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Determination of Mechanical Behavior and Physical Properties of Quail Eggs

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ABSTRACT

Agricultural and animal products' mechanical and physical qualities are crucial in the design of a wide range of agricultural equipment. The quail eggs of length, diameter, mean value diameter, volume, sphericity, mass, shape index, packaging coefficient of eggs, shell mass, and shell thickness were identified. The static friction coefficients between quail eggs surfaces and rubber, plywood, plastic, and cardboard surfaces were measured. The mechanical Behavior of quail eggs was investigated in terms of average rupture force, deformation, and absorbed energy. The egg tests' X axis and Z axis were crammed. The following measurements and calculations for quail eggs of length and diameter, sphericity, mean diameter, surface area, egg mass, volume and packaging coefficient and egg shells of thickness, and mass were: 32.66 mm, 25.86 mm 85.61 %, 27.94 mm, 2455 mm^2, 11.74 g, 11464 mm^3, 0.439, 0.24 mm and 1.342 g respectively. The coefficients of friction on rubber, plywood, plastic, and cardboard surfaces were 0.47, 0.33, 0.37, and 0.45, respectively. The rubber surface had the most friction, followed by cardboard, plastic, and plywood. When quail eggs were loaded along the X-axis, the greatest rupture force, absorbed energy, and deformation were obtained. Compression along the Z-axis required the most un-compressive power to break the eggs compared to the X-front pressure axis. The rupture force, absorbed energy, and deformation along the X-front axis were calculated to be 13.22 N, 7.41 N mm, and 1.66 mm, respectively.

Keywords: physical properties of quail eggs; coefficient of friction; correlation coefficient; mechanical Behavior

INTRODUCTION

Quail eggs are one of the most cost-effective protein sources since they include all of the essential amino and fatty acids, vitamins, and minerals that humans require (Moura *et al*., 2010). The nutritional quality of quail and chicken eggs was compared by Ali and Abd El-Aziz (2019) they reported that quail eggs had higher protein and lipid content than chicken eggs. They went on to say that quail eggs are chemically similar to chicken eggs. Some studies signed that, the moisture, protein, fat ash, and carbohydrates content of an entire egg is 73.80-74.60, 13.05-13.23, 10.8311.20, 1.10-1.13, and 0.41-1.03 %, respectively (Stadelman, and Cotterill (1995) and Tolik *et al*., 2014). Nedomovà *et. al*. (2013) The mechanical strength of the eggshell is an important consideration for design and efficient operation of transportation, packing, and storage equipment. Egg's physical and mechanical qualities must be understood. To ensure that eggshells are thick enough to avoid cracking on the way from the farm to the consumer. The physical properties of eggs and their resistance to mechanical shock damage can be explained by measuring a rupture force, specific deformation, and rupture energy (Altuntas and Sekeroglu, 2008). The mechanical parameters of quail eggs include a variety of physical qualities such as egg mass and volume, surface area, shell thickness, and shell mass. The eggshell's mechanical strength is an important aspect of the packaged egg material's quality. The eggshell's quality is determined by the egg's dimensions and mass. Eggshell thickness and breaking strength decrease as egg mass increases. The proportion of damaged eggs during handling and transportation is influenced by the egg shape index and shell thickness. (Anderson *et. al*., 2004). The quality of quail eggs produced in Benghazi, Libya, was investigated on both the external and internal levels. The egg mass was 12.74 g and had a volume of 12.21 cm^3, according to the statistics, while the quail egg shell mass was 1.29 g. (Salem and Haj-Saeed, 2020). Alaşahan *et. al*. (2015) determined internal and external quality of quail eggs with different eggshell color, spot color and spottiness. They found that the differences for values of eggshell percentage and shell index between groups were statistically significant ($P<0.01$). The differences for albumen index, yolk index and Haugh unit between groups were significant ($P<0.01$, $P<0.001$). The mechanical properties of a chicken egg are determined by its real properties, such as egg mass and volume, area, shell thickness and mass. To assess the shell strength of a chicken egg, a semi-static, nondestructive pressure is delivered to the egg between two equal steel plates (De Ketelaere *et. al*., 2002). The effect of egg shape on the mechanical Behavior of chicken eggs stressed was investigated by Altuntas and Sekeroglu (2008). However, there is a scarcity of technical information in the scientific community about the mechanical and physical Behavior of over mass chicken eggs. Many egg factors, such as relative density, mass, expanse, volume, thickness, shell mass, and shell percentage, influenced the rupture force of hen eggs (Narushin *et. al*., 2004). Breaking strength as a direct variable to measure of eggshell strength, is a difficult

