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Research Article

Ultraviolet and infrared rays effects on some mechanical properties of oil-stained eggshells using response surface methods

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ABSTRACT- Today, due to increasing public awareness, the use of eggs as a source of essential amino acids in the human body has expanded. Since the egg is a packaged food, the quality and mechanical integrity of the shell are of great importance. In this study, a number of healthy eggs were selected and then exposed to ultraviolet (UV) and infrared (IR) radiation. After this step, half of the samples were smeared in sunflower oil and stored for 2 days. In the next step, the fracture force of the eggshell was obtained with the help of the Instron device. The results of this experiment showed that a number of levels of ultraviolet radiation factors were able to cause changes in the amount of fracture force of the eggshell. In the study of the effect of infrared light on the fracture force of the eggshell, it was observed that with increasing the number of bulbs and irradiation time, the amount of breaking force has also increased and this had a direct relationship with the factors of number of lamps and irradiation time. Also, in the study of the effect of infrared samples and impregnation of the shell with sunflower oil, it was concluded that impregnation of the eggshell with the oil reduces the amount of refractive force from 30.3 to 26.5 N. Finally, it was observed that the infrared samples had a higher average refractive index than the ultraviolet samples.

INTRODUCTION

Egg as one of the most essential nutrients in the household's diet contains four essential nutrients, including protein, fat, vitamins, and minerals (Mohammadi-Alasti and Abbasgholipour, 2015). The health of consumers directly depends on its quality. The use of egg in the daily diet has become widespread as a main source of essential amino acids. The quality of the eggs is complicated. In addition to chemical properties, the characteristics of stability during storage period including storage time, egg size, color, shell quality, as well as some disadvantages such as the presence of blood and pieces of meat inside the eggs are of particular importance (Abdanan Mehdizadeh et al., 2014). Since eggs are packaged food, the quality and mechanical integrity of the eggshell are essential. The eggshell must be non-fracture and more resistant to dynamic loads, impacts, and static compression during transmission. Eggshell strength is related to genetics, hen age, and environmental effects like food, disease, climate, and farmer management. So poultry firms, food experts, and egg producers are interested in measuring eggshell strength fast and non-destructively (Coucke et al., 1999; Ketelaere et al., 2002).

Mechanical properties of animal products are necessary for designing and applying devices that are used in processing, transforming, packing, and storing. In natural conditions, the eggshells should be strong enough to prevent breaking during farm to market transportation, or processing (Jacob et al., 2011; Ketelaere et al., 2002). Also, the shell should be weak enough to break when needed.

Ultra violet (UV) rays comprise eight to nine percent of the solar spectrum and are divided into three ranges: UV-A (320-400 nm), UV-B (280-320 nm) and UV-C (200-280 nm). Due to the short wavelength of UV rays, they have more efficient energy in tissues than visible light (Booij-James et al., 2000). The protein, DNA, photosynthetic pigments, biological membranes, photosystems, and herbal hormones are some of the UV-affected parts (Allen et al., 1998). The UV radiation can produce free oxygen radicals like superoxide anions, hydrogen peroxides, and hydroxyl radicals (Costa et al., 2002) which are very active, and they can react with biological polymers such as lipids, protein, nucleic acids. The free oxygen radicals can disrupt the normal functions of the cells (Bischof et al., 2002). The induction of antioxidant enzymes is part of the immune response. In addition to these types of reactions in many species, synthesis, and accumulation of some of the UV sorbents such as flavonoids and anthocyanin in the epidermal tissue, can prevent penetrating radiation to the internal tissues (Turcsányi and Vass, 2000).

Infrared radiation is water-absorbable, so by absorbing available moisture in the product, heat is generated uniformly inside the product with vibrations of water molecules. As a result, vapor pressure can transfer moisture to the surface, and the heat is removed by the environment easily (Afzal et al., 1999).

