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A non-contact measuring device for determining poultry eggs weight

Безконтактно измервателно устройство за определяне масата на птичи яйца

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ABSTRACT

In this article a possibility of application of the non-contact method for prediction the poultry eggs weight in storage period of 21 days was researched. A prediction assessment was made by shape features, capacitance, resistance and conductance of eggs. Feature vectors were selected and reduced data by principal component and partial least squares regression methods were used. A non-contact device was proposed and developed to determine the egg weight by video sensor and measurement cell. In order to obtain data for post-processing, a software application was designed. The developed algorithms and procedures were applied to determine the eggs weight, whereby that parameter of eggs could be predicted with the lowest relative error. The survey results show that the eggs weight could be predicted by the proposed system for contactless measurement with accuracy of 94-98%.

Keywords: video sensor, measurement cell, shape features, dielectric features, egg weight

РЕЗЮМЕ

В тази статия е проучена възможността за прилагане на безконтактен метод за прогнозиране масата на птичи яйца в период на съхранение от 21 дни. Направена е оценка на възможността за прогнозиране по признаци на формата, капацитет, електрическо съпротивление и електрическа проводимост на яйцата. Избрани са характеристични вектори и са използвани редуцирани данни при регресия по главни компоненти (PCR) и метод частична регресия на най-малките квадрати (PLSR). Предложено и разработено е безконтактно устройство за определяне масата на яйца чрез видео сензор и измервателна клетка. За получаване на данни за последваща обработка, е създадено програмно приложение. Разработените алгоритми и процедури са приложени за определяне масата на яйца, при което този параметър може да се прогнозира с най-ниската относителна грешка. Резултатите от изследването показват, че масата на яйцата може да се прогнозира чрез предложената система за безконтактно измерване с точност от 94-98%.

Ключови думи: Видео сензор, Измервателна клетка, Признаци на форма, Диелектрични признаци, Маса на яйца

INTRODUCTION

The prediction of eggs weight in poultry farming is related to the characterization of bird development, egg morphology, breeding capacity. In the production of eggs, the main studies on the prediction of egg weight are directed in relation to their sorting, incubation, packaging (Kokoszyński et al., 2013). The refinement of different methods of measuring and indirectly determining eggs weight is a major topic in available research (Aragua and Mabayo 2018; Vasileva et al., 2018). In recent years, machine vision techniques have been used to predict the eggs weight for sorting purposes (Alikhanov et al., 2017).

For the prediction of eggs weight, regression methods have been used to find a link between basic shape features of an egg and its weight. In other studies, the weight is predicted by groups of features, either directly or as obtained by methods of reducing the amount of the feature vector data. Regression models, as well as classification procedures such as k-NN, SVM, neural networks, ANFIS, were used to classify the eggs according to their weight determined by indirect methods using image-derived data. The accuracy of using regression methods is 77-98%. When using classifiers and feature vectors, the reported accuracy is 80-98% (Javadikia et al., 2011; Dangphonthong and Pinate, 2016; Quilloy et al., 2018). The prediction of the eggs weight, whether using regression methods or complex calculation procedures, is close in accuracy.

The analysis shows that suitable classification methods are those that use simplified calculation procedures and can be used in technical tools placed directly on the production line (Kudlackova et al., 2013; Kumar and Annamalai, 2014; Wang et al., 2014) because they accelerate the computational process and reduce the time for sorting eggs.

A common disadvantage of the methods presented in the available literature is that digital image processing methods are primarily suitable for fresh eggs. These methods of analysis do not take into account the impact of egg storage, whereby physical, biological and microbiological changes occur in them, which affect the eggs weight.

Transmission spectra in the visible and near infrared region were used to predict the change in internal egg characteristics (Titova et al., 2012). Also ultrasonic techniques (Pan et al., 2011).

