Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 10 (14): 1405-1412, 2010
ISSN 1812-5654

Fertility Recognition of Ostrich Egg Using Physical Properties

M.H. Abbaspour-Fard, B. Emadi and M.H. Aghkhani
Biosystmes Engineering Group, Department of Farm Machinery Engineering, College of Agriculture,
Azadi Square, P.O. Box 1163, Ferdowsi University of Mashhad, Iran

Abstract: The aim of this study was to investigate some physical properties of ostrich egg, including eggshell porosity, dimensional and gravimetric properties which were nondestructively measured to find any probable correlation between these properties and egg fertility. Currently one of the blockade problems in ostrich egg production industry is the impossibility of egg candling prior to hatching. Therefore, fractions of the hatcher are occupied by infertile eggs and soon fall to decay without any economical use. Totally 301 eggs were sampled during three consecutive weeks of June. The results showed overall, about 63% of the eggs were fertile and among these eggs, 7% were not hatched successfully. No significant correlation observed between physical properties of eggs and fertility. However, the data analysis on frequency of fertile and infertile eggs of different categorized properties indicated that some groups of eggs might have a higher fertile eggs frequency than infertile eggs. In general, the groups of eggs with aspect ratio about 1.2, weight of 1500 g, density of 1.15 g cm $^{-3}$ and average shell pore diameter of less than 750 μm had a higher fertile egg frequency than infertile egg frequency. On the other hand, egg volume and dielectric properties had the least impact on egg fertility. Image processing of the eggshell pigment and thermal photography are recommended for further investigations.

Key words: Hatchability, infertility, gravimetric, porosity, candling

INTRODUCTION

Nowadays due to increasing demand of food, the human being is seeking for new sources of food and also increasing the quality of food products by suitable packaging (Estiri *et al*., 2010) and other qualitative factors influencing consumers demand (Ghorbani and Khajehroshanaee, 2009). One of the recent interested sources of food is ostrich, which is a native African ratite bird with no flying ability. Because of high metabolism and nutrition to energy conversion, fast growth and beneficial life, ostrich is superior to the other animals. Because of environmental and climate compatibility of ostrich, it can be raised almost in all climate conditions. Based on the degree of maturity, each bird is able to lay about 30 to 100 eggs, annually. The average length and weight of an ostrich egg are about 20 cm and 2 kg, respectively. The average fertility and hatchability of ostrich egg are about 60 and 50%, respectively. The price of each incubated ostrich egg ranged from 25 to 30 USD, while the price of a one-day chick may reach up to 60 USD in Iranian market (Anonymous, 2008).

With the worldwide expansion of ostrich industry, currently reducing ostrich chick death, increasing growth rate, improving nutrition output, along with the optimization of production and eventually maximization of production efficiency are the main challenges (Black, 2001). In this regard introducing some feasible ways for economical use of egg, feather and skin along with the meat, could increase the profitability of this industry.

The first step to have a successful ostrich farm is the production of eggs with high fertility and hatchability. By this time, several studies have been carried out on different aspects of ostrich egg. Most of these studies focused on nutritive characteristics of ostrich egg as food alternative processing applications (Fernaandez-Lopez *et al*., 2006; Fink *et al*., 2006; Miguel *et al*., 2005; Machiko *et al*., 2003; Sales *et al*., 1996). According to Machiko *et al*. (2003), despite some differences between hen and ostrich eggs in the weight and also physical and chemical properties of their yolk and albumen, the ostrich egg could be also considered as an important nutrition source. However, from economical point of view, the fertility is still preferential to the food value of ostrich egg. Nonetheless, no reliable method(s) has been reported for separation of fertile from infertile ostrich eggs. Due to the high thickness of the eggshell, the so-called candling method also cannot be applied.