In 1976 Carter's investigation on an egg was able to find out the relationship between eggshell resistance and its shape index (Carter, 1976). In 2014, a study conducted on the eggshell indicated that the most muscular integrity was obtained between eggshell fracture force and weight percentage (Narushin et al., 2004). Some researchers have examined the physical and mechanical properties of the eggs of hens and the eggs of Japanese quail by different compression loads. Because only one measurement can be taken from each egg, and it is strongly dependent on the compression speed, egg breaking strength is a challenging parameter to measure eggshell strength. However, the technical information and egg mechanical behavior data exist in different types of compression (Voisey and Hunt, 1969; Ketelaere et al., 2002; Lin, 2004; Narushin et al., 2004). In another study, some of the physical and mechanical properties of eggs, under the influence of magnetic field and storage conditions, was investigated. In that study, it was observed that samples under the magnetic field have the highest ratio of force to the measured parameters as compared to the control samples (Mahmoodi et al., 2019). The purpose of this study was to investigate fracture force under the influence of UV and IR. According to this evaluation, the impacts of UV and IR on eggshell hardness could be determined.

MATERIALS AND METHODS

Samples preparation and treatment selection

Fifty six intact eggs were collected from an egg layer flock (Hyline W36 strain with 30 weeks of egg) in a private company near Gorgan, Golestan Province on October 13, 2018. Samples were then transferred to Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Twenty eggs were exposed to UV radiation and also another batch of 28 eggs was subjected to IR radiation. Next, each group was divided into two parts including sunflower oil-smeared, and non-smeared categories. Sunflower oil was used due to its positive effect on the shelf life and quality of eggs. (Jones et al., 2018). The samples were stored for two days and then their physical and mechanical properties were measured.

Moisture measurement

Due to the presence of various levels of moisture content in the produced eggs and in order to report the moisture level of the samples in the experiment and perform a comprehensive evaluation, the moisture contents of the samples were measured. To measure the moisture content of the samples, the internal contents of the eggs were prepared in a completely homogeneous manner and placed in drying containers (Aluminum containers). The complete drying process of the samples was performed for 24 hours at 105 ° C (Mahmoodi et al., 2020) (Azadbakht et al., 2016; Marsilio et al., 2000).

Ultraviolet radiation and infrared ray production method

As can be seen in Fig. 1. the UV light was produced by several LEDs. The LEDs were 3mm in diameter, 400 nm in wavelength and between 3-4 volts in voltage. The radiation type of the light source was UV-A. The distance between the UV light source and the egg samples was 40 cm. The lamps were powered by a 12-volt circuit and the UV area was 20 x 50 cm2.

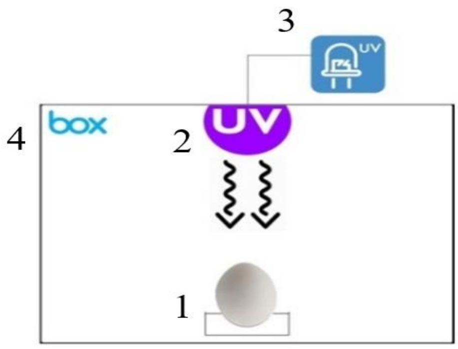

Fig. 1. Schematic view of the UV radiation rig
(1) Sample location; (2) light source; (3) lamp circuit; (4) radiation chamber

The data of the proposed model and shell fracture force that were used in the experiments are shown in Table 1. Each test number represents the selections or eggs in different conditions, the number of lamps, the radiation time, sunflower oil-smeared or non-smeared samples, and the output fracture force. The curve fitting was based on the quadratic polynomial.

Fig. 2. shows the source of IR light, and the egg radiation method. In this method, several IR LEDs were used. The specifications of LEDs were 3 mm in diameter, 940 nm in wavelength and 3.3-4 volts in voltage. The distance between the infrared light source and the samples was 40 cm. The circuit lamps had a power supply of 12 volts and the area of application of IR radiation was 50×20 cm2.

Quasi-static test

The required fracture force of the samples was investigated under quasi-static loading (number of LEDs, irradiation time and oil impregnation) and UV and IR irradiation. Quasi-static loading indicates sample resistance to failure, so the extracted data is suitable for investigating the effect of the IR and UV radiation and sunflower oil application.

