



## Investigating the Amount of Resistance to Break the Eggshell Under the Influence of a Strong Magnetic Field (MRI)

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### Abstract

Bird eggs should have high internal and external quality to maintain the economic life of the product and hence recognizing and understanding the factors affecting egg quality have great importance. In this experiment, 18 healthy eggs were selected and then exposed to a 1.5 Tesla magnetic field. After this stage, 6 samples of them were immersed in sunflower oil and stored for two days. In the next step, length and width, failure force, thickness and weight of eggshell were measured. Then, the amount of shell density, volume, spherical coefficient, and egg shape index were obtained using the desired formulas. Due to the effect of the calculated parameters on the failure force of eggshells, and in order to remove this effect, the calculated failure force was divided on the calculated parameter. The results of experiment showed that the highest ratio of failure force of eggshell on the parameters was related to the samples placed in the magnetic field and no immersed with sunflower oil. As in all cases was significantly different from control samples. The lowest amount was also attributed to control samples. In general, it was concluded that the presence of samples in the magnetic field increases the shell's resistance to failure, but samples that are immersed in sunflower oil had a lower failure force than those which are not immersed in sunflower oil. Finally, it can be concluded that with the presence of eggs in a high-power magnetic field, we can see an increase in the resistance force to the shell failure.

### Introduction

Eggs are one of the cheap but very nutritious foods which the health of the customer is directly related with its quality. Today, due to increased public awareness, the use of eggs as a source of essential amino acids is expanded. Egg quality is complex and its stability in storage, in addition to the chemical composition, includes egg size, the color and the quality of the shell, as well as defects such as the stain of blood and pieces of meat (Abdanan *et al.*, 2014). The egg industry around the world has an excellent quality of internal and external egg production that is essential for its economic life. Egg quality problems are currently causing huge costs in the industry. Therefore, there is a great deal of importance to understanding the factors which affect the internal and external quality of eggs (Roberts,

2004). Quality is defined as the property of food that is effective in accepting or refusing to consume it. Egg quality is a general term defined as the quality of the contents and the eggshell (Cutts *et al.*, 2007). Since eggs are a packaged food, the qualitative aspect and mechanical integrity of the shell is of great importance. The shell should be without any fracture and resistant to dynamic loads, impact and static compression during transmission. Eggshell resistance is determined by genetic, the age of laying hens, environmental factors such as food composition, diseases, climatic conditions, and farmer management. Therefore, breeders and nutritionists and egg producers are interested in quick checking and non-destructive measurement methods to monitor the properties of eggshell resistance (Coucke *et al.*, 1999; Ketelaere *et al.*, 2002). Also, the mechanical

properties of animal materials are one of the essential requirements for the design and efficient use of used equipment in transportation, processing, packing and storage of agricultural products. In a natural environment, shell eggs should be strong enough to prevent cracking eggs as well as weak enough so that if necessary they can be broken and thin enough to be able to exchange gas and thus maintain its contents. In this context, maintaining the power of the eggshell is necessary to prevent damage and preservation of eggs when moving from farm to market. The egg failure force depends on its different properties, such as specific gravity, weight, volume, surface area and thickness of the egg, shell weight and shell percentage (Ketelaere *et al.*, 2002; Jacob *et al.*, 2011). Egg size and shell thickness are strongly related to each other. As the weight of egg increases during production, eggshell thickness and failure resistance is usually reduced (Harms *et al.*, 1990). The quality of the egg depends on the size and weight of the egg. Egg properties such as shell shape index and thickness affect egg damage during transportation (Anderson *et al.*, 2004). Narushin *et al.* (2004) found a strong correlation between shell failure force and shell percentage (Narushin *et al.*, 2004). In Carter's research on eggs in 1976, he determined the relationship between shell strength and shape index (Carter, 1976). A number of researchers have examined the physical and mechanical properties of egg and Japanese quail egg by different compression loads. Breaking power as a direct variable to measure the strength of an eggshell is a difficult variable to measure, because only one measurement can be taken from each egg and heavily dependent on the speed of compression. However, there are technical and available data in the references on the mechanical behavior of eggs in different compression directions (Voisey & Hunt, 1969; Ketelaere *et al.*, 2002; Lin *et al.*, 2004; Narushin *et al.*, 2004).