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variable to measure, because only one measurement can be taken from each egg, and is highly dependent on compression speed Nedomová and Buchar (2013) studied ostrich eggs geometry. They found that the egg surface area is single value function of the long circumference length. The physical properties and mechanical Behavior of Japanese quail eggs were studied by Polat *et al.* (2007) they found that, the X and Z axis of the egg samples were crushed. The length and diameter of their shells, as well as their thickness, geometric mean diameter, mass, surface area, sphericity, volume, and packaging coefficient, were all determined 34.87 mm, 26.20 mm, 0.27 mm, 28.82 mm, 12.69 g, 2608.5 mm^2, 1.10, 359.17 mm^3, 0.469, respectively. Quail eggs on plywood, glass, galvanized steel, and fiberglass had coefficients of friction of 0.301, 0.282, 0.274, and 0.266, respectively. The rupture force, deformation, and hardness of Japanese quail eggs were at their highest when loaded along their X-axis. The pressure along the Z-axis required the least amount of compressive force to break the eggs when they were placed near to the opposite pressure axis. The X-front axis rupture force, deformation, absorbed energy, and toughness were 10.51 N, 1.5 mm, 7.88 N.mm, and 0.219 Mj/mm^2, respectively. Altuntas and Sekeroglu (2008) carried out the effect of egg weight on physical properties and mechanical behavior under compression of chicken eggs. The found that the force required to initiate egg rupture on the z-axis decreased as egg weight increased from medium to jumbo. The specific deformation and rupture energy values observed for chicken eggs compressed along the z-axis were higher than the values obtained when testing eggs in the x-back and x-front orientations. The results indicated that the rupture force along all three axiss is highly dependent on the egg weight over the compression speed. Buchar *et al.* (2015) measured the typical rupture force, deformation, and rupture energy of quail eggs to compression along the X-front, X-back, and Z-axis. When Japanese quail eggs were loaded along their X-axis, they discovered the following: increased force, deformation at the egg's energy absorbed up to the fracture, and breakage. The rupture force increased as the pressure (loading) rate increased. The eggshell rupture force's speed affectability was similar to that of hen's eggs.

The objective of this study was to determinate some physical and mechanical properties of quail eggs. These properties are, namely, dimensions, mass, geometric mean diameter, surface area, volume, sphericity, eggshell thickness, shape index, and mass, and, rapture force, deformation and absorbed energy. Egg production, processing and packaging systems must be designed while taking these properties into consideration like that, physical properties of eggs and their resistance to damage through mechanical shock.

MATERIALS AND METHODS

Sample collection and preparation of raw material

Sixty eggs were purchased from commercial farm in Tanta city, El-Gharbia Governorate, Egypt. The eggs were washed and dried at room temperature. Thereafter, the eggs length and diameter, were measured by a Caliper (0-150 mm with ± 0.01 mm accuracy). While the eggshell thickness was measured by Micrometer (0-50 mm with ± 0.01 mm accuracy), the eggs and eggshell mass were measured by a digital balance (± 0.01 gm accuracy).

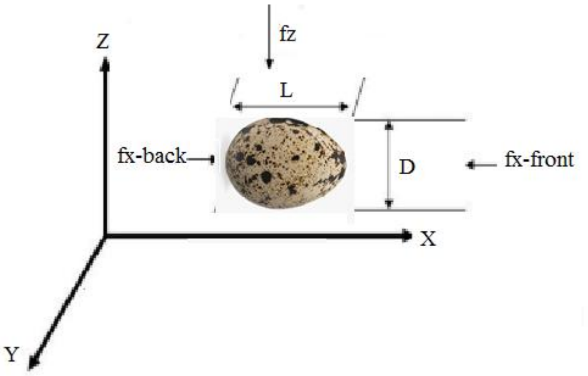


Fig. 1. Axis and three major perpendicular dimensions of quail egg (polat *et. al*. 2007) and (Altuntas and Sekeroglu, 2008).