Thin edge, quasi-static testing was performed using a universal tension and compression testing machine (Instron, Santam-STM5) with a capacity load of 500 N for the compression tests. The thin edge of a plastic jaw was considered with a surface of 3×15 mm2 (Fig. 3.). In order to increase the accuracy of the measurements, the loading rate of the device was set to 0.33 mm/min (Mahmoodi et al., 2019), in the direction of the z-axis (Fig. 4.), and three replications were considered.

In the next step, the breaking force of the eggshell was obtained. The focus of compression strength was chosen in the order of the z-axis due to the high vulnerability of the egg. Loading was continued until the eggshell failure, and then the force-extension diagram was drawn and its data was extracted (Mahmoodi et al., 2019). The eggshell fracture force was determined by the force-deformation curve. In order to determine this value, it was observed that when the shell breaks, a significant change in the amount of pressure will occur (Galic et al., 2018).

Table 1. The data of the proposed model and the shell fracture forces which were used in the experiments

Test number	Number of LEDs	Time (h)	Oil impregnation	fracture force (N)	Test number	Number of LEDs	Time (h)	Oil impregnation	fracture force (N)
1	40	3	Level 1	31.4	15	40	2	Level 1	25
2	40	2	Level 1	17.5	16	40	2	Level 1	33.2
3	40	2	Level 1	20	17	60	2	Level 2	28.9
4	20	2	Level 2	20	18	40	2	Level 2	27.7
5	40	2	Level 2	36.3	19	60	1	Level 2	8
6	20	1	Level 2	26.7	20	60	3	Level 1	24.2
7	40	2	Level 2	23.5	21	40	2	Level 1	28.7
8	60	3	Level 2	23.5	22	40	3	Level 2	33
9	60	2	Level 1	12.1	23	20	3	Level 2	30.3
10	40	1	Level 1	4.5	24	40	2	Level 2	21
11	40	2	Level 1	26	25	20	3	Level 1	18.9
12	20	1	Level 1	32.7	26	40	1	Level 2	36.1
13	60	1	Level 1	31.4	27	40	2	Level 2	40.2
14	40	2	Level 2	17.5	28	20	2	Level 1	33.6

Level 1 indicates the eggshell is not impregnated with oil
Level 2 indicates the eggshell is impregnated with sunflower oil.

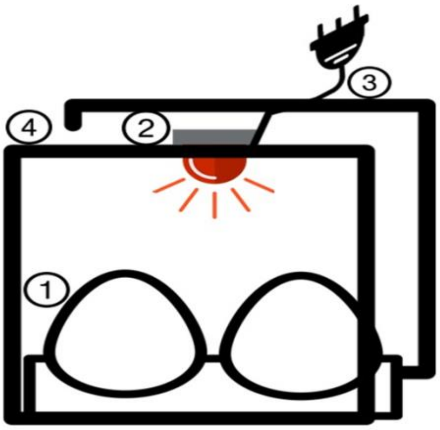

Fig. 2. A schematic view of the IR radiation method
(1) Sample location; (2) light source; (3) lamp circuit; (4) radiation chamber

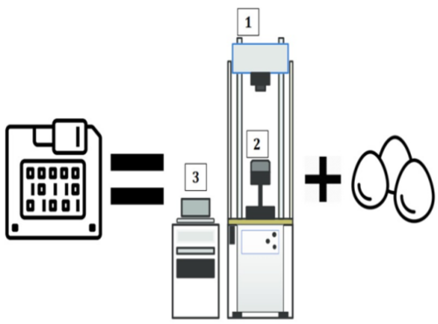

Fig. 3. The egg quasi-static loading diagram
(1) Universal Testing Apparatus (2) the location of the egg; (3) Computer device