Corresponding Author: M.H. Abbaspour-Fard, Department of Farm Machinery Engineering, College of Agriculture, Azadi Square, P.O. Box 1163, Ferdowsi University of Mashhad, Mashhad, Iran
Tel: +98 511 8795615-19 Fax: +98 511 8796844

Besides the relatively low percentage of ostrich egg fertility, the low hatchability is another limitation for the growers of ostrich, which is mainly due to the low Egg Weight Loss (EWL) during incubation. This may be affected by the size of egg, the porosity and thickness of eggshell and storage period before incubation (Gonzalez *et al*., 1999; Hassan *et al*., 2005). According to these findings by increasing the storage period, EWL is increased. In addition, the hatchability of small eggs was higher than medium ones. Since the eggshell porosity represents the quality of eggshell conductance (oxygen and carbon dioxide exchange) and hence the quantity of fetus growth environmental condition (Tullett and Deeming, 1982; Board and Scott, 1980), it may affect the hatchability. Although, the porous characteristics of eggshell affect the fetus growth, however, Wagner-Amos and Seymour (2002) reported that the fetus growth is independent of pore distribution of eggshell.

Sahan *et al*. (2003) studied the effect of ostrich eggshell characteristics (thickness and porosity) on the weight loss and hatchability. They reported that while the porosity of the ostrich eggshell had a positive correlation with hatchability, the thickness had no meaningful correlation with hatchability. According to their findings, the eggs with thinner shells exhibited more weight losses. In addition, the eggs with healthy chick had more weight loss than the eggs with dead chicks. Therefore measuring this attribute of ostrich egg in a non-destructive manner is of great importance. Bamelis *et al*. (2008) used Acoustic Resonance Technique (ART) and light transmission through the hen egg as two non-destructive methods for measuring and predicting the conductance of eggshell. Because of the low correlation Coefficient (R = 0.67) obtained through this method and due to the higher thickness of ostrich eggshell, it is not feasible to employ it for measuring ostrich eggshell porosity and conductance.

Shafey *et al*. (2007) investigated the effect of the electrical field within the hatcher on the hatchability performance of hen egg. They observed that by applying an electrical field within the hatcher the hatchability improved, chick weight increased, egg weight loss during incubation increased and the early fetus death decreased.

As said, most of the studies on ostrich egg are intensive on hatchability performance; while hatchability is an attribute, which is only assigned to the fertility and hence cannot be applied on infertile eggs. The statistics gain from this study and others indicate that about 40 to 50% of ostrich eggs are infertile. Currently there is no direct, secure, safe and nondestructive method of recognizing fertile eggs form infertile ones. Thus, the chick producers are forced to put all the fertile and infertile eggs in the hatcher and only after approximately two weeks or more, the fertile eggs can be identified from infertile ones. Unfortunately, at this stage the infertile eggs are rotten, useless and therefore unprofitable. If there would be a nondestructive and simple method, with no need of any special and expensive equipment, which can be carried out by the growers on site, for fertility identification of eggs prior to entering the hatcher, without any serious damage, then it could prohibit the unduly occupation of the machine. In addition, due to the high quantity and quality nutrition value of ostrich egg, the infertile fresh eggs can be used for cooking or other industrial usage. This will make the ostrich farms more beneficial and from economical point of view more competitive with other sectors. Besides, measuring different properties of eggs could provide appropriate information for design, manufacturing and improvement of relevant machineries including hatchers and setters.

MATERIALS AND METHODS

The experiments and data collection were carried out in Binalud ostrich farm located the midway of Mashhad and Neyshabur cities in the Northeast of Iran. This farm had more than 1000 adult ostriches and about 1350 chicks of different ages. The eggs were daily collected and cleaned with a dilute formalin solution. The damaged eggs (cracked) were identified by visual inspection and removed from the intact eggs. The intact cleaned eggs collected during a week, were stored in a chamber with 120 eggs capacity, at 17 to 27°C.

The eggs placed upwards in the chamber (air cell on the top) with a 90 degrees swinging rotation with 2 h cycle. The eggs were coded with a three-digit number label (the authors were strongly prohibited of using any kind of marker or ink spray pen by the owner of the farm to prevent any unwanted effect on the fetus) and consecutively collected for three weeks, started from 8th June 2008. All necessary measurements were recorded for the stored eggs on Sunday and Monday of week. Totally 301 eggs were examined in this study (Fig. 1a, b).