As a method of predicting the internal properties of eggs, their dielectric properties are used, with the determination of dielectric constant and capacitance (Wang et al., 2009). A major drawback of studies related to the use of dielectric methods is that frequencies in the MHz and GHz bands are used. These waves are dangerous to human health. A solution to this problem is suggested by Soltani and Omid (2015) and (Soltani et al., 2015). The authors combine a machine vision system and a capacitor cell operating in the kHz range to determine changes in the external and internal properties of eggs during storage. A major disadvantage of the proposed system is that complex electronic circuits and a signal generator are used. This system is suitable for laboratory eggs analysis but is not suitable for direct application in industrial egg sorting systems.

The purpose of the article is to propose a system for predicting poultry eggs weight, taking into account changes in their characteristics during storage.

MATERIAL AND METHODS

A total of 108 quail eggs from three producers were used. 140 hen eggs from three producers too. The eggs were purchased from a commercial network in Yambol, Bulgaria. They are selected without internal and external defects. They are stored for a period of 21 days at 4±2 oC and a relative humidity of 46±3% RH. At 0, 7, 14 and 21 days of storage, measurements of eggs shape indices and dielectric properties were made.

The eggs weight are determined by a technical balance, with a maximum specified mass of 200 g and a resolution of 0.02 g.

A system consisting of two main modules - a module for obtaining shape indices and one for obtaining dielectric features of eggs - has been developed.

The module for obtaining of shape features consists of a video camera and a lighting system. The video camera is a Logitech C320 (Logitech). It is mounted in a protective housing, with protection class IP 54. The change in height is made with a movable stand with a maximum height up to 40 cm.

The lighting system is a dome type. The inside of the dome is covered with Pure White Matte RAL 9010 paint. The maximum diameter of the dome is 250 mm and height 110 mm. On the inside, two rows of white LEDs with a maximum light intensity of 450 nm, are mounted at the bottom and at a distance of 60mm from each other.

The quail eggs images were obtained at a height of 7.5 cm from the video camera to the egg and the images of hen eggs at a distance of 14 cm. The resulting images have a resolution of 640x480 pix. The size adjustment is made with a digital caliper, with resolution 0.02 mm. The k_d, mm/pix size correction coefficient is specified.

From the digital images obtained with a video camera are determined the shape indices of eggs. For that purpose, regionprops function in Matlab (The MathWorks Inc.) software environment is used. The designations are as follows: x_i, y_i - coordinates of the outline contour of the egg; x_c, y_c - coordinates of the center of gravity of the egg; θ = 0-2π; n-number of points in the contour of the egg; D - long axis; d – short axis; V_{sb} - volume of standard packing box; Radius, r; Area, A_{egg}; Perimeter, P_{egg}; Volume, V_{egg}; Ideal area, A_{ideal}; Area of bounding box, A_{mr}; Packing coefficient, K_v, in which the dimensions of the standard box are 300x200x100mm; Coefficient of form, K_f; Eccentricity, K_1; Ovality, c; Roundness, r; Area ratio, K_A; Area ratio, K_{AM}.

$$r_i = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2},\ i = 1, 2, ..., n$$

$$A_{egg} = \frac{1}{2}\sum_{i=1} r_i\, r_{i+1}\, n \sin \Delta\theta$$

$$P_{egg} = \sum_{i=1}^{n} \sqrt{r_i^2\, r_{i+1}^2\, n - 2 r_i^2\, r_{i+1}^2\, n \cos \mathit{\Delta}\theta}$$

$$V_{egg} = \frac{4}{3}\pi\, \frac{D}{2}\left(\frac{d}{2}\right)^2$$

$$A_{ideal} = \frac{\pi d D}{4}$$

$$A_{mr} = d\ D$$

$$K_v = \frac{V_{egg}}{V_{sb}}$$

$$K = \frac{P_{egg}^2}{\mathit{\Delta}_{egg}}$$

$$K_1 = \frac{D}{d}\,100$$

$$c = \frac{P_{egg}^2}{4\pi A_{egg}}$$

$$r = \frac{1}{c}$$

$$K_A = \frac{A_{egg}}{A_{ideal}}$$

$$K_{AM} = \frac{A_{egg}}{A_{mr}}$$

The module for obtaining dielectric properties of eggs consists of a single-board microcomputer, a humidity and temperature sensor and a capacitor cell.