So far, little researches have been carried out

on the effects of the magnetic field on the properties and behavior of the agricultural products as well as the physical, mechanical and biochemical properties of the eggs. In similar cases, the effects of the magnetic field on the growth of different plants have been evaluated. For example, Rio & Rio (2013) in research, it has been determined that the magnetic field causes faster growth of the olive plant. So that it has a positive effect on the height, length, diameter, weight, and the number of fruits in the olive bush and it can make it heavier and larger (Rio & Rio, 2013). Also, the magnetic field has had a positive effect on the growth of okra. It has reduced the incidence of pests and insects (Rio & Rio, 2013).

The purpose of this experiment was to investigate some of the physical and mechanical properties of eggs, under the influence of magnetic field and storage conditions. These features include dimensions, weight, volume, spherical coefficient, eggshell thickness, shape index, and breaking force of the eggshell.

## Materials and Methods

### Sample preparation and selection of treatments

18 healthy eggs were collected from an egg layer flock (Hyline W36 strain with 30 weeks of age) in a private company near the city of Gorgan, Golestan province, on October 13, 2018, and then transferred to Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. 12 eggs were placed in a magnetic field for 13 minutes, with 1.5 Tesla strength and then divided into two groups of immersed and non-immersed sunflower oil while the six rest eggs was kept without any treatments as control. In order to impregnate eggs, the oil was poured into a sack and smeared with cotton at the same rate. Sunflower oil was used due to its positive effect on durability and preservation of egg quality. Then the samples were stored for two days and the physical and mechanical properties were measured.



Figure 1. Magnetic resonance imaging device.

### Magnetic field

The magnetic resonance imaging (MRI) device (Alltech Echostar 1.5 T, Made in China) was utilized to apply a magnetic field to the samples. The MRI system consists of a magnet to create a strong magnetic field, send and receive coils of radio frequency, magnetic field gradients, a computer system, and accessories (Figure 1). 12 samples were exposed to a magnetic resonance imaging device to apply the desired magnetic field. The Transverse axis of the eggs was aligned with the longitudinal axis (z) of the magnetic field. Cardboard boxes were used to hold eggs during the process of stacking in the magnetic field.

### Physical characteristics of the eggs

After placement eggs in a magnetic field, half of the samples were impregnated with sunflower oil and then stored for two days. Then, the length (L) and width (W) of the eggs were measured using an electronic digital caliper with a precision of 0.01 mm. Volume (V), spherical coefficient ( $\phi$ ) and Shape index (SI) were calculated using Equations 1 to 3.

$$V = \frac{\pi}{6}(LW^2) \quad (\text{Equation 1; Mohsenin, 1986})$$

$$\phi = [(LW^2)^{\frac{1}{3}} / L] * 100 \quad (\text{Equation 2; Polat et al., 2007})$$

$$SI = (W / L) * 100 \quad (\text{Equation 3; Altuntaş & Şekeroğlu, 2008})$$

Where:

L: Length (mm), W: Width (mm),  $D_g$ : Geometric diameter (mm), V: Volume ( $\text{mm}^3$ ),  $\phi$ : Spherical coefficient (%), SI: Form index (%).

The eggshell thickness determined using an electronic digital caliper with a precision of 0.01 mm. Eggshell density (SD) was calculated using Equations 4.

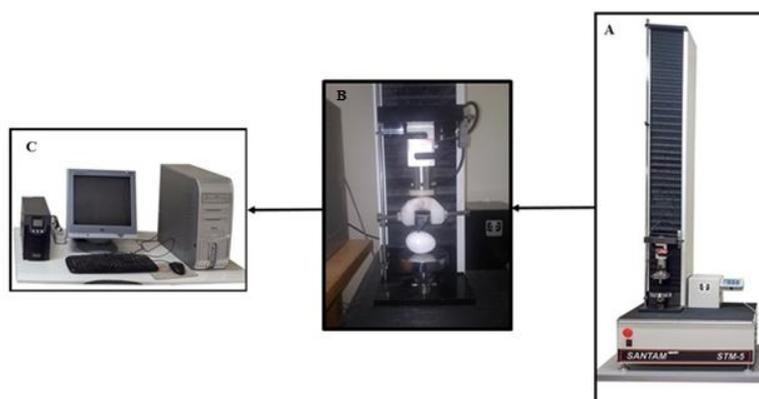
$$SD = \frac{SW}{S * ST} \quad (\text{Equation 4; Curtis et al., 1985})$$

Where: SD: Eggshell density ( $\text{g.cm}^{-3}$ ), SW: Eggshell weight (g), S: Surface area ( $\text{mm}^2$ ), ST: Eggshell thickness (mm).