For dimensional (major and minor diameters) measurements of the eggs, a simple apparatus was made which is shown in Fig. 2a, b. This unit comprised of a wooden base containing two vertical metallic plates with adjustable horizontal distance, inside. Each egg was firstly positioned inside the plates with longitudinal orientation to measure the major diameter and then with lateral orientation for its minor diameter. With this arrangement, the egg is positioned in such a manner that both diameters were correctly detected and then measured using a caliper with accuracy of ±0.1 mm. Without this

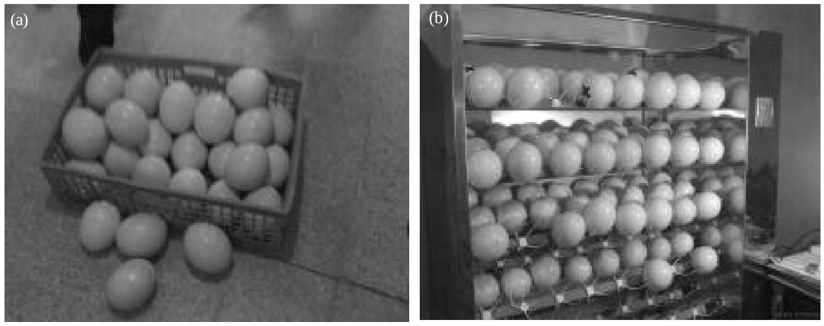

Fig. 1: Eggs preparation: (a) cleaning and separation of cracked eggs from intact eggs and (b) storage chamber with adjustable temperature and swinging mechanism

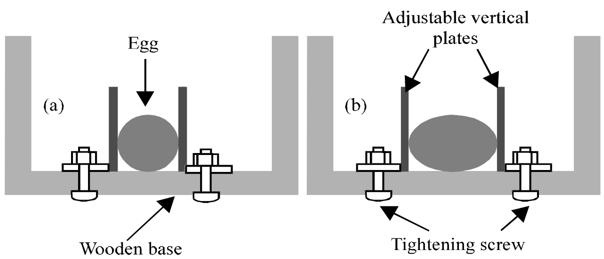

Fig. 2: The apparatus constructed and employed for dimensional measurements of eggs: (a) arrangement for minor and (b) major diameter measurement

measuring method finding the right place of the egg's diameters and hence their correct measurements were laborious and time consuming.

Having both diameters, the aspect ratio (A_r) of eggs was calculated to quantify the sphericity as follow:

$$A_r = \frac{D_{max}}{D_{min}} \quad (1)$$

where, D_{max} and D_{min} are major and minor diameters of egg in mm.

The egg weight was measured using a digital GF-6000 Japanese balance with accuracy of ±0.1 g.

Egg density: Density is one of the important properties of egg because it is an indirect explanatory of the egg's constitutive materials and the size of air cell, hence it can alter the egg fertility and hatchability. The egg density can be calculated by dividing the mass (weight) of egg to its volume. Since the protective layer of the eggshell is sensitive to water, by washing out the layer, the pores on the calcic shell are opened and the possibility of microorganism diseases increases, therefore the egg safety is at risk. This issue has limited the measuring of egg volume by employing the simple prevalent water submerging method as used for any irregular shape solid object.

Several attempts have been made to find a safe method of measuring egg's volume without any damage to the eggs. The outcome was an innovative and accurate method that has not been reported elsewhere. In this method instead of water, very fine, dry, smooth, cohesion less and uniform sand (known as sea sand) was used as a medium for measuring the occupied volume of the eggs. Firstly, it was necessary to measure the bulk density of the sand. In this procedure, a large enough container was selected and its volume was accurately measured by filling the container with distilled water and then weighted. Knowing that the distilled water density is exactly 1 g cm^{-3}, the weight (mass) of water in gram equals the volume of container in cm^{-3}. The volume of the container was measured with five replications and the average was used. Having known the volume of the container and the mass of the sand inside, the bulk density of the sea sand is calculated as:

$$\rho_{b_s} = \frac{m_c}{V_c} \quad (2)$$

where, ρ_{bs}, m_c and V_c are the bulk density of the sea sand (g cm^{-3}), the mass of sea sand inside the container (g) and the volume of container (cm^{-3}), respectively.