A single-board microcomputer Mega 2560 (Kuongshun Electronic Ltd.) was used. A DHT11 sensor (Waveshare International Ltd.) was used to measure ambient temperature and relative humidity. The sensor measures relative humidity in the range of 20-90% RH, with an accuracy of 5% RH and a resolution of up to 1% RH. It measures temperature, in the range 0-50 °C, with an accuracy of ±2 °C and a resolution of 1 °C.

The capacitor cell for hen eggs consists of copper plates 0.63 mm thick, 80 mm long, 50 mm high. They are located 50 mm apart from each other. A second capacitor cell, suitable for measuring the capacity of quail eggs, has been developed, consisting of copper plates 0.63 mm thick and dimensions 50x30x30 mm (Length x Width x Height). Capacitance measurement library (Nethercott, 2018) was used to determine the capacitance of the capacitor cell. In this library, the capacity measurement is by the time constant determined at 63% of the full charge of the capacitor. The measurement frequency is 5 kHz.

Figure 1 shows a schematic diagram of a developed system for measurement of shape and dielectric characteristics of eggs. A video camera and a single board microcomputer are connected to the personal computer via USB interface. The lighting is provided by SMD3528-120/1 diode lighting, 6500K white IP65 (V-TAC Innovative LED Lighting), mounted in a dome-shaped two-row section, 8 cm form each other. The DHT11 humidity and temperature sensor and the capacitor cell are located in the dome. For communication with the DHT11 sensor, a pin D2 of the microcontroller connected via a pull up resistor 10 kΩ was used. The capacitor cell is charged via digital pin D7 and discharge and measurement via analog pin A2.

The temperature compensation of the measured capacity is made by determining the temperature coefficient α_{T25}. C_T, F is the measured capacity at temperature T; C_{25} - capacity at 25 °C. A compensation of measured capacity by relative humidity is made. C_1 is the capacity measured at RH_1; C_2 - capacity measured at RH_2 relative humidity. This compensation is required at a relative humidity of above 50 to 95% RH. The dielectric permittivity k, along the area of the electrodes A, m^2, the distance between them d, m and the dielectric permittivity of air ε_0 are also determined. Measurements are at frequency f=5000 Hz.

A coefficient of Υ_{EC25} is determined by which temperature compensation of conductance can be made. The electrical conductance has been determined. T is the temperature at which the measurement was made. EC_{25} is the electrical conductance after temperature compensation.

E_{CT} - conductance measured at temperature T, °C. An electrical resistance R is determined which is inversely proportional to the electrical conductance.

