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Engineering Properties of Japanese quail Eggs in Different Levels of Dietary Calcium

M. H. Aghkhani[1*], M. Baghani[2]

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Abstract

The eggshell of birds, as a natural shield and package, protects the tissues inside it from microbial and mechanical damages. Proper intake of calcium, as an important and effective factor in increasing the strength and quality of the eggshell, could reduce complications. In this paper, the effect of dietary calcium at five different levels on engineering features of Japanese quail eggs in a Parent stock in their first laying period was investigated. The values for an average of mass, volume, specific mass, shell thickness, major diameter, central diameter and rupture force along the longitudinal and transverse axes were measured. Rupture energy or toughness, slope of the rupture curve (hardness), deformation along the longitudinal and transverse axis to the point of rupture as well as longitudinal and transverse deformation of 450 tested quail eggs (3 period of time, 5 treatment of calcium, 5 replication, 6 observation) were measured. The characters of the specific mass, shell thickness, rupture force, and slope of the rupture curve of quail eggs indicate the strength of quail egg. In this study, variations in all parameters indicating shell strength at different levels of dietary calcium were consistent with each other. Five different treatments with 1.5%, 2%, 2.5%, 3%, and 3.5% calcium content were supplied for the study. By increasing the calcium content of the quail diet from 1.5 to 3 wt%, the volume and weight of quail eggs dropped and shell thickness was reinforced. According to the results, the shell strength of quail eggs along the transverse axis was slightly less than the longitudinal axis, but the flexibility and energy required for quail egg rupture were much greater across the longitudinal axis.

Keywords: Calcium, Eggshell, Mechanical properties, Physical properties, Strength

Introduction

The eggshell of birds, as a shield and natural package, protects the embryo and other materials inside it from microbial and mechanical damages. It provides a bacteria and virus-free environment deprived of any contaminants that may damage the embryo. The eggshell also acts as a respiratory organ for the balut and supplies nutrients (mainly calcium) for the growth of the embryo (Ancle *et al.*, 1992). The quail eggshell, given its impact on packaging machinery and equipment, incubation, warehousing and sale market, plays a key role in the profitability of this industry. The economic consequences of neglecting shell defects could be meaningful. Economically, the rupture of eggshells accounts for about 8-10% loss in the industry (Ketta and Tumova, 2016). Therefore, research in this area is necessary and can contribute to boost the industry of egg-laying and breeder quails.

Calcium is one of the most important nutritional factors affecting the quality of eggshell of birds. Both deficiency and excess of calcium in birds' diet decrease the quality of the eggshell (North, 1984). Low levels of calcium in the diet reduces the thickness of the shell and increases the number of thin shells or shell-less eggs. High amounts of calcium also affect phosphorus absorption, reduce the quality of the eggshell and give a bad taste to the bird's diet, which leads to the lower intake of quail feed (Robert and Ball, 1998).

Furthermore, the quality of eggshell of birds is determined by measuring shell thickness and resistance against brittleness. Usually, the resistance of the eggshell increases proportional to the thickness of the

1- Professor, Department of Biosystem Engineering, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran
2- PhD student, Department of Biosystem Engineering, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran
(*- Corresponding Author Email: aghkhani@um.ac.ir)
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shell (Ketta and Tumova, 2018), but the thick shell does not always mean a solid shell. The shell strength is chiefly related to the structure of organic and inorganic compounds (Roque and Soares, 1994). The system of growing chickens in a cage produces eggs of higher resistance compared to the method of growing them on the breeding farm (Ketta and Tumova, 2018). The birds' age also affect the quality of the eggshell. It is showed that as birds grow older, the shell thickness is decreased (Ketelaere *et al.,* 2002; Mazzuco and Hester, 2005). Information about the engineering features of animal products is necessary to design equipment for different rearing sectors which affect production costs and the quality of the products (Correa *et al.,* 2010). Experiments have been carried out to study the engineering properties of eggshell. It is reported that the mechanical resistance of quail egg in the longitudinal axis was greater than of the transverse axis (Polat *et al.,* 2007; Altuntas and Sekeroglu, 2008; Buchar *et al.,* 2015; Nedomova *et al.,* 2016). However, deformation and rupture energy along the longitudinal axis of quail eggs were lower than the transverse axis (Altuntas and Sekeroglu, 2008). Some studies also showed that, as the loading rate of quail eggs is increased, the force necessary for egg rupture was amplified (Buchar *et al.,* 2015). Furthermore, some physical properties of quail eggs (e.g., egg weight, specific mass, and shape index) have been assessed in some studies (Yannakopoulos and Tserveni-Goussi, 1986; Gonzalez, 1995). Although these studies have concentrated on the physical and mechanical properties of Japanese quail eggs, no specific study on the effect of different levels of dietary calcium on engineering properties was investigated on a commercial farm. Therefore, the main object of this study was to determine the average mass, volume, specific mass, shell thickness, major diameter, central diameter, rupture force, rupture energy and slope of the rupture curve of quail eggs in five levels of calcium dietary.