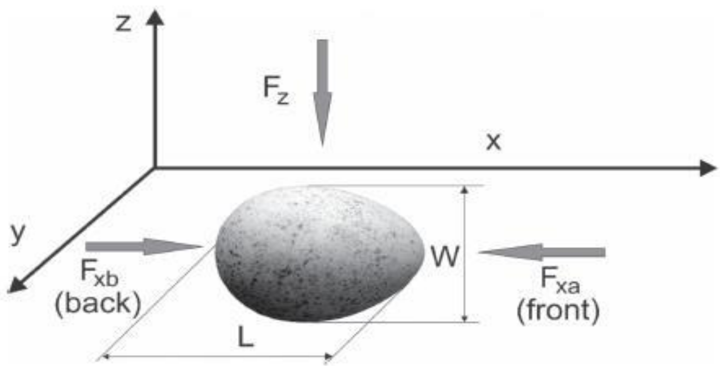

Fig. 4. A schematic view of the physical characteristics of the egg, for the input of different forces.

L: Length, W: Width, Fxa, Fxb: Force along the x-axis, Fz: Force along the z-axis. (Retrieved from Mahmoodi et al., 2019)

The proposed model and statistical methods

In this study, Design-Expert® software was used to predict the effect of UV and IR radiations on the mechanical properties of the eggshells. Determining the number of experiments, general design of the experiment and data analysis were performed by this software and response level method. The statistical design of the experiment was based on two numerical factors: the number of LEDs (n) and the duration of irradiation in each sample (t) and with a comparative factor (impregnated with sunflower oil or without stains). In this study, the central composite statistical design (CCD) was used. Actual and coded levels are shown in Table 2 to evaluate net errors. Twenty-eight tests were performed with six main points.

RESULTS AND DISCUSSION

Ultraviolet rays

The initial fracture force of eggshells due to the number of lamps, the radiation time, and the impregnation of the eggshell with sunflower oil has been shown in Fig. 5. As can be seen, different levels of the number of LED lamps and irradiation time could not have a significant effect on the refractive index. In other words, the values of the breaking force will remain unchanged in a certain range. This result, and the ineffectiveness of the pretreatments, might be due to the limited number of lamps used and the short duration of irradiation. However, according to research conducted before (Turtoi and Borda, 2014), it has been shown that UV treatment was effective for the inactivation of the bacterial population present on clean eggshells and recently contaminated shells. Combined treatments such as UV light with ozone or hydrogen peroxide (H2O2) improved the inactivation of microorganisms (Turtoi and Borda, 2014). But these effects could not have significant changes on egg samples in this study.

Fig. 6 shows the distribution error rates of the investigated data. According to this figure, it can be said that except for one case of fracture force which was predicted meaningless, other issues were plotted well and close to the standard error line. This indicates a low error of the proposed model.

Infrared rays

Fracture force variations as affected by the number of lamps and IR radiation (Fig. 7.) indicated that with increasing the number of lights and IR radiation time, the amount of fracture force increases. Higher levels of lights and IR radiation time resulted in decreasing eggshell moisture, strengthening hydrogen bonds, and increasing the bonds between protein and starch and other cell components. Finally, the mechanical strength of the eggshells increased and their plasticity was reduced. According to similar previous findings (Foutz et al., 1993), the reason for the results is thus justified,

Given the changes in factor C (oil smeared, listed in Table 2) and Fig. 8. smearing the eggshell with sunflower oil, reduces the amount of fracture force. The percentages of crude protein in smeared and non-smeared samples were found to be 30.3 and 26.5 N, respectively. The reason for lower percentage of protein is that by impregnating the eggshell with sunflower oil, the protective layer of the cuticle, which acts as a defense barrier (protects the egg from the entry of pathogenic microorganisms and dust) will be destroyed. Also, sunflower oil cannot play the role of an alternative coating. For this reason, the entry of pathogenic microorganisms and dust reduces the quality of eggs and, as a result, a lower level of the fracture force of the shell is obtained as compared to the no impregnation of the shell with sunflower oil. Considering the effect of infrared LEDs on moisture content, researchers in a similar study (Tang et al., 2020) examined the relationship between moisture and the breaking force required by rice grains . In this study, it was concluded that with increasing the moisture content of the product, the amount of breaking force has also increased. Therefore, in the present study, considering the role of infrared LEDs in reducing humidity, the resulting changes can be attributed to the same case.