For measuring the occupied volume of egg, first one fourth of the container was filled with sea sand, the egg was placed inside the container and then the rest of container was accurately filled with sand. The container with egg inside and fully filled with sand was then weighted and hence the egg volume was calculated as follow:

$$m_{es} = (m_c - m_{ce}) - m_e \quad (3)$$

where, m_{es} is the mass of sand occupied by the egg volume; m_{ce} is the net mass of the fully filled container

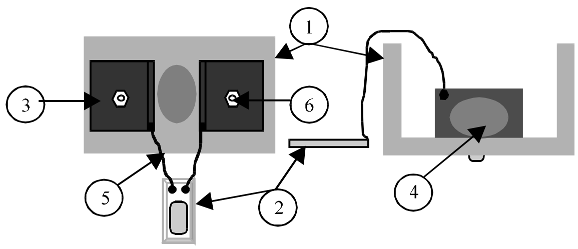

Fig. 3: The test rig for measuring dielectric property of eggs, right, side view and left, top view: (1) wooden box; (2) capacitance meter; (3) capacitor plate; (4) egg; (5) connecting leads; (6) plate tightening screw

with sand plus egg inside and m_e is the mass of egg, all in grams. Hence the volume of sand occupied by the egg, which is equal to the egg volume, is:

$$V_e = V_{es} = \frac{m_{es}}{\rho_{b_s}} \quad (4)$$

In this equation, V_{es} and V_e are the occupied volume of sand and egg volume, both in cm^{-3}, respectively. Knowing the egg volume, the egg density in g cm^{-3} is calculated as:

$$\rho_e = \frac{m_e}{V_e} \quad (5)$$

Egg dielectric property: Researches show that the dielectric property of materials has a high correlation with moisture content, molecular structure and constitutive material (Nelson, 2008). Hence, there might be a correlation between this property and egg fertility. For measuring the comparative dielectric property of eggs, a plate type capacitor was made with suitable dimensions. Each egg was positioned between the plates and the capacity of capacitor was measured in Pico Farad. The capacitor was made of two vertical conductive (aluminum) blades inside a box with 150 mm apart so that the largest egg can be place inside the plates. The aluminum sheets with 250 mm lengths, 150 mm width and one-millimeter thickness were used. This apparatus was placed in the egg storage room with a stable temperature and humidity condition. The egg positioned between the capacitor plates and the capacity was read in Pico Farad with the help of a Digital Capacitance Meter model TES1500, made in Taiwan as shown in Fig. 3.

Since, the eggs dimensions were varied and the distance between the capacitor plates was fixed, every time before placing the egg between the capacitor plates the meter was reset to zero so that the air between the plates do not affect the measurement and the reading would only be affected by the substance inside the egg.

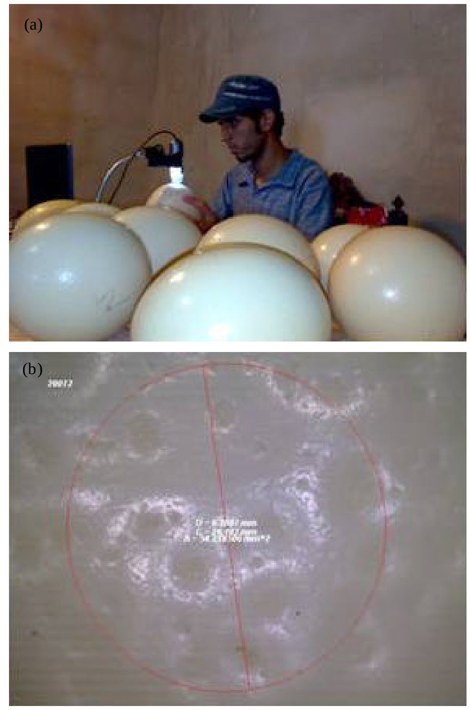

Fig. 4: Measuring porosity property of eggshell. (a) the digital USB microscope and (b) a typical image obtained by microscope; the selected area of interest is seen by a circle