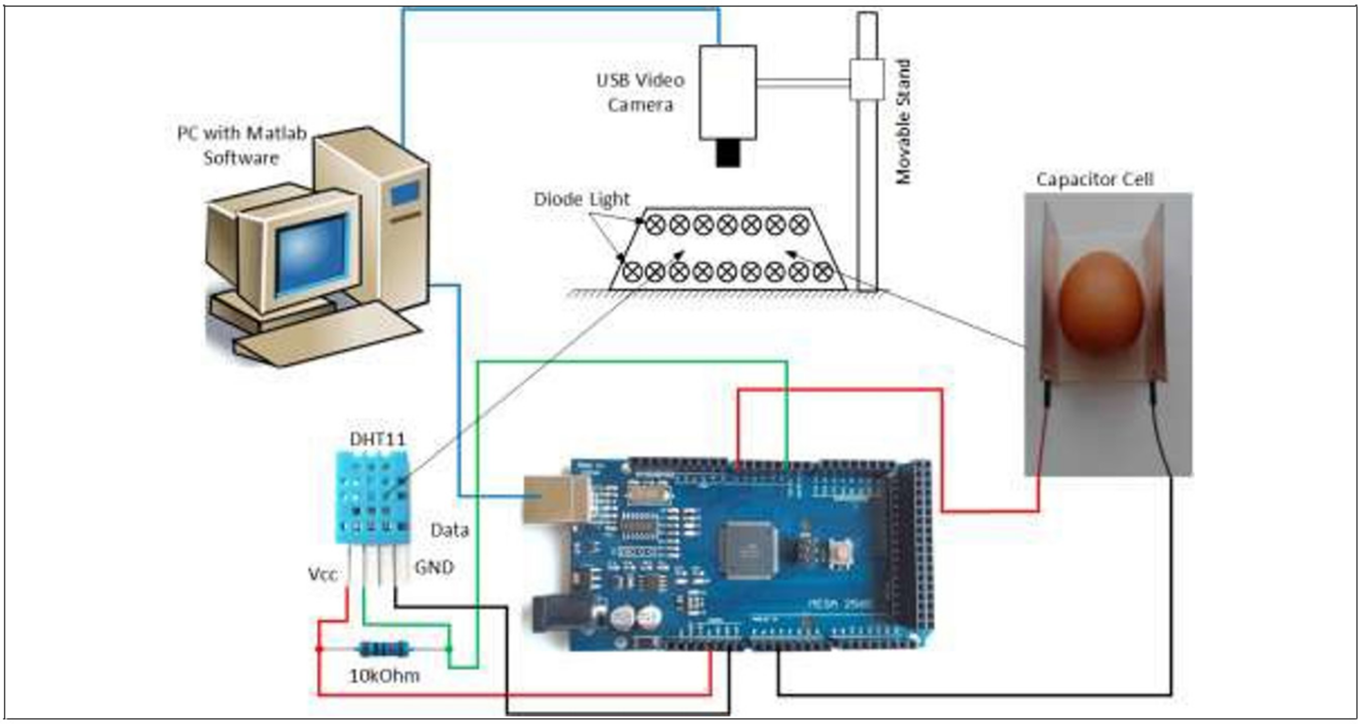

Figure 1. Schematic diagram of the developed measurement system

$$\alpha_{C25} = \frac{C_T - C_{25}}{C_{25}(T-25)} 10^6, \; ppm/^\circ C$$

$$k = \frac{\varepsilon_0 A}{c_d}$$

$$\beta_{RH} = \frac{2(c_2 - c_1)(RH_2 - RH_1)}{c_1 + c_2} 10^{-6} \; ppm \; \%RH$$

$$\gamma_{EC25} = \frac{EC_{T1} - EC_{T2}}{(T_1 - T_2)EC_{T1}} 100, \; \%/^\circ C$$

$$R = \frac{1}{2\pi f C}, \Omega$$

$$EC = \frac{1}{R}, S$$

$$EC_{25} = \frac{EC_T}{1 + \gamma_{EC25}(T-25)} S$$

The following methods were used to select egg parameters suitable for predicting their weight (Mladenov et al., 2015; Xu et al., 2018): Correlation method (CORR); Significant Prediction Parameter Method (RELIEFF); Method for selecting regression parameters by neighbor component analysis (FSRNCA). By these methods three feature vectors are selected, that are suitable for predicting eggs weight.

For data analysis the methods Partial least squares regression (PLSR) and Principal component regression (PCR) are used. The obtained model was evaluated by: coefficient of determination (R^2); root mean square error (RMSE), and the sum of squared errors (SSE) (Wang and Wang, 2017). All data used were processed at level of significance α=0.05.

RESULTS

Digital visual images and dielectric characteristics of hen and quail eggs were obtained. Shape indices and dielectric characteristics were selected by which the eggs weight could be predicted. Models were developed and analyzed with sufficient accuracy to describe the relationship between the selected traits and the weight of eggs.

Figure 2 shows a general view of the developed measurement system. The designations are as follows: 1-personal computer with software; 2-video camera in a protective housing mounted on a movable stand; 3-lighting system; 4-single bord microcomputer; 5-capacitor cell; 6-humidity and temperature sensor; 7-measured samples.

