Mechanical behaviour under compression loading and some physical parameters of Japanese quail (*Coturnix coturnix japonica*) eggs

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ABSTRACT: Technical information and data on the physical and mechanical properties of agricultural and animal products are necessary to design various equipments for agriculture and industry. In this study some physical properties such as mass, length, diameter, geometric mean diameter, surface area, sphericity, volume, coefficient of friction and packaging coefficient were determined for Japanese quail eggs. Furthermore, the mechanical behaviour of Japanese quail eggs was determined in terms of average rupture force, deformation and toughness (energy absorbed by the Japanese quail eggs per unit volume). Egg samples were compressed along their *X* and *Z*-axes. The average values of their mass, length, width, shell thickness, geometric mean diameter, surface area, sphericity, volume and packaging coefficient were measured to be 12.69 g, 34.87 mm, 26.20 mm, 0.27 mm, 28.82 mm, 2 608.5 mm^2, 1.10, 359.17 mm^3, 0.469, respectively. The values of the coefficient of friction for quail eggs on the surfaces of plywood, glass, galvanized steel and fibreglass were 0.301, 0.282, 0.274 and 0.266, respectively. The highest rupture force, deformation and toughness were obtained when Japanese quail eggs were loaded along their *X*-axis. Compression along the *Z*-axis required the least compressive force to break the eggs as compared to the other compression axes. Rupture force, deformation, absorbed energy and toughness for the X-front axis were determined to be 10.51 N, 1.5 mm, 7.88 Nmm and 0.219 Mj/mm^2, respectively.

Keywords: quail egg; physical properties; mechanical behaviour

Japanese quails are raised for their tasty meat and nutritious eggs all over the world (Tikk and Tikk, 1993; Baumgartner, 1994; Yildirim and Yetisir, 1998; Minvielle, 2004).

The physical and mechanical properties of both animal and plant materials are needed for the design and effective utilization of the equipments for transportation, separation, packaging and storage. Important physical properties are shape, size, geometric mean diameter, projected area, sphericity, mass, volume, coefficient of packaging and coefficient of friction on different surfaces (Mohsenin, 1970; Rehkugler, 1973; Dehspande et al., 1993; Narushin, 1997; Aydın, 2002). The mechanical properties of biological materials represent their strength under various loads in terms of several parameters such as rupture force, deformation and toughness (Voisey and Hunt, 1969; Abdallah et al., 1993; Vursavus and Ozguven, 2004; Altuntas and Yildiz, 2007). The mechanical and physical properties of chicken eggs have been comprehensively studied in the literature (De Ketlaere et al., 2002; Lin et al., 2004; Narushin et al., 2004). However, the technical information and data on the physical properties and mechanical behaviour of Japanese quail eggs are very scarce in the literature. The aim of this study was to determine physical properties of Japanese quail eggs such as dimensional properties, sphericity, unit mass, volume, static friction coefficient on different surfaces, packaging coefficient, and their mechanical behaviour such as rupture force, deformation and toughness.

MATERIAL AND METHODS

Material

The eggs of wild-type European-originated quails were obtained from the quail breeding unit at Harran University, Şanlıurfa. Şanlıurfa Province is located in the southeast of Turkey, within 36 41' 28" and 37 57' 50" north latitude and 37 49' 12" and 40 10' 00" east longitude. The average air temperature and relative humidity were 19.5°C and 48% during the time period when the eggs were collected. The quails were nine weeks old. The composition of feed given to the quails is presented in Table 1. Birds were allowed an *ad libitum* access to feed and water.

Methods

Physical analyses

Physical properties of Japanese quail egg were determined using 40 repetitions. The physical properties of egg samples were determined by the following methods: linear dimensions, i.e. length (L) and width (W), were measured with a digital calliper to the nearest 0.01 mm. The geometric mean diameter of eggs was calculated using the following equation given by (Mohsenin, 1970):

$$D_g = (LW^2)^{1/3}$$

According to Mohsenin (1970) the degree of sphericity of Japanese quail eggs can be expressed as follows:

$$\Phi = D_g/W$$

The surface area of eggs was calculated using the following relationship given by (Mohsenin, 1970, Deshpande et al., 1993; Baryeh, 2003):

$$S = \Pi D_g^{\,2}$$

The Japanese quail egg mass (M) was measured with an electronic balance to the nearest 0.001 g. Length and width were used to calculate the volume of individual egg in the present investigation. For the material of ellipsoidal shape, the volume of individual egg (V) was calculated from the following equation (Mohsenin, 1970):

$$V = (\Pi/6) \times W^2$$

Packaging coefficient (λ) was defined by the ratio of the volume of eggs (V) packed to the total volume (V_0) of the 15 cm wide, 10 cm deep and 20 cm long rectangular box and calculated by the following equation (Topuz et al., 2005):

$$\lambda = V/V_0$$

Coefficient of static friction (μ_s) was measured with a friction device whose surface was covered either with rubber or with glass or with galvanized metal. For this measurement, the sample was placed on the surface, and then the surface was gradually tilted from its initial horizontal position by the