### Quasi-static edge test

The required failure force of eggshells under quasi-static loading was investigated in three cases of impregnated specimens without impurities in sunflower oil under the magnetic field and control. Quasi-static loading indicates sample resistance to failure, so the extracted data is suitable for investigating the effect of magnetic field and impurity on sunflower oil.

For thin edge quasi-static testing was performed using an Indestron (Santam-STM5) device with a load of 500 N strain for the pressure test, the thin edge of a plastic jaw was considered with a surface of  $3 \times 15$  mm (Figure 2). In order to increase the accuracy of the measurement, the speed of the device when applying the pressure force was 0.33 mm/min, in the direction of the z-axis (Figure 3) and in three replications was performed, and as a result failure force of the eggshell was obtained. Loading was continued until the egg shell's failure, and then the force-extension diagram was drawn up by Instron and its data was extracted. The eggshell breaking force is determined by the force-deformation curve. So that in the shell breaking force, there is a large change in the force in the curve (Galić et al., 2017).



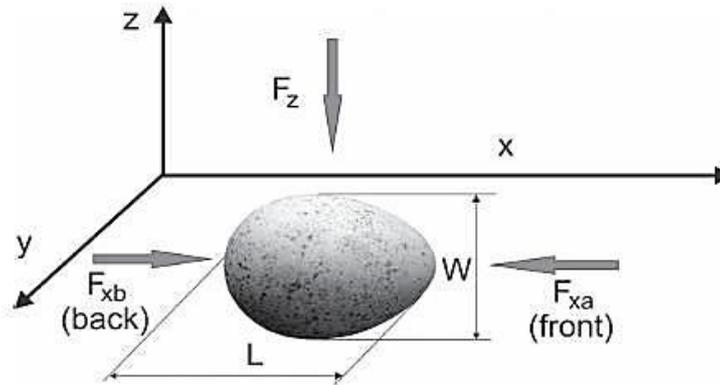
**Figure 2.** The quasi-static loading diagram of the egg.

A: Force-difomation device (Indestron); B: Eggs arrangement; C: Computer.

### Statistical analysis

Data were analyzed in a completely randomized design with SAS statistical software. Breaking force of eggs after 2 day storage was considered as resistance in breaking, while breaking force of the

eggs was considered as covariate for eggshell parameters (eggshell weight, eggshell thickness, egg volume, egg spherical coefficient, egg shape index, and eggshell density). Comparison of experimental data was performed by LSMeans.



**Figure 3.** A schematic view of the physical characteristics of the egg, for the input of different forces.  
L: Length, W: Width,  $F_{xa}$ ,  $F_{xb}$ : Force along the x-axis,  $F_z$ : Force along the z-axis.

### Results and Discussion

The results of the analysis of variance of the variables studied include control samples and magnetic fields (impregnated and not impregnated with oil) on the amount of eggshell breaking force. According to the

results obtained in this table, it can be concluded that the studied variables have a significant effect on the ratio of breaking force to the shell thickness, volume and spike coefficient of egg, and in the rest of the cases, no significant changes were observed.

**Table 1.** Effects of impregnated and non-impregnated variables on eggshell oil in a magnetic field on the amount of eggshell breaking force.

Variable	DF	Mean Squares	F value
The failure force ratio to eggshell weight	2	0.4791	7.09**
The failure force ratio to eggshell thickness	2	193.9777	9.19**
The ratio of failure force to egg volume	2	0.0093	14.63**
The ratio of failure force to the egg spherical coefficient	2	0.0046	3.11 <sup>ns</sup>
The failure force ratio to the egg shape index	2	0.0106	4.01*
the failure force ratio on the eggshell density	2	33867942.38	2.48 <sup>ns</sup>

\*\*Indicates a significant difference at 5% level; \* Indicates a significant difference at 1% level; ns indicates no significant difference.