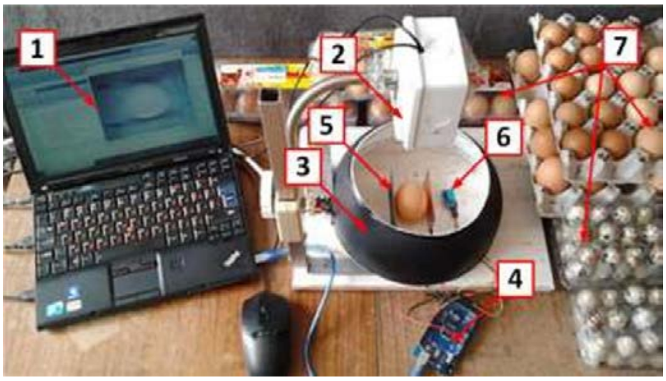

Figure 2. Measurement system - general view

Figure 3 shows the developed system operation algorithm. The algorithm consists of two main modules. The first module implements image acquisition, processing and analysis functions.

The resulting color digital RGB image is converted to HSV. An S(HSV) color component is used, which is converted to a black and white image. After enhancing the image, which involves removing small objects smaller than 1000 pix in size and clearing small holes in the egg area. The *regionprops* function determines the large, small axis and the area of the egg. Size adjustment is made by kd, mm/pix. In this way the egg shape indices are defined in mm.

The second module, implemented in a single-board computer, is used to obtain capacitance data, compensate it by temperature and humidity, and calculate electrical resistance, electrical conductance and dielectric constant. At temperatures other than 25 °C and relative humidity above 50% RH, the measured capacity is compensated. The dielectric features of the eggs are calculated.

Selected shape indices (SI) and dielectric indices (DI) are combined into a common feature vector (FV), which, after conversion to principal components or latent variables, can be used to predict eggs weight.