Materials and Methods

In this study, 200 female quails and 100 male quails were selected randomly from a quail parent stock commercial farm at the age of 10 weeks. In this way, we had 100 cages, each containing two females (Average Weight of 230 g) and one male bird. The experimental section of this study was carried out in Karaj, Iran. The diet was based on NRC1994 standard nutritional requirements (National Research Council, 1994), and the feeding treatments differed only in terms of calcium content. The light exposure and moisture were maintained equal across the breeding farm throughout the day. During the three-month experiment, lights were switched on from 6:00 AM to 10:00 PM. The temperature of the breeding farm ranged from 18 to 23 °C and humidity was in the range of 40 to 80%.

Five different treatments with 1.5%, 2%, 2.5%, 3%, and 3.5% calcium content were supplied for the study. The quail diet was prepared according to NRC1994, and the recommended calcium in NRC 1394 for quail is 2.5%. Treatments of calcium in this study were recommended diet calcium in NRC1394 ± 1% (National Research Council, 1994). Each treatment included 60 quails (40 females and 20 males) put in 20 cages. Each treatment had 5 repetitions which contained 4 cages per each (5×4). The diet was also provided at 11 weeks of age, after birds' adaptation to the new breeding environment. After one month of breeding under controlled conditions, the sampling of quail eggs was carried out in three stages after 15 weeks, 19 weeks and 23 weeks (Baghani and Aghkhani, 2016). At each sampling stage, 6 samples were taken from each repetition and a total of 450 samples of quail eggs were selected and examined. The sample of quail eggs was always performed at 6:00 PM.

In terms of physical properties, large diameter (L), central diameter (W) and eggshell thickness were measured using a caliper with a precision of 0.01 mm and mass of samples (M) was measured using a digital scale (AND, Japan) with a precision of 0.01 g. The volume (V) of the eggs was determined using fluid displacement or fluid weights

(Mohsenin, 1986). The specific mass, one of the most common parameters for determining the shell strength of eggs (Ketta and Tumova, 2016), was obtained by dividing the mass in egg volume. Eqs. 1 to 5 were used based on (Altuntas and Sekeroglu, 2008; Alahdadi *et al.,* 2012; Rohani *et al.*, 2015) to calculate the geometric mean diameter (Dg), degree of sphericity (Φ), external surface area (S), shape index (SI) and specific deformation (ε).

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

$$\Phi = (D_g/L) \times 100 \quad (2)$$

$$S = \pi D_g^2 \quad (3)$$

$$SI = (W/L) \times 100 \quad (4)$$

$$\varepsilon = dL/L \quad (5)$$

The strength and other mechanical properties of quail eggs were determined by the rupture resistance method using the quasi-static compression test between two metal plates of universal test apparatus (Instron Universal Testing Machine SMT-5, SANTAM Co., Iran). The loading speed was 6 mm/min and the test was performed along with two directions: longitudinal (large diameter) and transverse (middle diameter) axes of quail eggs (Figures 1 and 2).