Eggshell porosity: The eggshell has a direct effect on the health and safety of the semen and fetus. The shell should keep safety of fetus from mechanical damages and gains the necessary oxygen for the semen and fetus while prevent entering bacteria and diseases into the egg (Tullett and Deeming, 1982). Board and Scott (1980) found five different types of pore on the ostrich eggshell. The quantity and quality of the pores is an explanatory of the egg conductivity for different gases (oxygen and carbon dioxide) that enters and leaves the egg. In this project for measuring the pores of eggshell a digital DINO-LITE USB microscope model AM413T made by Mineralogical Research Company including DINO CAPTURE software with adjustable magnification up to 200 times was used. (Fig. 4a, b).

The microscope connected to the computer via USB port and could be handheld or used on a fixed stand. To measure the porosity, each shell is divided into three sections, top (adjacent to the air cell), center and below, each section was pictured with 120-degree sector interval around the egg; hence nine microscopic pictures were taken per egg. Each picture was then imported to the included software and an area of eggshell was randomly selected to calculate the porosity characteristics of eggshell. The pores inside the area of interest were counted and their diameter was measured. With these information the average pore diameter and the number of pores per unit area was calculated for each picture, section and the whole eggshell.

RESULTS AND DISCUSSION

Hatchability and fertility of eggs: Table 1 shows the final status of the studied eggs for hatchability, fertility and infertility. In general, 56% of the eggs turned into healthy chicks and for any reason 7% lost their hatchability (with dead chick). In other words, 63% (including the healthy and dead chicks) and 37% of the eggs were fertile and infertile, respectively. Table 1 shows that in the three consecutive weeks of egg collection, some variations in eggs performance are seen. The minimum fertility was observed in the second week with 63% and the fertility of the first and second weeks of egg collection was almost the same with 67%. The minimum hatchability of the eggs with 53% also belonged to the second week and the maximum with 64%, was observed in the first week. This shows a variation of 11% in hatchability.

Since all conditions such as feeding were unchanged and the ostriches were in an unsheltered place, it could be said that environmental factors and parameters such as temperature, humidity and light may affect the status of egg hence, needs more researches. It is recommended that the ostrich growers record the status of their eggs yearly and specify the best period regarding to hatchability and fertility. Besides, more researches are also required to investigate the effect of different environmental conditions and the characteristics of male and female ostriches on egg fertility and hatchability.

Eggs dimensional properties: As mentioned before, minor and major diameters and aspect ratio were considered and measured as dimensional properties of eggs. The results of these measurements showed that the minimum, maximum and average of minor diameter of eggs were 117.8, 144.0 and 133.2 mm, respectively and the corresponding values for the major diameter were 138.9, 196.0 and 160.2 mm. These values were separately determined for fertile eggs with healthy chick, fertile with dead chick and infertile eggs. For the fertile eggs with healthy chicks the minimum, maximum and average of minor diameter were 120.0, 143.4 and 133.4 mm, respectively. The corresponding values for the eggs with dead chicks were 126.4, 140.2 and 133.0 mm and for infertile eggs were 117.6, 144.0 and 133.1 mm, respectively. The average minor diameter of the fertile eggs (with both healthy chick and dead fetus) was 133.3 mm. According to these results, a very small difference is seen between the average minor diameter of the fertile and infertile eggs (about 0.1%). In other words, this property cannot be used as an effective criterion to discriminate between fertile and infertile eggs. The statistic analysis also showed that there is no significant correlation between egg fertility and the minor diameter.