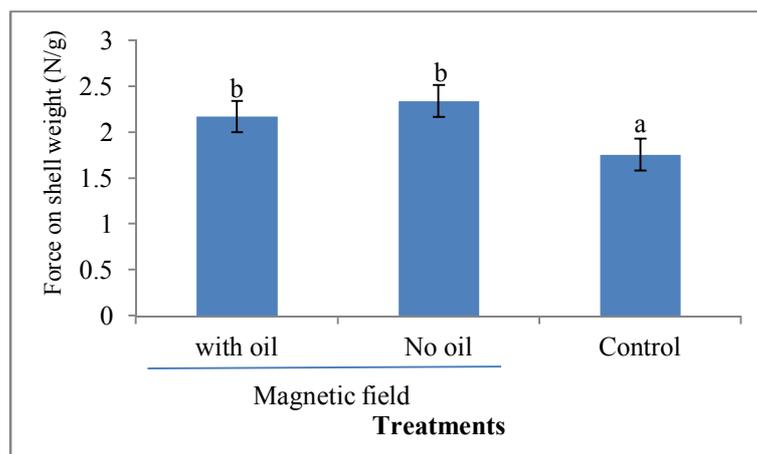
### Investigation of the failure force ratio to eggshell weight

Figure 4 shows the effect of different pre-treatments on the ratio of failure force on eggshell weight. Divide the amount of failure force by the eggshell weight can be attributed to the difference in shell weight of each sample and its possible effect on the amount of eggshell failure force. In fact, the effect of the difference in the shell weight on different samples is eliminated, and results can be verified with high confidence. According to the results, pre-treatment of the magnetic field has the highest ratio of failure force to eggshell weight. Also, the lowest value of the calculated ratio was for control samples. In the membrane, the eggs placed in the magnetic field will penetrate more water, thereby further exchanging water and carbon dioxide. Therefore, they have more airbag area and volume. Considering the correlation between the area or volume of egg airbags with the resistance to shell defects, the reason for this observation can be stated as follows (Nematinia *et al.*, 2017). Due to the lack of effect of storage time on eggshell weight in similar studies, it can be concluded that the observed changes in eggshell failure force

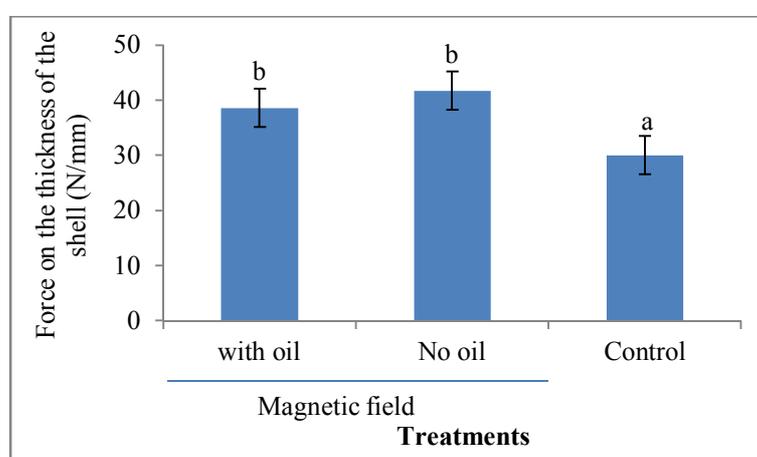
were due to the effect of a strong magnetic field on it (Nematinia *et al.*, 2017).

### Investigation of the failure force ratio to eggshell thickness

Figure 5 shows the effect of different modes of magnetic field pre-treatment on the value of the failure force ratio to the shell thickness of the egg. The reason for dividing the failure force by the thickness of the eggshell can be explained by the effect of eggshell thickness in the presence of the difference in shell failure force. According to the results, pre-treatment of the magnetic field has the highest ratio of failure force to the eggshell thickness and there was a significant difference between the control samples. Also, the lowest value of the calculated ratio is for control samples with a value of 25.998. Increasing the power of the magnetic field increases the reaction velocity to the deformation, or the viscosity of the solid (eggshell), and due to the direct relationship between the reaction speed and breaking force, the reason for this observation can be rooted in this reason (Kumagai *et al.*, 1978).



**Figure 4.** The effect of different pre-treatments on the ratio of failure force to eggshell weight. The same letters indicate no significant difference ( $P < 0.05$ ).



**Figure 5.** The effect of different pre-treatments on the ratio of the failure force ratio to eggshell thickness. The same letters indicate no significant difference ( $P < 0.05$ ).