Table 1. Ingredients (%), nutrient values (%) and metabolizable energy (kcal/kg) of PSM and diets

Ingredients	Percentage	Nutrient values	Percentage
Maize	44.0	Crude Protein	18.0
Popy seed meal	11.0	Dry matter	89.0
Soybean meal	10.0	Crude cellulose	5.7
Full fat soya	6.2	Crude fat	4.6
Sunflower seed meal	13.8	Crude ash	13.5
Scurfy flour	4.2	Sodium	0.1
Vegetable fat	0.8	Calcium	3.5
Limestone	8.0	Phosphorus	0.7
Dicalcium phosphate	1.2	Lysine	0.05
Vitamin + mineral premix	0.2	Methionine	0.15
KS-20/50	0.1	Metabolizable energy (KCal/kg)	2 650.0
Salt	0.3		

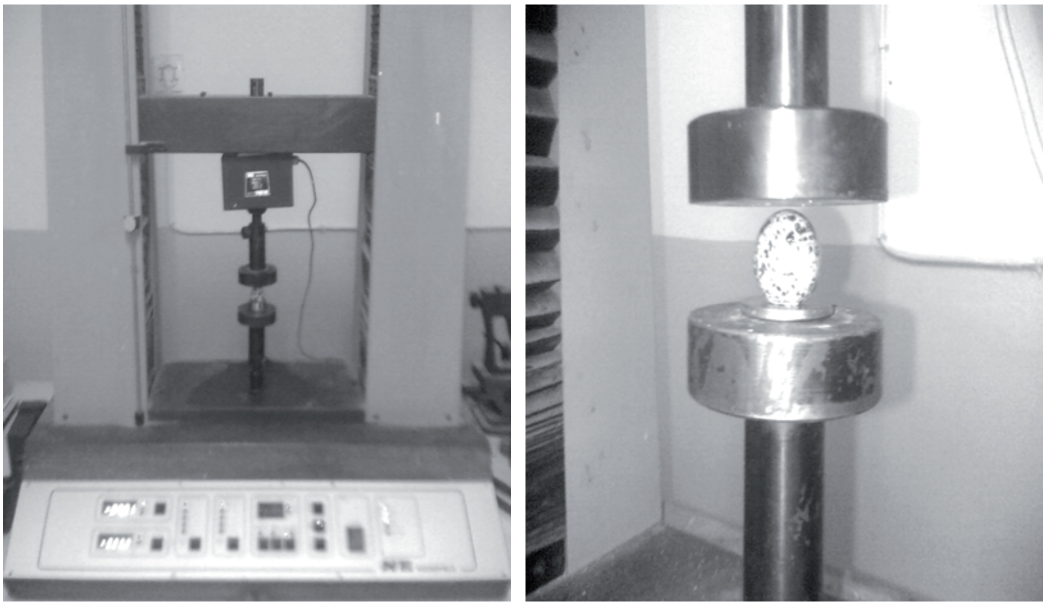

Figure 1. Biological material test unit

screw. Vertical and horizontal height values were read off with a ruler when the sample started sliding over the surface. The tangent value of the angle gave the coefficient of friction (Baryeh, 2003).

Mechanical Properties

A biological material test device (digital dynamometer) was used to determine the mechanical properties of Japanese quail egg (De Ketelaere et al., 2002; Vursavus and Ozguven, 2004; Altuntas and Yildiz, 2007) as seen in Figure 1. The biological material test device has three main components: a stationary and a moving platform and a data acquisition system. Compression force was measured by the data acquisition system. The egg sample was placed on the moving platform and loading position at a speed of 8 mm/min and pressed with a plate fixed on the load cell until the egg ruptured. It was assumed that rupture occurred at the bio-yield point that was the point on the force–deformation curve where there was a sudden decrease in force. As soon as the bio-yield point was detected, the compression was stopped. The compression test gave the maximum force and deformation that the shell of Japanese quail egg withstood prior to rupture.

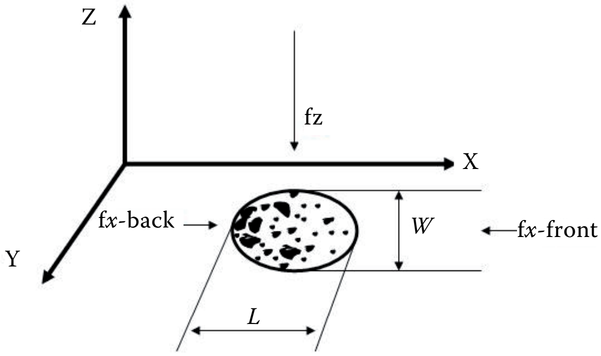

Figure 2. Axis and three major perpendicular dimensions of Japanese quail egg

Two compression axes (*X and Z*) for the egg were used in order to determine the rupture force, deformation and toughness (Figure 2).