CONCLUSIONS

This study showed that different levels of UV radiation on the samples did not change significantly in the amount of refractive force. More simply, UV rays couldn't affect the required fracture force of the eggshell. It was also observed that with increasing the number of LEDs and the time of infrared radiation, the amount of crust failure force increases. Therefore, there is a direct relationship between the number of lamps and the irradiation time with the amount of refractive power. Finally, by examining the samples under IR and UV rays, it was concluded that IR samples need more refractive force than UV samples.

Table 2. Independent variable surface test with response surface methodology.

Numerical Parameters		Unit	Levels			
Real	Encoded		-1	0	+1	+2
Number	A	-	20	40	60	-
Time	B	Hour (h)	1	2	3	-
Oil impregnation	C	-	-	-	No oil	With oil

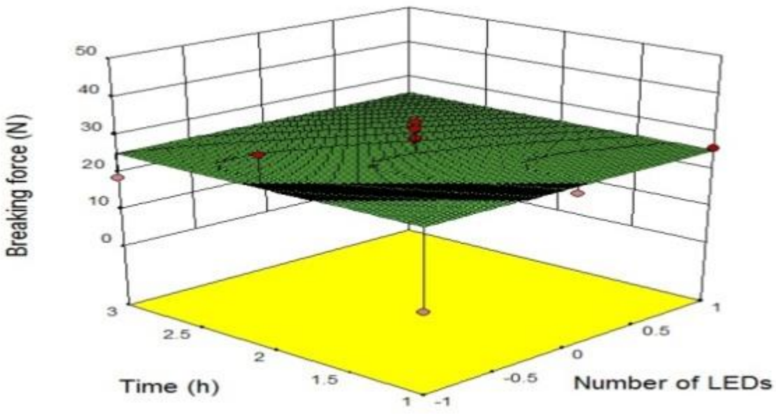

Fig. 5. Fracture force resulting from different levels of lamps and radiation time

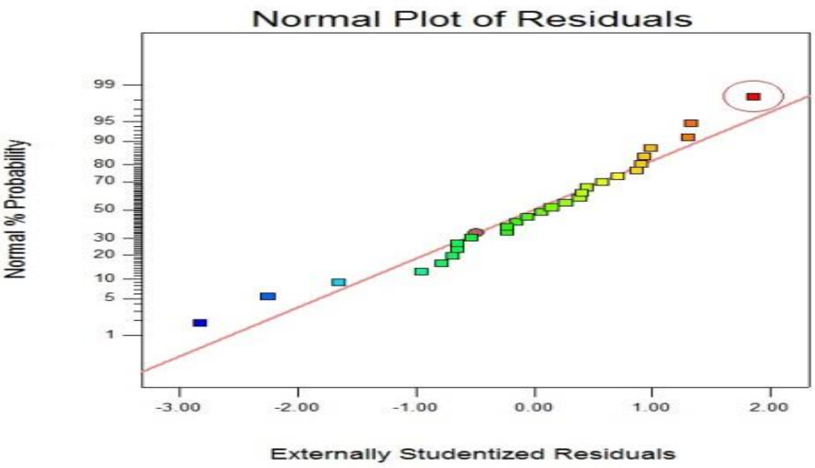

Fig. 6. Scattering of fracture force data

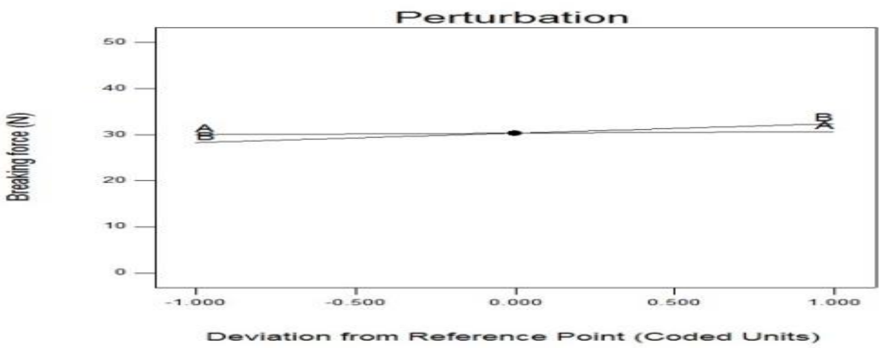

Fig. 7. Fracture force as affected by the number of lamps and the UV radiation time of LED