Determination of egg shape index

The shape index was characterized by the length and diameter of the egg dimensions. The egg length and diameter were measured using a digital measuring vainer caliper (mm), proposed by Schonwetter (1960) and Anderson *et al*., (2004):

$$\text{Shape Index (SI)} = (D/L) \times 100$$

Where: L = Egg length, mm, and D = Egg diameter, mm

Determination of the geometric mean diameter.

The geometric mean diameter was determined according to (Mohsenin, 1970). The geometric mean diameter was calculated thus:

$$Dg = (LD^2)^{1/3}$$

Determination of the egg sphericity.

The sphericity of the egg was determined according to the method of (Baryeh and Mangope, 2003 and Güner *et. al*., 2003), by using the physical dimensions of length and diameter of the eggs as shown below:

$$\text{Sphericity}, \phi = (Dg/L) \times 100$$

Determination of the surface area

The surface area of the samples was calculated by using the geometric mean diameter, Baryeh and Mangope (2003).

$$SA = \pi Dg^2$$

Determination of the egg volume

The volume of the egg was determined by two methods: (1). Measurement of the volume of eggs with a graduated measuring 200 ml volumetric flask, and (2). Using the method of Baryeh and Mangope (2003) by measuring the dimensions of length and diameter and calculated as follows:

$$V = (\pi/6) * LD^2$$

Packaging coefficient of quail eggs

Packaging coefficient (Pc) is defined as the ratio of the volume of a sample of egg to packed total volume (mm^3) in 150 * 100 * 200 mm long rectangular box (Polat *et al.* 2007; Altuntas and Sekeroglu, 2008).

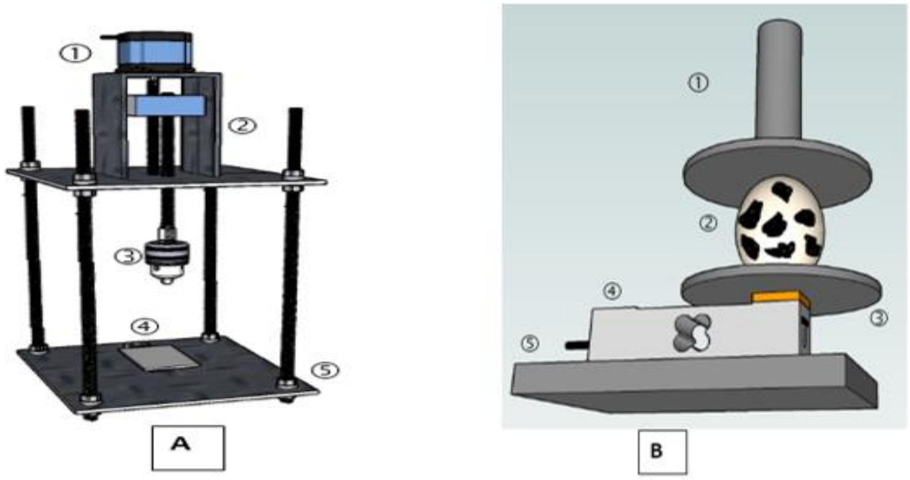
$$Pc = (\text{Total volume} / 150*100*200) = \text{Total volume (mm}^3\text{)} / 3000000 \text{ (mm}^3\text{)}$$

Determination the coefficient of friction of quailegg

To determine the coefficient of friction, the sample of 5 eggs were sticked tape and placed on the friction surfaces rubber, plywood, plastic, and cardboard and so from its initial horizontal posture, the surface was gradually tilted when the eggs start of sliding over the friction surface. The tangent value of the angle gave the coefficient of friction (Polat *et al*., 2007).