The *X*-axis (force F_x) was the loading axis through the length dimension, and the *Z*-axis (force F_Z) was the transverse axis containing the width dimension. Egg shell deformation was computed using the load speed and time. Energy absorbed (E_a) was calculated from the following equation (Vursavus and Özgüven, 2004):

$$E_a = (F_r D_r)/2$$

where:
F_r = the rupture force
D_r = the deformation at rupture point

Toughness (P) = expressed as the energy absorbed by the egg up to rupture point per unit volume of the egg and was determined using the following formula (Olaniyan and Oje, 2002; Vursavus and Özgüven, 2004):

$$P = E_a/V$$

where:
E_a = the energy absorbed by the egg
V = the volume of the egg

Table 2. Some physical properties of Japanese quail egg

Physical properties	No. of observations	Unit of measurement	Mean	Min value	Max value	Standard deviation
Length (L)	40	mm	34.87	32.31	36.78	1.21
Width (W)	40	mm	26.20	24.65	27.52	0.72
Shell thickness (S_T)	40	mm	0.27	0.23	0.31	0.02
Geometric mean diameter (Dg)	40	mm	28.82	27.44	30.27	0.69
Surface area (S)	40	mm^2	2 608.50	2 363.70	2 876.40	126.40
Volume (V)	40	mm^3	359.27	317.98	396.34	19.65
Mass (M)	40	g	12.69	10.58	14.25	1.01
Sphericity (Φ)	40	%	1.10	1.07	1.13	0.014
Packaging coefficient (λ)	40	–	0.469	0.458	0.477	0.003
The coefficient of static friction						
Plywood	40	–	0.301	0.267	0.324	0.018
Glass	40	–	0.282	0.258	0.296	0.013
Galvanized steel	40	–	0.274	0.240	0.296	0.017
Fibreglass	40	–	0,266	0.252	0.281	0.014

The statistical evaluations were done by the Minitab Package Program (Minitab, 1991).

RESULTS AND DISCUSSION

Physical parameters

The numeric values of the physical parameters of Japanese quail eggs are shown in Table 2. The Japanese quail egg mean length and width (or thickness) were found to be 34.87 mm and 26.20 mm, respectively. Mohsenin (1970),), Omobuwajo et al. (1999) and Owolarafe et al. (2007) discussed the importance of these and other characteristic axial dimensions in determining the aperture size of machines, particularly in separation of materials. These dimensions may be useful in estimating the size of machine components. The geometric mean dimension, surface area, sphericity and volume of Japanese quail eggs were found to be 28.82 mm, 2 608 mm^2, 1.10% and 359.27 mm^3, respectively. The average mass of the Japanese quail egg was 12.69 g and average packaging coefficient was 0.469. The average egg mass (11.23 g) found by Vali et al. (2006) is slightly lower than the current results. This difference can be caused by variations in rearing conditions of both studies. The egg mass was found to effect positively the hatching weight of quail chicks (Yildirim and Yetisir, 1998)

The coefficient of static friction for Japanese quail eggs was determined on the surfaces of galvanized steel, plywood, glass and fibreglass. The coefficient of static friction of the Japanese quail egg was

Table 3. The correlation coefficients of Japanese quail eggs

Particulars	Ratio	Degrees of freedom	Correlation coefficient
L/W	1.33	98	0.69^{**}
L/S_T	129.14	98	0.92^{**}
L/Dg	1.21	98	0.74^{**}
L/V	0.097	98	0.66^{**}
L/M	2.78	98	0.88^{**}
L/S	0.013	98	0.54^{**}
L/Φ	31.70	98	0.74^{**}
L/λ	74.22	98	0.91^{**}

**Significant at 1% level

0.301 on plywood, 0.282 on glass, 0.274 on galvanized steel, and 0.266 on fibreglass. The coefficient values of static friction obtained on plywood, glass, galvanized steel and fibreglass for Japanese quail eggs were not statistically different from each other. The coefficient of static friction describes the limit of eggs to start moving on different surfaces which can be used for transportation and separation processes. On the other hand, many plant materials responded differently to various surfaces. For instance, chickpea seeds had the highest coefficient of static friction on rubber surface while they had the lowest coefficient of static friction on galvanized metal sheet (Konak et al., 2002).