Table 1: Final status of eggs after candling or hatching; all numbers are in percent

Date of egg collection	Final egg status: Healthy chick	Infertile egg	Fertile egg with dead chick
8th June	64	33	3
15th June	53	37	10
22nd June	59	33	8
All eggs	56	37	7

The minimum, maximum and average of major diameter of the fertile eggs with healthy chick were 138.9, 173.0 and 159.6 mm, respectively. The corresponding values for the eggs with dead fetus were 152.0, 168.4 and 158.5 mm and for the infertile eggs were 143.0, 196.0 and 161.4 mm, respectively. The average major diameter of the fertile eggs (with both healthy chick and dead fetus) was 159.5 mm. According to these results, the average major diameter of the fertile eggs was about 1% lower than the infertile eggs. In other words, the eggs with a lower major diameter should be preferred for chick production. However, the statistic analysis showed that major diameter also had no significant correlation with fertility.

The minimum, maximum and average of eggs aspect ratio were 1.108, 1.446 and 1.203, respectively. These values were separately determined for fertile eggs with healthy chick, fertile with dead chick and infertile eggs. For the fertile eggs with healthy chick the minimum, maximum and average of aspect ratio were 1.108, 1.319 and 1.197, respectively. The corresponding values for the fertile eggs with dead fetus were 1.128, 1.283 and 1.193 and for the infertile eggs were 1.133, 1.446 and 1.214, respectively. The average aspect ratio of fertile eggs (with both healthy chick and dead fetus) was 1.195. It is seen that the average aspect ratio of fertile eggs was about 1.5% lower than the infertile eggs. In other words, the eggs with a lower aspect ratio should be preferred for chick production.

For further analysis of aspect ratio data, the fertile and infertile eggs were categorized in five groups and in each group the frequency was determined as percent of total eggs which is shown in Table 2. The highest difference between the frequency of fertile and infertile

Table 2: Frequency (in percent) of fertile and infertile eggs based on aspect ratio of eggs

Egg aspect ratio	Fertile eggs	Infertile eggs
1.15	5.8	9.8
1.20	51.5	37.5
1.25	33.3	29.5
1.30	8.8	16.1
1.35	0.6	6.2

Table 3: Frequency (in percent) of fertile and infertile eggs based on egg weight

Egg weight (g)	Fertile eggs	Infertile eggs
1300	1.68	5.2
1500	27.30	20.5
1700	48.20	52.6
1900	21.10	19.6
2100	1.18	1.8

eggs was seen for the eggs with aspect ratio of about 1.2. In other words, the occurrence of fertile eggs in this group is about 15% greater than infertile eggs. On the other hand, the eggs with aspect ratio lower than 1.15 and higher than 1.3 showed a lower fertility and hence is not recommended for hatching purpose. However, statistical analyses indicated that there is no significant correlation between fertility and aspect ratio.

Gravimetric properties: As mentioned before weight, volume and density of eggs were measured as gravimetric properties. On the whole, the lowest, highest and average egg weights were 1118.5, 2011.8 and 1584.2 g, respectively. The average weight of the fertile eggs with healthy chick, infertile eggs and fertile eggs with dead chick were 1417.6, 1406.2 and 1339.7 g, respectively. However, this shows a negligible difference between the fertile and infertile eggs. For a closer examination, based on weight, the eggs were categorized in five groups including: 1300, 1500, 1700, 1900 and 2100 g. In each group the frequency was determined as percent of total eggs which is shown in Table 3. As seen, there is no significant difference between the frequency of fertile and infertile. However, with a closer look, it is seen that the light medium eggs with the weight of about 1500 g and medium heavy eggs with the weight of about 1900 g are preferred, because in these weight groups the percentage of fertile eggs is greater than the infertile ones.

The results of egg volume show that the average volume of all eggs was 1408.3 cm^3. The average volume of fertile eggs with healthy chick, infertile eggs and fertile eggs with dead chick were 1417.6, 1406.2 and 1339.7 cm^3, respectively. This indicates that the healthy eggs were 0.8 and 5.5% more massive than infertile and the fertile eggs with dead fetus, respectively. Based on egg volume, the fertile and infertile eggs were categorized in five groups including: 1100, 1300, 1500, 1700 and 1900 cm^3. In each group the frequency was determined as percent of total eggs which is shown in Table 4. It can be seen that the egg groups with an average volume of about 1700 and 1100 cm^3 have more fertile eggs than infertile ones, so these two groups are preferred for hatching purpose.