Determination of mechanical Behavior

To determine the mechanical Behavior (rupture force and deformation) of the quail eggs, a developed test device by Geasa (2021) was used as shown in figure (2A) The core of the developed apparatus is based on a screw-driven linear actuator system with a moving sledge. Moving sledge end connected with drill chunk where flat grip was attached. Load cell fixed on bottom base plate under moving sledge both of which are carefully aligned to each other The egg sample was positioned on the bottom base plate and linear actuator system converts stepper motor rotational speed to linear movement tends to compress the egg as shown in figure (2B). Compression force was measured by the info acquisition system which consists of load cell; Arduino board and memory card module connected with computer Linear speed adjusted to be 0.31 mm/s The rupture was thought to occur at the break point, which was the purpose on the force–deformation curve (figure 3) where the force suddenly decreased. The compression test determines how much force and distortion the quail egg shell can withstand before it ruptures. Two compression axis were used to quantify the egg's rupture force, distortion and toughness (X and Z). The X-axis (force Fx) was the loading axis in the length dimension, while the Z-axis was the loading axis in the diameter dimension (force Fz). The egg's mechanical Behavior was assessed using absorbed energy, rupture force, and initial deformation. The load speed and time were used to compute the egg shell deformation. The energy required for egg rupture ("E", N.mm) corresponds to the domain under the curve between the beginning and, thus, the rupture point. The compression axis of the quail eggs was used to calculate the force-deformation curve (X and Z). The amount of energy absorbed by the quail egg at the time of rupture was calculated using the area under the force–deformation curve by using Microsoft Excel software and various coordinates along the curve from the origin point to the rupture point. Typical force–deformation curve for compressed quail egg is shown in figure (3) (Polat *et al*., 2007). The information obtained were subjected to descriptive statistics such as; range (minimum “Min” and maximum “Max”), mean, standard deviation (SD) and coefficient of variation (CV).



A. 3D illustration of the used device
1-Stepper motor.
2- Screw-driven linear actuator part.
3-Drill chunk.
4-Load cell component.
5-Supported frame.

B. Egg installation on developed device
1-Movable upper plate.
2-Quail egg.
3- Fixed base plate.
4- Load cell.
5-Supported frame.

Figure 2. a developed test device by Geasa (2021)

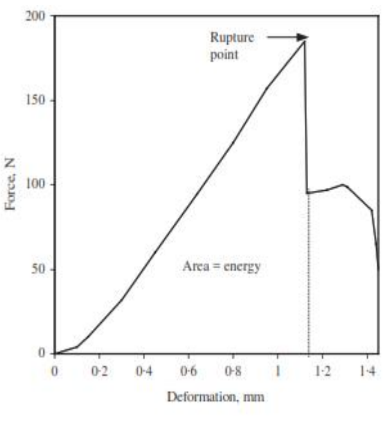


Fig. 3. Typical force–deformation curve for compressed quail egg (Polat *et al*., 2007.The deformation ranged from 0.8 to 1.8 mm for three axis)

RESULTS AND DISCUSSION

Physical Properties

Table 1 showed that physical properties of quail eggs. The minimum and maximum of length and diameter (or thickness), geometric mean diameter, and mass of the quail eggs were ranged from 30.9 to 36.1 mm, 24.6 to 29.2 mm, 26.88 to 31.34 mm, and 10.33 to 16.32 g, respectively. The packaging coefficient was 0.439, and the surface area of the quail eggs ranged from 2269 to 3084 mm^2. The volume of the eggs tested ranged from 10166 to 16108 mm^3. The length, diameter, geometric mean diameter, mass, surface area, volume, and packaging coefficient all increased as egg mass increased. In each case, the mean shape index (SI) values ranged from 75.00 to 83.17 %. The thickness and mass of the shells varied from 0.20 to 0.30 mm and 1.1 to 1.64 g, respectively.