Table 3 shows the relationships and correlation coefficients between Japanese quail egg dimensions. The correlation coefficients show that all ratios are significant at 1% level but L/M, L/λ and L/S_T ratios are more significantly related to each other than the other ratios for Japanese quail egg. The mass, packaging coefficient and shell thickness show a closer relationship with the length of eggs than the other particulars (width, geometric mean diameter, volume, surfaces area, sphericity).

Mechanical behaviour

Eggshells must be strong enough to prevent cracking during their handling from farm to market and to preserve safely the embryo during hatching. On the other hand, they should be thin enough for gas exchange and weak enough to allow the chick to crack when hatching. Eggshell strength has been described using various variables such as eggshell thickness, shell stiffness, breaking (rupture) force, etc. (De Ketelaere et al., 2002). The average shell thickness of eggs was found to be 0.27 mm. The thickness of hen eggs ranged from 0.319 mm to 0.363 mm, which changed with hen strain (De Ketelaere et al., 2002).

Table 4 shows the average values of rupture force, deformation and toughness obtained from the experiment at different compression axes. The response of the quail eggshell to compression load depended on the loading orientation.

The loading orientation that gave the least resistance to rupture force was along the Z-axis. The rupture force measured in loading along the lateral axis (Z-axis) was found to be 6.83 N. The highest rupture force value was determined to be 10.51 N in loading along the X-front axis. The rupture force was measured to be 9.67 in loading along the X-back axis. Absorbed energy was measured as a function of rupture force and deformation on the surface of eggs. Absorbed energy values were found to be 7.88 (X-front axis), 3.41 (Z-axis) and 4.35 Nmm (X-back axis). The deformation values along the three axes after compression were measu-red to be 1.5 mm (X-front axis), 1 mm

Table 4. Some mechanical properties of Japanese quail egg

Physical properties	Compression axis	No. of observations	Mean	Min value	Max value	Standard deviation
Rupture force (N)	X-front	40	10.51[a]	9.6	11.4	0.98
	Z-axis	40	6.83[b]	6.2	8.3	0.69
	X-back	40	9.67[a]	8.00	11.1	0.94
Deformation (mm)	X-front	40	1.5[a]	1.0	1.8	0.40
	Z-axis	40	1.0[b]	0.9	1.2	0.66
	X-back	40	0.9[b]	0.8	1.0	0.10
Absorbed energy (Nmm)	X-front	40	7.88[a]	4.80	10.26	0.19
	Z-axis	40	3.41[b]	2.79	4.98	0.23
	X-back	40	4.35[b]	3.20	5.55	0.05
Toughness (Mj/mm^2)	X-front	40	0.0219[a]	0.0150	0.0258	0.009
	Z-axis	40	0.0094[b]	0.0087	0.0125	0.011
	X-back	40	0.0121[c]	0.0101	0.0140	0.002

Means of each group with different letters ([a,b,c]) are significant at 1% level

(Z-axis) and 0.9 mm (X-back axis). The deformation values for quail eggs compressed along the X-front axis were higher than for those compressed along the X-back axis and Z-axis. This shows that the front of quail egg is more flexible than the other two axes and is more resistant to rupture along the X-front axis. The toughness for Japanese quail eggs was measured to be 0.0219 (X-front axis), 0.0094 (Z-axis) and 0.0121 (X-back axis), respectively. The toughness values for eggs compressed along the X-front axis were higher than for those compressed along the other two axes. The average rupture force for the horizontally placed hen eggs ranged from 30.9 N to 37.8 N (De Ketelaere et al., 2002). The rupture force of hen eggs depended on various egg properties (egg specific gravity, egg mass, egg volume, egg surface area, egg thickness, shell weight, shell percentage (shell weight/egg weight, etc.) Narushin et al. (2004). The strongest correlation was found between shell rupture force and shell percentage (r = 0.58) (Narushin et al., 2004).

CONCLUSIONS

1. Length, width, shell thickness, mass and volume of Japanese quail eggs were found to be 34.87 mm, 26.20 mm, 0.20 mm, 12.69 g and 359.27 mm^3, respectively.
2. Geometric mean diameter, surface area, sphericity and packaging coefficient of quail eggs were found to be 28.82 mm, 2 608 mm^2, 1.10% and 0.469, respectively.
3. The coefficient of static friction of the Japanese quail egg was 0.301 on plywood, 0.282 on glass, 0.274 on galvanized steel, and 0.266 on fibreglass.
4. Rupture force, deformation, absorbed energy and toughness of Japanese quail egg were found to be higher for compression along the X-front axis when compared to the other two axes (X-back axis and Z-axis). These values for X-front axis are 10.51 N, 1.5 mm, 7.8 Nmm and 0.0219 Mj per mm^2, respectively.

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Received: 2006–09–14
Accepted after corrections: 2006–12–11

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