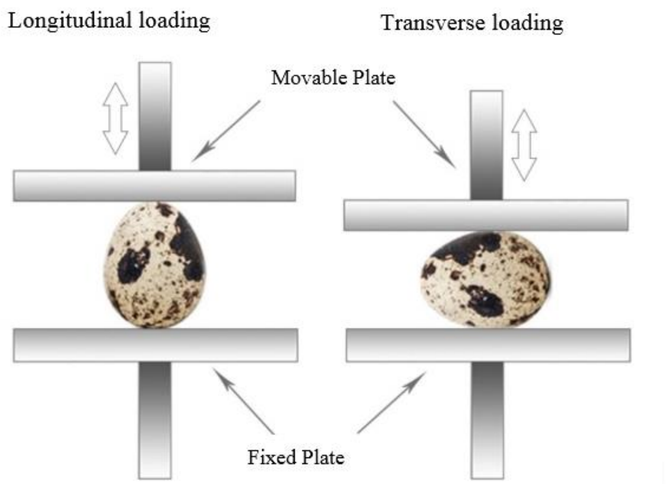


Fig.1. schematic of load applied along the longitudinal and transverse direction on quail eggs in a single axial pressure test. The load applied along the central diameter (right) and the large diameter (left)

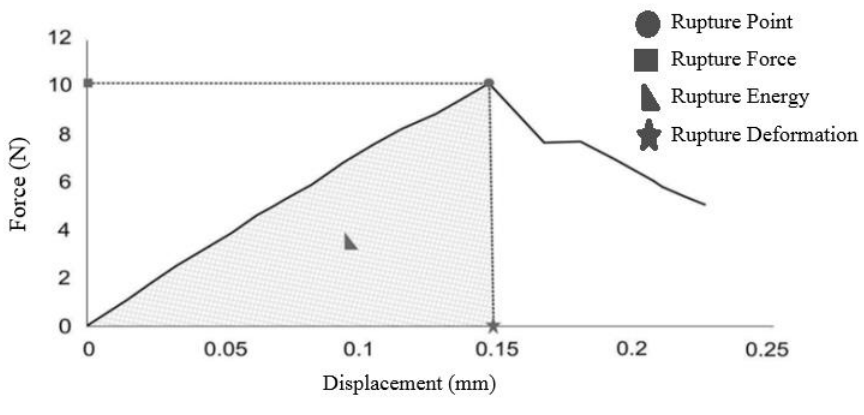


Fig.2. An example of a force- deformation diagram for quail eggs

The gradient of the deformation and rupture energy of quail eggs were calculated using Eqs. 6 and 7 based on Figure 2. (Mohsenin, 1986).

$$Q = F_m / P_m \quad (6)$$

$$W = \int F_{(p)}\, dP \quad (7)$$

Finally, by performing data analysis using SAS® software, all data derived from physical measurements and single-axis pressure tests were compared at different levels of calcium.

Results and Discussion

The values of mass, volume, specific mass and diameter of quail eggs at various levels of calcium are shown in Table 1. By increasing the calcium level of the diet from 1.5% to 3%, the weight and volume of quail eggs dropped. A comparison of mean of measured data for the specific mass is shown in Table 1.

Table 1- Average mass, volume, specific mass, and diameter of quail eggs at different levels of calcium of quail diet