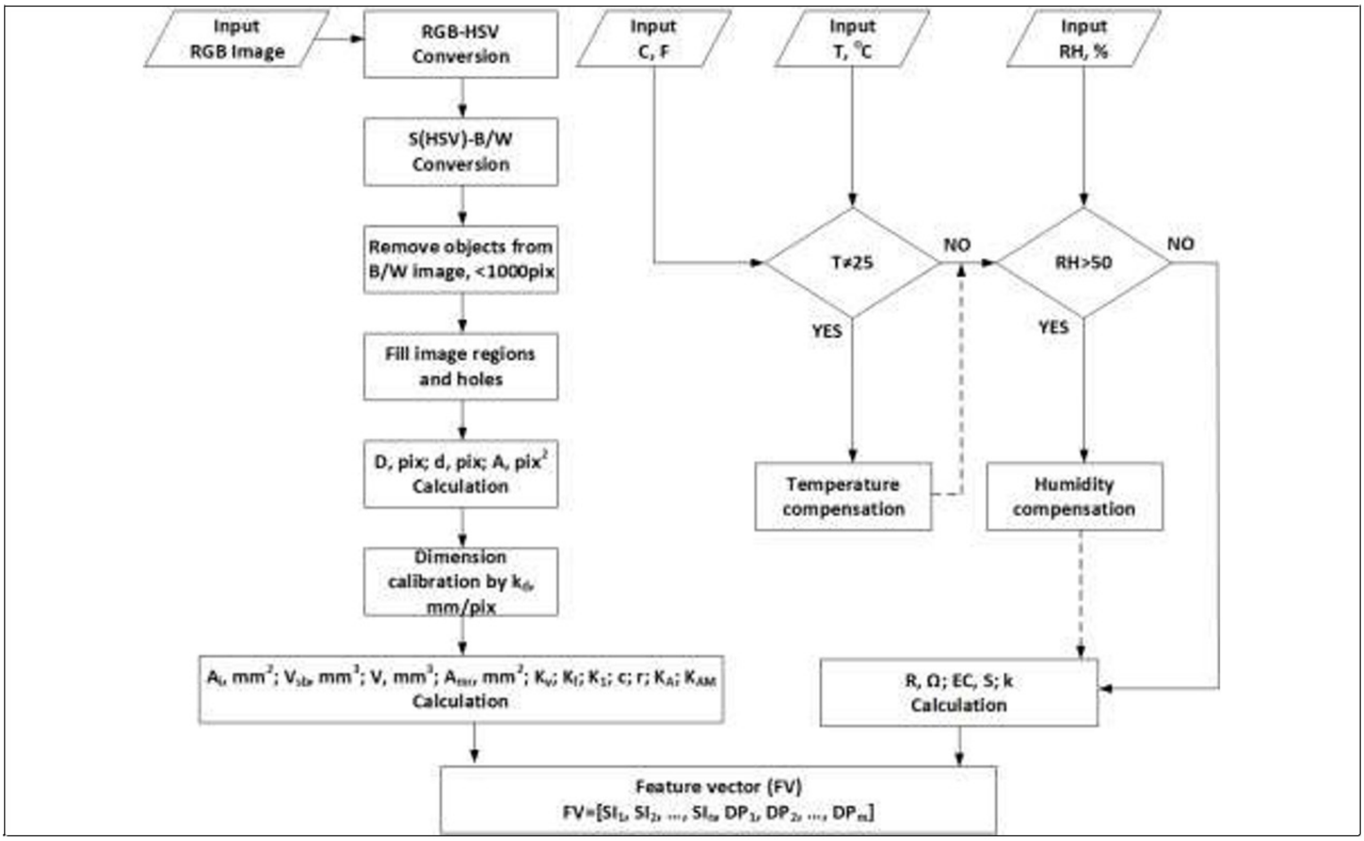

Figure 3. System operation algorithm

Feature vectors for hen and quail eggs were selected. They are reduced to two principal components and two latent variables. The values obtained were used to evaluate the ability to predict eggs weight of the two bird species.

The following feature vectors (HFV) for hen eggs are selected:

HFV_1=[A, P, A_i, V, A_{mr}, R, k];

HFV_2=[d, P, V, K_f, R];

HFV_3=[A, P, V, K_f, K_1, C].

Based on the data obtained, a model for 2 principal components was constructed, the results of the analysis are presented in Table 1. It is seen that when using all feature vectors, the coefficient of determination is R^2>0.9. This is maintained throughout the storage period of the eggs. High predictive ability stands out for feature vector HFV1 obtained by the CORR method.

Table 2 shows the results for the prediction of the weight of hen eggs by the PLSR method. These results coincide with those obtained by the PCR method.

Two latent variables are described with sufficient accuracy over 95% of the variation in feature vectors. Here again the HFV1 feature vector stands out because it shows high values of determination coefficient and low error values for the entire storage period. The approach used for analyzing hen eggs was also used for quail eggs. The following feature vectors (QFV) have been selected for quail eggs:

QFV_1=[D, A_i, A_{mr}, K_1, C, R, k];

QFV_2=[A, A_i, A_{mr}, C, R, K];

QFV_3=[A, V, A_{mr}, K_1, C, k].

Table 3 shows the results for the prediction of the weight of quail eggs by the PCR method. It can be seen that the prediction of the weight in the first days of storage is possible with a coefficient of determination above 0.9 and low error values. SSE is 2.8 to 7.4; The RMSE is 0.3 to 0.5. On day 21, the coefficient of determination was slightly above 0.8. Increases in error rates are also observed. Table 4 shows the results for predicting the quail eggs weight by PLSR method.

Table 1. Amendment of the parameters of PCR for hen eggs at different days of storage

Day of storage	Day 1			Day 7			Day 14			Day 21		
	Parameter											
Feature vector	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE
HFV1	0.73	0.98	0.14	0.54	0.98	0.12	0.66	0.98	0.13	0.89	0.97	0.15
HFV2	0.77	0.98	0.14	0.23	0.96	0.25	0.10	0.97	0.17	1.75	0.96	0.21
HFV3	1.56	0.96	0.20	0.26	0.92	0.26	0.20	0.96	0.23	2.64	0.94	0.26

Table 2. Amendment of the parameters of PLSR for hen eggs at different days of storage

Day of storage	Day 1			Day 7			Day 14			Day 21		
	Parameter											
Feature vector	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE
HFV1	0.73	0.98	0.14	0.54	0.98	0.12	0.66	0.98	0.13	0.89	0.97	0.15
HFV2	0.77	0.98	0.14	0.23	0.96	0.25	0.10	0.97	0.17	1.75	0.96	0.21
HFV3	1.56	0.96	0.20	0.26	0.92	0.26	0.20	0.96	0.23	2.64	0.94	0.26