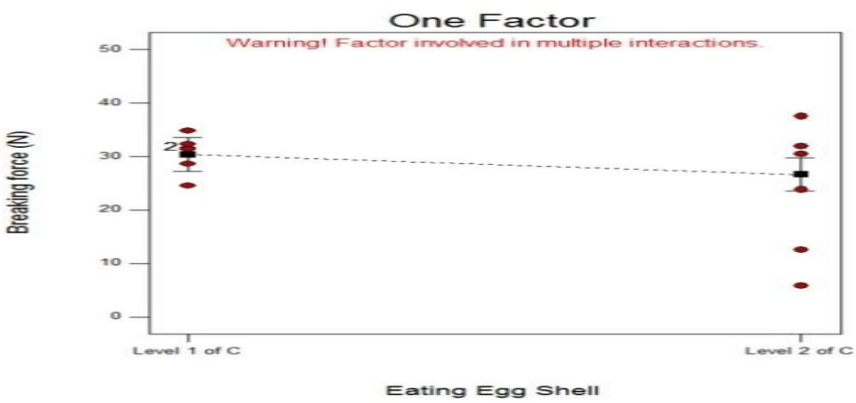

Fig. 8. The effect of sunflower oil impregnation on the amount of breaking force

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مقاله علمی- پژوهشی

تأثیر اشعه ماورابنفش و مادون قرمز بـر برخـی خـواص مکـانیکی پوسته تخم مرغ آغشته به روغن با استفاده از روش سطح پاسخ

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واژه‌های کلیدی:
تخم مرغ
پوسته تخم‌مرغ
نیروی شکست
مادون قرمز
ماورابنفش

چکیده- امروزه، به دلیل افزایش آگاهی مردم، استفاده از تخم‌مرغ، به عنوان منبعی از اسیدهای آمینه ضروری بدن انسان، گسترش یافته است. از آن جایی که تخم‌مرغ، یک غذای بسته‌بندی شده محسوب می‌شود، جنبه کیفی و یکپارچگی مکانیکی پوسته آن از اهمیت بالایی برخوردار است. در این تحقیق، تعدادی تخم‌مرغ سالم انتخاب شد و سپس تحت اشعه ماورابنفش و مادون قرمز قرار گرفت. پس از این مرحله، نیمی از نمونه‌ها به روغن آفتابگردان آغشته و به مدت ۲ روز در انبار نگهداری شدند. در مرحله بعد، مقدار نیروی شکست پوسته تخم‌مرغ، به کمک دستگاه اینستران بدست آورده شد. نتایج این آزمایش نشان داد که تعدادی از سطوح فاکتورهای پرتودهی ماورابنفش توانستند تغییراتی در مقدار نیروی شکست پوسته تخم‌مرغ به وجود آورند. در بررسی تاثیر نور مادون قرمز بر نیروی شکست پوسته تخم‌مرغ مشاهده شد که با افزایش تعداد لامپ و زمان پرتودهی، مقدار نیروی شکست نیز افزایش پیدا کرده است و دارای یک رابطه مستقیم با فاکتورهای تعداد لامپ و زمان پرتودهی بود. همچنین در بررسی تاثیر نمونه‌های تحت پرتو مادون قرمز و آغشتگی پوسته به روغن آفتابگردان، نتیجه شد که آغشتگی پوسته تخم‌مرغ به روغن، سبب کاهش مقدار نیروی شکست از ۳۰/۳ به ۲۶/۵ نیوتن می‌شود. در نهایت مشاهده شد که نمونه‌های تحت پرتو مادون قرمز دارای مقدار نیروی شکست متوسط بیشتری نسبت به نمونه‌های تحت پرتو ماورابنفش بودند.