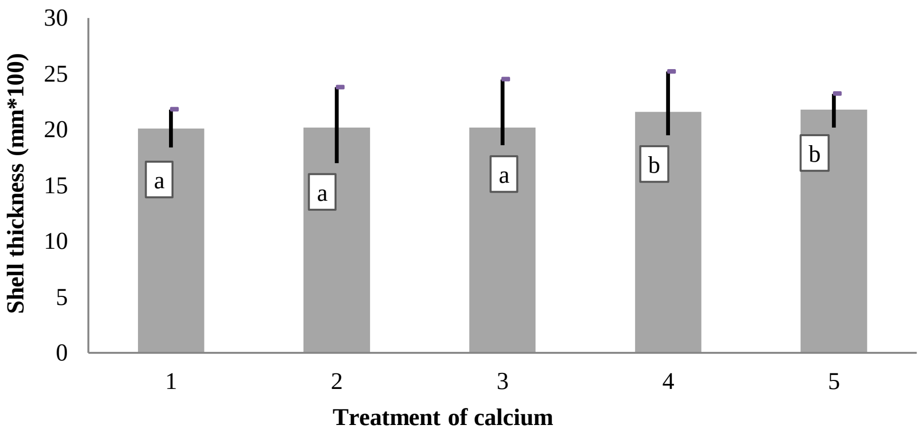
	Sampling age	Calcium levels (%)					CV (%)	SEM
		1.5	**2**	**2.5**	**3**	**3.5**		
Mass (g)	15 weeks	12.44 a	12.73 a	12.38 a	12.25 a	12.17 a	8.04	0.081
	19 weeks	12.27 a	12.28 a	12.13 a	12.34 a	12.55 a	8.75	0.088
	23 weeks	12.70 a	12.46 a	12.38 ab	12.04 b	12.46 ab	8.90	0.090
Volume CC (cm^3)	15 weeks	11.70 ab	11.95 a	11.53 ab	11.4 b	11.3 b	8.19	0.077
	19 weeks	11.4 a	11.5 a	11.3 a	11.4 a	11.68 a	9.00	0.085
	23 weeks	11.8 a	11.54 ab	11.54 ab	11.1 b	11.51 ab	9.33	0.0088
Specific Mass ($kg.L^{-1}$)	15 weeks	1.064 a	1.068 a	1.073 b	1.076 b	1.074 b	1.01	0.00088
	19 weeks	1.078 b	1.067 a	1.076 b	1.079 c	1.075 bc	0.91	0.00080
	23 weeks	1.070 a	1.079 ab	1.072 a	1.080 b	1.083 b	1.38	0.01225
Middle diameter (mm)	15 weeks	26.14 a	26.51 a	26.13 a	25.9 b	25.8 b	3.05	0.065
	23 weeks	26.4 a	26.16 a	25.97 a	25.8 b	26.02 b	3.29	0.069

Means with different letters are significantly different from each other ($P<0.05$).

There was a significant difference (level of 0.05) between the average specific mass of quail eggs for different levels of calcium. By increasing the calcium of the quail diet from 1.5 to 3%, the specific mass of the quail egg was increased.

Figure 3 shows the shell thickness of quail eggs at various levels of calcium. The thickness of the quail eggshell was also increased by raising calcium in the diet.

The highest shell thickness, meaningfully was different from other levels of calcium (at the level of 0.05), at 3 and 3.5% of calcium.



Means with different letters are significantly different from each other ($P<0.05$).

Fig.3. Average shell thickness of quail eggs (hundredths of a millimeter) at different levels of calcium along with standard deviation

The averages shape index, surface area, degree of sphericity and geometric mean diameter of quail eggs for different levels of calcium at 15th and 23th weeks are shown in Table 3. The statistical analysis of the calculated parameters indicated that the mean values of these physical characters at different levels of calcium did not differ significantly and calcium dietary levels had no effect on the amount of these Characteristics.

Table 3- mean of shape index, surface area, percent of sphericity and geometric mean diameter at different levels of dietary calcium

	Calcium treatments (%)	Number of samples	Shape index	Surface area (mm)	Percent of Sphericity	Geometric mean diameter (mm)
	1.5	30	0.768	2561	83.91	28.54
	2	24	0.781	2604	84.82	28.78
	2.5	29	0.772	2551	84.16	28.48
	3	20	0.760	2536	83.31	28.39
	3.5	16	0.775	2493	84.41	28.16
Average	All	119	0.771	2554	84.12	28.50
CV (%)	All	119	3.729	5.822	2.538	2.917
SEM	All	119	0.0023	12.14	0.0174	0.0679

All the Means of a parameter are not significantly different from each other ($P>0.05$)

The measured values of the rupture force were analyzed using SAS® software in a completely randomized method. The results of variance analysis are presented in Table 4 and the variations of the rupture force at various levels of calcium are also shown in Figure 4. The difference in mean rupture at different levels of calcium was significant at the level of 0.01. A comparison of the means showed that with an increase in calcium intake of quails from 1.5 to 3 wt% of the diet, the egg rupture rate of quail eggs was raised so that the maximum strength was obtained at 3% calcium diet treatment.