Table 1. Physical properties of quail eggs

Physical properties	No. of observations	unit	min	max	mean	S. D.	C. V.
Egg length	60	mm	30.9	36.1	32.66	1.33	4.07
Egg diameter	60	mm	24.6	29.2	25.86	1.00	3.87
Geometric mean diameter	60	mm	26.88	31.34	27.94	1.02	3.63
Sphericity	60	%	82.55	88.44	85.61	1.84	2.15
Surface area	60	mm^2	2269.06	3083.98	2455.11	184.27	7.51
Volume	60	mm^3	10166.08	16108.36	11464.11	1335.08	11.65
Shape index	60	%	75	83.17	79.22	2.55	3.22
Egg mass	60	gm	10.33	16.32	11.74	1.34	11.44
Eggshell mass	60	gm	1.1	1.64	1.34	0.16	12.15
Eggshell thickness	60	mm	0.2	0.3	0.237	0.023	9.823
Packaging coefficient	Volume of rectangle box needs about 115 eggs			0.439			

Statistical correlation coefficients

The results of the correlation coefficients between some physical properties and rupture force (acting on X-axis and Z-axis) measurements of quail eggs are presented in table (2).

Table 2. Statistical correlation coefficients of quail egg properties and rupture force.

Some physical properties	Rupture force, N.	
	X-axis	Z-axis
Sphericity	0.623	0.560
DG	0.239	-0.340
shape index	0.622	0.559
Eggshell	-0.336	-0.091
Eggshell thickness	0.280	-0.099
Shell, %	-0.721	0.056
Volume	0.201	-0.514
Mass	0.235	-0.373
diameter	0.351	-0.041
length	-0.065	-0.520

The relationship between the eggshell and rupture force (acting on X-axis and Z-axis) was negative significant. The correlation coefficients were (-0.336) and (-0.0.91). Also, the relationship between the egg length and rupture force (acting on X-axis and Z-axis) was negative significant. The correlation coefficients were (-0.065) and (-0.52). On the other hand, the relationship between (shape index and rupture force for X and Z axis) and (sphericity and rupture force for X and Z axis) were positive significant. The correlation coefficients were (0.62 and 0.56) and (0.62 and 0.56), respectively. Altuntaş and Şekeroğlu (2008) reported that the rupture force is highly dependent on SI value. Breaking strength is correlated with shape index.

The static coefficients of friction

It was varied from 0.425 to 0.466 for plywood, for cardboard from 0.466 to 0.488, for rubber, and 0.325 to 0.364 for plastic to egg examined the static friction coefficients varied from 0.306 to 0.433. (Table 3). Rubber has the highest static coefficient of friction, followed by cardboard, plastic, and plywood. Similar results have been reported by Polat *et al.* (2007) and Buchar *et al.* (2015). The coefficient of static friction shows how eggs are restricted from moving on various surfaces that could be utilized for transportation and partitioning.

Mechanical Behavior of quail egg

Eggshells must be strong enough to avoid cracking during transportation from the farm to the market and to keep eggs safe during hatching. To represent eggshell strength, many criteria such as rupture force, eggshell thickness, shell stiffness, and so on have been utilized (De Ketelaere *et al.*, 2002). The shell thickness and mass of quail eggs were ranged from 0.2 to 0.3 mm and 1.1 to 1.64 g with average 0.237 mm and 1.34 g. Table 3 shows typical rupture force, deformation, and absorbed energy values obtained from the experiment along various compression axis. The loading orientation determined the response of the quail eggshell to compression force.

In loading along the lateral axis (Z-axis), the rupture force was 12.55 N. Along the Z-axis, the loading orientation offered the least amount of resistance to rupture force. The rupture force was determined to be 13.22 N when loading along the X-front axis. On the surface of quail eggs, absorption energy was calculated as a function of rupture force and deformation. 7.41 N mm (X-front axis) and 6.67 N mm (Y-front axis) were discovered to be the absorbed energy values (Z-axis).

Table 3. Coefficients of friction on various surfaces for quail eggs

The coefficient of static friction	No. of observations	Min	Max	Mean	SD	CV, %
Plywood	5	0.306	0.364	0.332	0.0295	8.885542
Cardboard	5	0.425	0.466	0.445	0.0205	4.606742
Rubber	5	0.466	0.488	0.473	0.0127	2.684989
Plastic	5	0.325	0.433	0.374	0.0547	14.62567

Table 4 shows the deformation values along the three axis after compression: 1.66 mm (X-front axis), 1.5 mm (Y-back axis), and 1.5 mm (Z-axis). The deformation values of quail eggs compressed along the Z-front axis were lower than those compressed along the X-axis. This shows that the front of a quail egg is more flexible than the Z-axis, and that it is more resistant to quail egg rupture along the X-front axis.