#### Investigating of the ratio of failure force to egg volume

The effect of different magnetic field pre-treatments on the ratio of failure force to egg volume is shown in Fig. 6. As in the previous cases, due to the effect of measured parameters in determining the amount of its failure force, the failure force ratio was calculated on total egg volume. According to the results, the control samples with the lowest amount of 0.1293 and the samples of the magnetic field without impregnation with sunflower oil with a value of 0.2255 have the highest amount of failure force per egg volume. The reason for this observation can be attributed to the positive correlation between the volume of egg airbags and the resistance to failure of the shell. Egg bags placed in the magnetic field have the potential to absorb more ions, especially  $\text{Ca}^{+2}$ , and this increases the exchange capacity of water and carbon dioxide in the egg bag and thus increases the resistance to break egg shells (Kumagai *et al.*, 1978). Due to the lack of similar work with this research, it can be concluded that observing the changes in the eggshell defect due

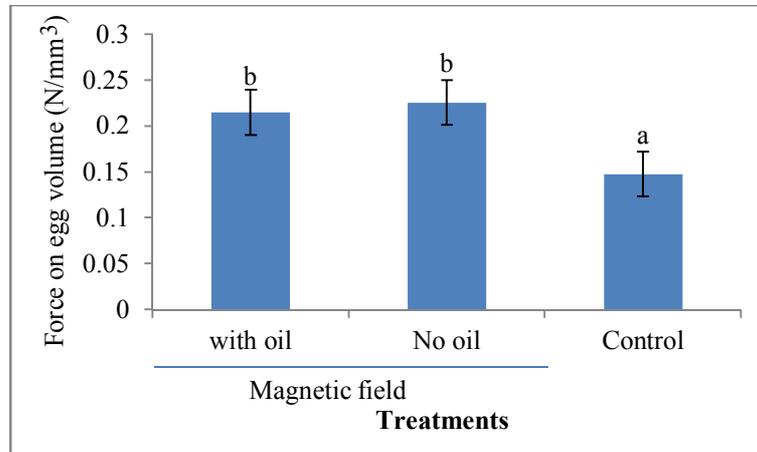
to the presence in the magnetic field can rely on the results of researches on the positive effect of the magnetic field on the plants agreed (Rio & Rio, 2013).

#### Investigating the ratio of failure force to the egg spherical coefficient

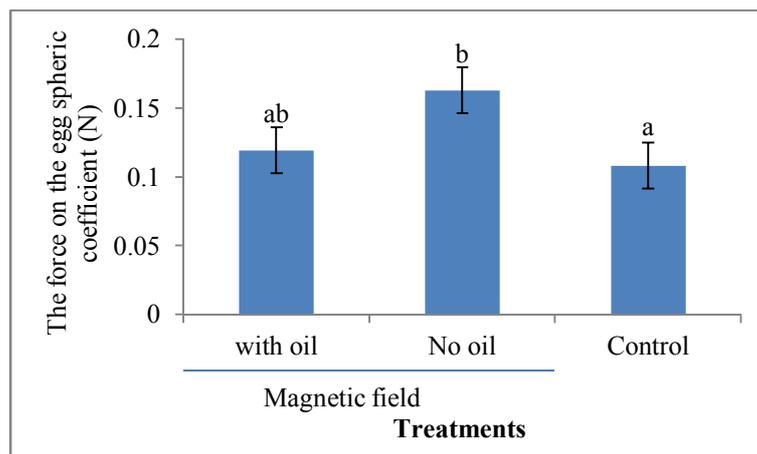
Figure 7 shows the effect of different magnetic field pre-treatments on the value of the failure force ratio to the eggshell spherical coefficient. Considering the effect of the spherical coefficient to the failure force and the necessity of eliminating this effect in the calculations, the ratio between failure force and spherical coefficient was calculated and shown in the graphs. According to the obtained results, the pre-treatment of the magnetic field has the highest ratio of eggshell failure force to the egg spherical coefficient. Also, the lowest value of the calculated ratio was for the control samples. Increasing the absorption power of  $\text{Ca}^{+2}$  ions due to the presence of egg samples in the magnetic field, resulting in a greater exchange of water and carbon dioxide that

causes an increase in the volume of a contained airbag in the egg. This increase in the volume of egg internal airbag is justified by other studies about the effects of magnetic fields on plants. Now considering