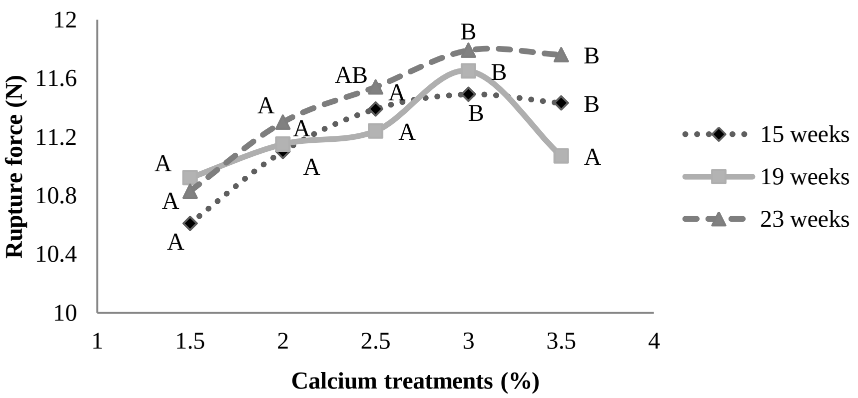


Fig.4. Changes in Rupture Force at various levels of calcium

The slope of the rupture curve (hardness) of quail eggs was raised by increasing the dietary calcium from 1.5 to 3 wt%. The average gradient of the force-deformation curve at various levels of calcium is shown in Table 5. A summary of values obtained from three stages of measuring the gradient of the force-deformation curve were also shown in Figure 5.

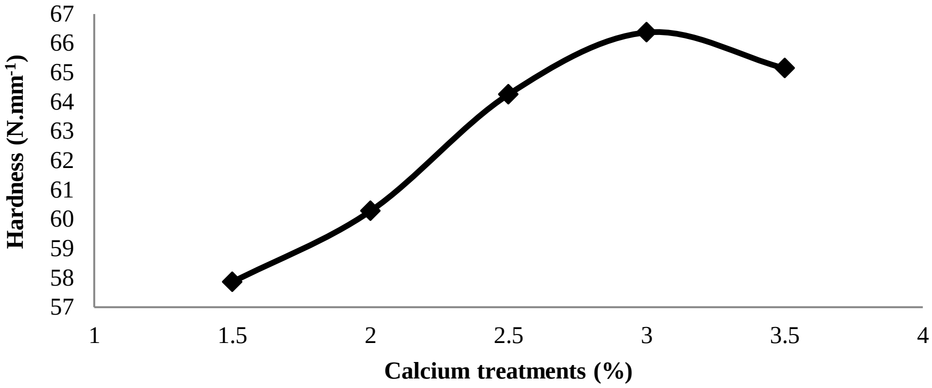


Fig.5. Variation in the slope of rupture curve (hardness) of quail eggs at different levels of calcium

Table 5- The slope of rupture curve along the longitudinal axis of quail eggs at different levels of calcium

Age of bird	Calcium treatments (%)	Number of samples	Hardness ($N.mm^{-1}$)	Min ~ Max	SEM	CV (%)
15 weeks	1.5	26	65.152 a	33.9~83.7	2.485184	19.4505
	2	22	66.854 a	35.4~85.7	2.616399	18.35752
	2.5	26	70.929 b	46.2~99.5	2.260435	16.25212
	3	23	71.707 b	5.06~86.4	1.9861	13.28452
	3.5	27	71.235 b	45.5~96.8	2.381955	17.37611
	Total	124	69.2062	33.9~99.5	1.066855	17.16763
19 weeks	1.5	26	54.506 a	39.0~67.7	1.338885	12.52661
	2	19	54.835 a	45.3~72.3	1.688959	13.42696
	2.5	29	61.031 b	39.6~76.6	1.61425	14.24381
	3	21	62.174 b	47.6~78.7	2.061723	15.19704
	3.5	23	62.832 b	46.4~90.7	2.30325	17.58077
	Total	118	59.150	39.0~90.7	0.861474	15.82079
23 weeks	1.5	29	53.9111 a	28.0~72.6	2.098517	20.96246
	2	30	59.142 ab	44.6~82.7	1.652834	15.30765
	2.5	27	60.8067 b	28.3~93.0	2.730575	23.33632
	3	22	65.2219 b	47.6~76.9	1.502526	10.80569
	3.5	28	61.3617 b	35.6~82.9	2.323619	20.03819
	Total	136	59.79775	28.0~93.0	0.992142	19.3515

Means with different letters are significantly different from each other ($P<0.05$).

