصوتي وقوة الكسر وسمك القشرة، كما أمكن التنبؤ بقوة الكسر عن طريق الصلابة الديناميكية ووزن القشرة الجاف وسمك القشرة ونسبة القشرة ودليل الشكل. وتتلخص أهم النتائج فيما يلي:

٧- معامل الارتباط بين الصلابة الديناميكية وأبعاد البيضة (الطول والقطر) معنوياً علي مستوي ٠.٠١ (٠.٥٣٣، ٠.٦١٠ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

٨- معامل الارتباط بين الصلابة الديناميكية ووزن وحجم البيضة معنوياً علي مستوي ٠.٠١ كان (٠.٦١٨، ٠.٦٢٥ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

٩- معامل الارتباط بين الصلابة الديناميكية ودليل القشرة معنوياً علي مستوي ٠.٠١ كان (٠.٦١٤) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

١٠- معامل الارتباط بين الاهتزازات الصوتية ووزن وحجم البيضة معنوياً علي مستوي ٠.٠١ (٠.٣٨٦، ٠.٣٩٢ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

١١- معامل الارتباط بين الاهتزازات الصوتية وأبعاد البيضة (الطول والقطر) معنوياً علي مستوي ٠.٠١ كانا (٠.٣٥٨، ٠.٣٧٧ علي الترتيب) للسلالات المحلية بينما كان غير معنوي بالنسبة للسلالات الأجنبية.

١٢- كما وجد أنه عندما تتعرض قشرة البيضة لصدمة غير متلفة، يكون لقشرة البيضة رد فعل بموجة صوتية. بالنسبة للقشرة السليمة تكون نبضة الصوت متماثلة عند كل النقط علي محيط البيضة، بينما القشرة المشروخة تظهر نبضات مختلفة في مواضع علي محيط البيضة.

١٣- وجد أن الاهتزازات الصوتية للبيضة السليمة تراوحت من ٤٣٠ إلي ٨٦١٣ هرتز أما بالنسبة للبيضة المشروخة فقد وجد أن الاهتزازات الصوتية تراوحت بين ١٤٢٠ و ١٢٢٧٣ هرتز.