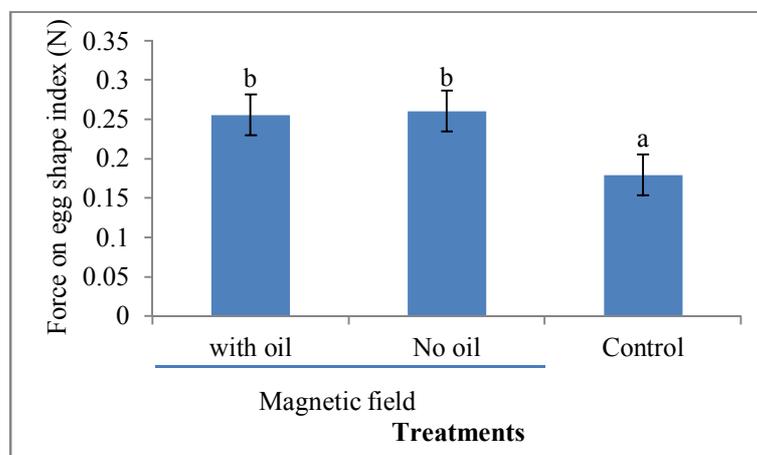
the direct relationship between the volume of the inner airbag and the resistance to breaking of the eggshell, the reason for this observation can be explained as follows (Selim & El-nady, 2011).



**Figure 6.** The effect of different pre-treatments on the ratio of failure force of eggshell to egg volume. The same letters indicate no significant difference ( $P < 0.05$ ).



**Figure 7.** The effect of different pre-treatments on the ratio of failure force of eggshell to egg spherical coefficient. The same letters indicate no significant difference ( $P < 0.05$ ).

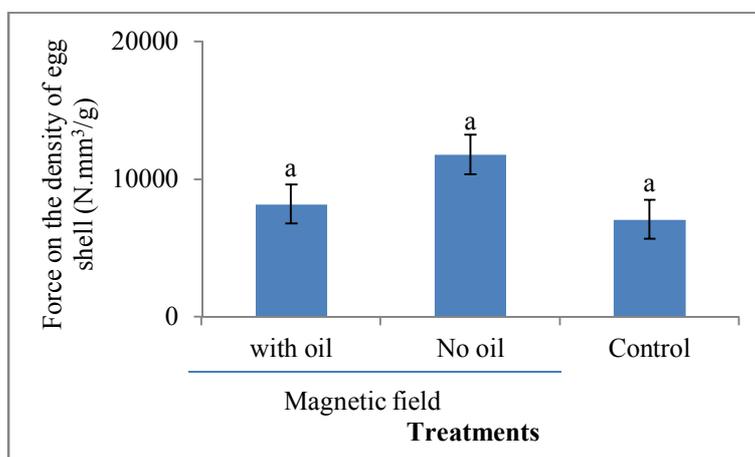


**Figure 8.** The effect of different pre-treatments on the ratio of failure force of eggshell on the egg shape index. The same letters indicate no significant difference ( $P < 0.05$ ).

### Investigation of the failure force ratio to the egg shape index

In Figure 8, the effect of different magnetic field pre-treatments on the amount of shell failure force ratio to the egg shape index is shown. According to the results, the control samples have the least amount of calculated ratio, and the magnetic field samples,

without impregnating with oil, have the highest fracture strength ratio on the eggshell shape index. These results are considered as positive results for increasing the strength of eggshell against failure, which can be attributed to the increase of water and carbon dioxide power exchange in eggs (Nematinia et al., 2017).



**Figure 9.** The effect of different pre-treatments on the ratio of failure force on eggshell density. The same letters indicate no significant difference ( $P < 0.05$ ).

### Investigation of the failure force ratio on the eggshell density

The numerical value of the effect of different pre-treatments on the ratio of the failure force on the eggshell density is shown in Figure 9. Due to the possible effect of eggshell density on the amount of failure force, a proportion of them is calculated to prevent its effect on the conclusion and dispersion of the quantities. According to the results, the pre-treatment of the magnetic field has the highest and the control samples have the least value of the failure force ratio to the eggshell density. An increase in the internal airbag contents of located eggs in the magnetic field and the direct relationship between the volume of the airbag and the size of the eggshell

failure force leads to this justification (Nematinia et al., 2017).

### Conclusions

It was observed that samples under the magnetic field have the highest ratio of force to the measured parameters compared to the control samples. Also, non-impregnated sunflower oil samples showed higher resistance to oil impregnated specimens than shell breaking. In general, it can be concluded that the application of the magnetic field increases the resistance to breaking the shell relative to the samples without a presence in the magnetic field after two day storage time.

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