Table 4. Some mechanical properties of quail egg

Mechanical properties	Compression axis	No. of observations	Mean	Min.	Max.	SD	CV,%
Rupture force, N	X-front	60	1.66	1.3	1.9	0.2258318	11.88588
	Z-axis	60	1.5	1.3	1.75	0.1581139	9.035079
Deformation, mm	X-front	60	13.221	9.579	16.15	2.4314777	15.05559
	Z-axis	60	12.551	8.338	14.986	2.0425671	13.62984
Absorbed energy*, N.mm	X-front	60	7.41291	3.8323	10.3997	2.5359069	24.38442
	Z-axis	60	6.674	3.588	8.645	1.5130736	17.5023

***The area under curve force-deformation didn't triangle area but it was some trapezoid areas.**

CONCLUSION

1- Quail eggs measured 32.66 mm in length, 25.86 mm in diameter, 0.24 mm in thickness, 11.74 g in mass, and 11464 mm^3 in volume.

2- Quail eggs had a geometric mean diameter, surface area, sphericity, shape index, and packaging coefficient of 27.94 mm, 2455 mm^2, 85.61 %, 79.22 percent, and 0.439, respectively.

3- On plywood, the quail egg had a coefficient of static friction of 0.33, 0.45 on cardboard, 0.47 on rubber, and 0.37 on plastic.

4- A significant positive relationship between (shape index and rupture force for X and Z axis) and (sphericity and rupture force for X and Z axis).

5- When measuring compression along the X-front axis to compression along the Z-axis, the quail egg rupture force, deformation, and absorbed energy were found to be higher. For the X-front axis, the values are 13.22 N, 1.66 mm, and 7.41 N mm, respectively.

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تحديد السلوك الميكانيكى والخصائص الفيزيائية لبيض السمان

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تعتبر الخصائص الفيزيائية والميكانيكية للمنتجات الزراعية والحيوانية ذات أهمية كبيرة لتصميم المعدات الزراعية المختلفة ومن بينها الخصائص الفيزيائية والميكانيكية لبيض السمان. تم تحديد الخصائص الفيزيائية لبيض السمان مثل الطول والقطر، متوسط القطر الهندسي، الكروية، الحجم، مساحة السطح، معامل تعبئة البيض، مؤشر الشكل، كتلة القشرة وسمك القشرة. تم قياس معاملات الاحتكاك الاستاتيكي على أسطح مختلفة، مثل المطاط، والخشب الأبلاكاش ، والبلاستيك ، والكرتون. تم تحديد السلوك الميكانيكي لبيض السمان من حيث متوسط قوة الكسر، والتشوه، وكذلك الطاقة المستهلكة. وتم اختبار البيض على طول المحورين X و Z. وكانت النتائج كالتالى: متوسط الطول والقطر والقطر الهندسي ومساحة السطح والكروية وكتلة البيض والحجم ومعامل التعبئة وسمك القشرة وكتلة القشرة ٣٢,٦٦ مم ، ٢٥,٨٦ مم ، ٢٧,٩٤ مم ، ٢٤٥٥ مم^2 ، ٨٥,٦١ ٪ ، ١١,٧٤ جرام ، ١١٤٦٤ مم^3 ، ٠,٤٣٩ ، ٠,٢٤ مم ، ١,٣٤٢ جرام على التوالي. كانت قيم معامل الاحتكاك لبيض السمان على سطوح المطاط والخشب الأبلاكاش والبلاستيك والكرتون ٠,٤٧ و ٠,٣٣ و ٠,٣٧ و ٠,٤٥ على التوالي. وكان أعلى قوة كسر وتشوه وطاقة ممتصة لبيض السمان على طول المحور X مقارنة بالمحورZ ١٣,٢٢ نيوتن و ١,٦٦ مم و ٧,٤١ نيوتن مم على التوالي.