The effect of various levels of calcium in the diet of quail on the rupture force, rupture energy, and the slope of the rupture curve (hardness) along the transverse axis of the quail egg were similar to that of the longitudinal axis. According to Table 6 and Figure 6, with increasing calcium in the diet of quails from 1.5 to 3%, shell strength was raised in the direction of small diameter, so that the highest strength and the most specific deformation were obtained at 3% treatment of dietary calcium. The results of this study are consistent with previous findings that examined the effect of dietary calcium on eggshell hardness, finding that eggshell strength was improved by calcium (Jiang *et al.,* 2013).

In an experiment on analysis of the resistance of eggshells in different species of chickens several parameters (weight, dynamic stiffness, static stiffness, breaking force and eggshell thickness) were examined (Ketelaere *et al.,* 2002). They reported that changes in these parameters were not consistent, and mechanical strength (e.g. static stiffness, breaking force, and eggshell thickness) of the shell showed different values. In this study with increasing calcium, shell thickness was improved and resistance to rupture was increased. These results are consistent with the study of Ketta and Tumova (2017), who observed that reinforced eggshell thickness increased the resistance to rupture (Ketta and Tumova, 2018).

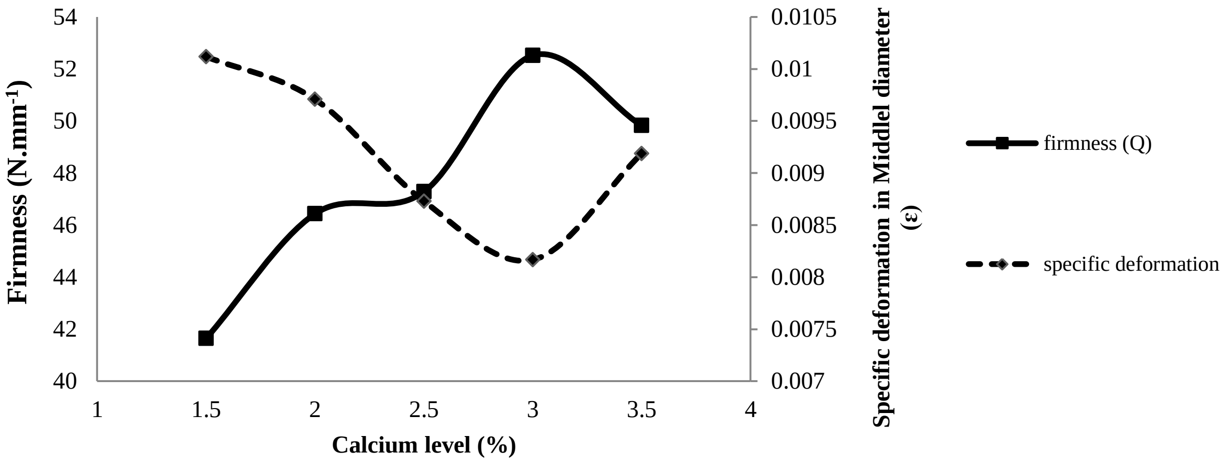


Fig.6. Variation of specific deformation and slope of rupture curve along the transverse axis of quail eggs at different levels of calcium

Table 6- Averages of deformation, specific deformation and hardness of quail eggs along the transverse axis of quail eggs at different levels of dietary calcium

	Level of calcium (%)					Min	Max	SEM	CV
	1.5	2	2.5	3	3.5				
Deformation (mm)	0.269c	0.2532bc	0.2253ab	0.2107a	0.2408abc	0.1161	0.6444	0.00545	0.23871
Specific deformation	0.0101c	0.0097bc	0.0087ab	0.0081a	0.0091abc	0.004324	0.023824	0.00020	0.23393
Hardness ($N.mm^{-1}$)	41.640a	46.432ab	47.278b	52.517c	49.824bc	15.754	72.606	0.84448	0.18500

Mean with different letters are significantly different from each other ($P<0.05$)

The mean values of the rupture force, rupture energy, the slope of the rupture curve and the deformation to the rupture point along the central diameter of the quail eggs were 10.94 N, 1.53 $N.mm^{-1}$, 47.65 $N.mm^{-1}$, and 0.238 mm, respectively. The mean rupture force and slope of the rupture curve along the transverse axis were lower than the longitudinal axis, while the rupture energy and deformation to the rupture point along the transverse axis of quail eggs were much greater compared to the longitudinal axis. The results are in line with the findings reported by (Polat *et al.,* 2007; Altuntas and Sekeroglu, 2008; Buchar *et al.,* 2015; Nedomova *et al.,* 2016).