Table 4: Frequency (in percent) of fertile and infertile eggs based on egg volume

Egg volume (cm^3)	Fertile eggs	Infertile eggs
1100	2.9	1.8
1300	21.1	24.0
1500	48.2	50.8
1700	25.8	19.6
1900	2.0	3.8

Table 5: Frequency (in percent) of fertile and infertile eggs based on egg density

Egg density (g cm^{-3})	Fertile eggs	Infertile eggs
1.09	11.8	15.2
1.15	46.0	29.4
1.21	16.5	23.1
1.27	20.0	27.9
1.30	6.5	4.5

Table 6: Frequency (in percent) of fertile and infertile eggs based on their capacitance

Egg capacitance (pF)	Fertile eggs	Infertile eggs
2.0	4.1	8.9
3.5	72.0	70.6
5.0	20.6	17.0
6.5	2.7	2.7
8.0	0.6	1.0

The results of egg density showed that the average density for all eggs was 1.133 g cm^{-3}. This value for fertile eggs with healthy chick, infertile eggs and fertile eggs with dead chick were 1.136, 1.149 and 1.187 g cm^{-3}, respectively. As seen, totally, the fertile eggs with dead chick had a higher density. For a closer examination, according to egg density the fertile and infertile eggs were categorized in five groups including: 1.09, 1.15, 1.21, 1.27 and 1.30 g cm^{-3}. In each group the frequency was determined as percent of total eggs which is shown in Table 5. As seen, the eggs with density about 1.15 g cm^{-3} are the best eggs from hatchability point of view, because in this group of eggs, the frequency of fertile eggs is higher than the other groups. The frequency of fertile eggs with density of 1.3 g cm^{-3} also is higher than the infertile eggs, however as the overall frequency of this group of eggs is low, it does not have a great importance.

Dielectric property of eggs: The respective dielectric property of eggs was recorded as observed capacitance. The results showed that the average capacitance of total eggs was 3.035 pF. This value for fertile eggs with healthy chick, infertile eggs and fertile eggs with dead chick were 3.065, 3.057 and 2.975 pF, respectively. These results indicate that, as a whole, there is no significant difference between the dielectric property of fertile and infertile eggs.

As shown in Table 6, in both fertile and infertile eggs, about 70% of the eggs had 3.5 pF. However, with a closer

Table 7: Pore characteristics of eggs

	Egg part						Whole egg surface			
	Top		Middle		Bottom		Percent*		Diameter**	
Egg type	Percent*	Diameter**	Percent*	Diameter**	Percent*	Diameter**	Average	SD	Average	SD
Fertile (healthy chick)	7.78	802	6.97	862	7.11	814	7.20	0.43	826	41
Infertile	8.36	840	7.60	832	8.21	851	8.06	0.40	841	9
Fertile (dead chick)	7.94	776	6.76	798	7.64	862	7.45	0.61	812	44

*The pore surface as percent of whole egg surface. **The average pore diameter in μm

look at Table 6 it is seen that the eggs with about 2.0 pF are not suitable for hatching purpose as in this group of eggs the frequency of infertile eggs is higher than the fertile eggs. On the other hand, the eggs with capacitance ranged from 3.5 to 5 pF are the best eggs from fertility point of view. Nonetheless because there is no a meaningful difference between the frequency of fertile and infertile eggs, this property has the least correlation on egg fertility.

Eggs porosity: The quantity and quality of eggshell porosity affect the fetus health by providing good gas exchange (oxygen and carbon dioxide). This property was measured and studied through different parts of the eggs. In general, the average pore diameter of eggs was 785 μm and the average percent of pore surface as total egg surface was 7.2%. These two parameters at the top (near the air cell), middle and lower parts of the egg were 770 μm and 8.0%; 798 μm and 7.15%; 786 μm and 7.6%, respectively. In other words, the average pore diameter at the middle of eggs was higher than the top and bottom of the egg, but the total porosity was higher at the top of eggs.