Table 3. Amendment of the parameters of PCR for quail eggs at different days of storage

Day of storage	Day 1			Day 7			Day 14			Day 21		
	Parameter											
Feature vector	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE
QFV1	2.84	0.95	0.29	7.37	0.84	0.47	3.29	0.94	0.31	6.36	0.88	0.43
QFV2	2.90	0.95	0.29	6.28	0.92	0.43	3.45	0.93	0.32	8.49	0.88	0.50
QFV3	2.99	0.94	0.29	6.12	0.92	0.42	3.32	0.94	0.31	8.61	0.88	0.50

Table 4. Amendment of the parameters of PLSR for quail eggs at different days of storage

Day of storage	Day 1			Day 7			Day 14			Day 21		
	Parameter											
Feature vector	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE
QFV1	2.84	0.95	0.29	7.37	0.84	0.47	3.29	0.94	0.31	6.36	0.88	0.43
QFV2	2.90	0.95	0.29	6.21	0.92	0.43	3.45	0.93	0.32	8.48	0.88	0.49
QFV3	2.99	0.94	0.29	6.12	0.92	0.42	3.32	0.94	0.31	8.61	0.88	0.50

The results are consistent with those obtained by PCR. At least, a minimum decrease in the SSE error was observed on day 7 of the storage, while maintaining the determination coefficient values above 0.9.

Again on day 21, the predictive power of feature vectors decreases. The coefficient of determination is slightly above 0.8 and higher error values are observed than in the previous days. The highest predictive ability stands out for the QFV3 feature vector obtained by the FSRNCA method, because for the whole storage period it shows high values of the coefficient of determination and low errors values.

DISCUSSION

The results obtained show that, by the joint use of shape indices and dielectric characteristics, the weight of poultry eggs can be predicted during storage period with a constant value of the coefficient of determination (R^2=0.92-0.98). Quail eggs achieve the same accuracy except on the last day of storage where the coefficient of determination reaches R^2=0.88.

In the reported results of the available literature, predominantly large and small axis measuring instruments are used to predict eggs weight. Alkan et al. (2008) achieved a coefficient of determination of R^2=0.83. Using image acquisition, processing, and analysis systems, Alikhanov et al. (2017) improve the prediction rate by R^2=0.98.

Aragua and Mabayo (2018) also obtained results with a low error values (e<5%) compared to manual measurement. The disadvantage of these methods is that they are mainly suitable for fresh chicken eggs.

The changes in the internal characteristics of eggs are important since the external characteristics of the eggs do not change significantly during storage, whereas the change in egg weight decreases (Stojčić and Perić, 2018).

The method presented here is inferior to the prediction accuracy over those using neural networks and different type of classifiers (Javadikia et al., 2011; Soltani et al., 2015).

The disadvantage of these methods is that they use complex computational procedures and require long processing time, making them unusable for direct use on the production line.

CONCLUSION

Method and tools for eggs weight prediction have been proposed and developed, based on the basic indices of egg shape and dielectric characteristics, as well as on a set of ratios between them.

Prediction models for the weight of hen and quail eggs have been developed, depending on the storage time, which can be used to predict the weight change of these products depending on the storage period.

A comparative analysis of the models of the two types of poultry eggs was made. Similarity was observed for the hen egg models with errors not exceeding 10%. For these properties, it is appropriate to use average models for the whole group of tested products.

In quail eggs, the predictive power of the models used is reduced by more than 10% in the last days of storage.

After reducing the amount of data with principal components or latent variables, feature vectors containing area, perimeter, volume, as well as electrical resistance and dielectric permittivity may be used to predict hen eggs weight. Prediction of quail eggs weight is possible using a feature vector containing an area, volume, coefficient describing the ratio of the long to short axis of the egg, as well as capacity and dielectric permittivity.

The proposed method and tools take precedence over the known solutions in this field, since it takes into account the properties of quail and hen eggs by their dielectric characteristics, and not only by shape indices, which do not change significantly during storage of the product.

The results of the work could be used in the indirect determination of eggs weight in their incubation, packaging, sorting.

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