Conclusions

The results of this study suggested that by increasing calcium in the diet of quail eggs from 1.5% of the diet to 3 wt%, the strength and thickness of eggshell were reinforced. The highest shell strength of quail eggs was obtained when calcium constituted 3% of the diet weight. By more increasing calcium content, the thickness of the shell remained constant, but the shell strength declined.

The characters of the specific mass, shell thickness, rupture force, and slope of the rupture curve of quail eggs all indicate the degree of shell strength for quail eggs. Increasing each of these characters will translate into enhanced shell strength of quail eggs. In this study, variations in all parameters exhibit that shell strength at different levels of dietary calcium is identical.

In the present study, with an increase in calcium intake, shell thickness was improved and resistance to rupture increased. A comparison of quail eggs in two longitudinal and transverse axes suggested that quail eggs displayed lower strength and greater flexibility along the transverse axis (central diameter) compared to the longitudinal axis.

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ویژگی‌های مهندسی تخم بلدرچین ژاپنی در سطوح مختلف کلسیم جیره غذایی

محمد حسین آق خانی[1*]، موسی الرضا باغانی[2]

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چکیده

پوسته تخم پرندگان، به‌عنوان یک بسته‌بندی طبیعی، از مواد موجود در تخم در برابر آسیب‌های میکروبی و مکانیکی محافظت می‌کند. مصرف مقادیر مناسب کلسیم در جیره غذایی پرنده، به‌عنوان یک عامل مهم و مؤثر در افزایش قدرت و کیفیت پوسته تخم می‌تواند عوارض ناشی از مشکلات پوسته را کاهش دهد. در این مقاله، تأثیر کلسیم جیره غذایی در پنج سطح مختلف بر ویژگی‌های مهندسی تخم بلدرچین ژاپنی در گله بلدرچین مادر در اولین دوره تخم‌گذاری آن‌ها بررسی شده است. مقادیر میانگین جرم، حجم، جرم مخصوص، ضخامت پوسته، قطر بزرگ، قطر میانی و نیروی شکست در امتداد محورهای طولی و عرضی اندازه‌گیری شد. انرژی شکست یا چقرمگی، شیب منحنی پارگی (سختی)، تغییر شکل در امتداد محور طولی و عرضی تا نقطه شکست و همچنین تغییر شکل طولی و عرضی ۴۵۰ عدد تخم بلدرچین مورد آزمایش بررسی و اندازه‌گیری شد. پارامترهای جرم مخصوص، ضخامت پوسته، نیروی شکست و شیب منحنی شکست تخم بلدرچین همگی بیانگر استحکام پوسته تخم بلدرچین بوده و در مقالات مختلف از هرکدام از این پارامترها برای نشان دادن استحکام و تغییرات استحکام پوسته استفاده شده است. در مطالعه‌ی حاضر تغییرات تمام پارامترهای بیانگر استحکام پوسته تخم در سطوح مختلف تغذیه‌ی کلسیم با یکدیگر همسو بوده و یکدیگر را تایید کردند. با افزایش مقدار کلسیم جیره غذایی بلدرچین از ۱/۵ به ۳ درصد وزنی، حجم و وزن تخم بلدرچین کاهش یافته و ضخامت پوسته تقویت می‌شود. طبق نتایج به‌دست آمده، مقاومت پوسته تخم بلدرچین در امتداد محور عرضی کمی کمتر از محور طولی است، اما انعطاف‌پذیری و انرژی شکست تخم بلدرچین در محور طولی بسیار بیشتر است.

واژه‌های کلیدی: استحکام، پوسته تخم، کلسیم، ویژگی‌های فیزیکی، ویژگی‌های مکانیکی

۱- استاد، گروه مهندسی بیوسیستم، دانشکده کشاورزی، دانشگاه فردوسی مشهد
۲- دانشجوی دکتری، گروه مهندسی بیوسیستم، دانشکده کشاورزی، دانشگاه فردوسی مشهد
(*- نویسنده مسئول: Email: aghkhani@um.ac.ir)

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