The percent of pore surface and the average pore diameter on fertile eggs with healthy chick, fertile with dead chick and infertile eggs were measured and the results are shown in the Table 7. These values were 7.2 and 826 μm for fertile healthy eggs; 7.4 and 812 μm for fertile eggs with dead chick; 8.1 and 841 μm for infertile eggs. In other words, the lowest porosity observed in healthy eggs. This characteristic was 2.8 and 12.5% higher than healthy eggs in eggs with dead chick and infertile eggs, respectively. The average pore diameter of infertile eggs was higher than the healthy eggs; however, the difference was not significant.

As seen in the Table 7, infertile eggs had the lowest standard deviation for both average diameter and percent of pore surface with 9 μm and 0.40, respectively. In other words, the porosity of infertile eggs was more uniform (for both pore diameter and pore surface) than fertile eggs. For fertile eggs, although the average of pore diameter at the top and near the air cell was lower than the middle and bottom, the pore concentration (pore coverage) was high. For a closer look at the effect of eggshell porosity on egg fertility, the percent of pore surface and the average pore diameter were separately calculated for infertile and fertile eggs, which are shown in Table 8 and 9.

Table 8: Frequency (in percent) of fertile and infertile eggs based on pore surface as percent of whole egg surface

Percent of pore surface	Fertile eggs	Infertile eggs
4	15.7	7.5
7	34.7	36.3
10	33.9	30.0
13	9.1	22.5
16	6.0	3.5

Table 9: Frequency (in percent) of fertile and infertile eggs based on average of pore diameter

Average pore diameter (μm)	Fertile eggs	Infertile eggs
750	36.4	23.8
900	43.8	47.5
1050	14.0	22.5
1200	4.1	5.0
1350	1.7	1.3

As seen in Table 8, for about 70% of both fertile and infertile eggs, the percent of pore surface was between 7 and 10%. Since, there is no meaningful difference between the frequencies of fertile and infertile eggs, this egg characteristic therefore can not effectively be used for egg segregation of these egg groups. Nonetheless it is seen that, for the egg group with percent of pore surface about 4%, the frequency of fertile eggs is about 10% higher than infertile eggs and hence should be preferred for hatching purpose. On the other side, the eggs with percent of pore about 14% are the worst egg group for hatching.

Table 9 shows the frequency (%) of fertile and infertile eggs according to the average pore diameter (μm). As seen, the eggs with average pore diameter of about 750 μm are preferred for hatching, as the frequency of fertile eggs (37%) is higher than infertile eggs (23%).

CONCLUSIONS

The results of this project showed that about 63% of the eggs were fertile which out of this amount, for any reason, about 7% lost their hatchability and had a dead chick. Moreover, the fertility of eggs was affected by the period of egg production and collection. Hence, more investigations are required to specify the effect of environmental factors on fertility. Several properties of the eggs including, dimensional properties (minor and major diameters, aspect ratio); gravimetric properties (weight, volume and density) and eggshell pore characteristics were studied. Although, there was no significant correlation between these properties and egg fertility, nonetheless the frequency of fertile and infertile eggs in different egg groups showed that in some cases the frequency of fertile eggs was higher than infertile eggs. In general, egg groups with aspect ratio about 1.2, weight of 1500 g, egg density of 1.15 g cm^{-3} and average pore diameter of 750 μm showed higher frequency of fertile eggs than infertile ones. On the other hand, other properties including dielectric and egg volume exhibited the least variation between fertile and infertile eggs. Although the correlation between the studied properties of the egg and fertility was not significant, the other egg characteristics such as eggshell pigment and thermal photography are recommended for further investigations.

ACKNOWLEDGMENT

The authors acknowledge the financial support from Research Deputy of Ferdowsi University of Mashhad and also thank Dr. Sadeghi Nameghi for providing the digital microscope.

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