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https://doi.org/10.52973/rcfcv-e33268 Revista Científica, FCV-LUZ / Vol. XXXIII, rcfcv-e33268, 1 – 6

Storage Time prediction of Frozen Meat using Artificial Neural Network modeling with Color values

Predicción del tiempo de almacenamiento de carne congelada usando modelado de redes neuronales artificiales con valores de color

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ABSTRACT

Among the various methods available to determine the storage time of frozen meat, including analyses based on physical and chemical properties, sensory analysis, particularly color changes, is an important aspect of meat acceptability for consumers. In this study, an artificial neural network (ANN) was employed to predict the storage time of the meat based on the CIELAB color space, represented by the Lab* (L*), (a*), and (b*) values measured by a computer vision system at two–month intervals over a period of up to one year. The ANN topology was optimized based on changes in correlation coefficients (R^2) and mean square errors (MSE), resulting in a network of 60 neurons in a hidden layer (R^2 = 0.9762 and MSE = 0.0047). The ANN model's performance was evaluated using criteria such as mean absolute deviation (MAD), MSE, root mean square error (RMSE), R^2, and mean absolute error (MAE), which were found to be 0.0344, 0.0047, 0.0687, 0.9762, and 0.0078, respectively. Overall, these results suggest that using a computer vision–based system combined with artificial intelligence could be a reliable and nondestructive technique for evaluating meat quality throughout its storage time.

Key words: Beef meat; ANN modeling; color parameters; storage time

RESUMEN

Entre los diversos métodos disponibles para determinar el tiempo de almacenamiento de la carne congelada, incluidos los análisis basados en propiedades físicas y químicas, el análisis sensorial, en particular los cambios de color, es un aspecto importante de la aceptabilidad de la carne por parte de los consumidores. En este estudio, se empleó una red neuronal artificial (ANN) para predecir el tiempo de almacenamiento de la carne con base en el espacio de color CIELAB, representado por los valores Lab* (L*), (a*) y (b*) medidos por un sistema de visión artificial a intervalos de dos meses durante un período de hasta un año.La topología ANN se optimizó en función de los cambios en los coeficientes de correlación (R^2) y los errores cuadráticos medios (MSE), lo que resultó en una red de 60 neuronas en una capa oculta (R^2 = 0,9762 y MSE = 0,0047). El rendimiento del modelo ANN se evaluó utilizando criterios como desviación absoluta media (MAD), MSE, error cuadrático medio (RMSE), R^2 y error absoluto medio (MAE), que resultaron ser 0,0344; 0,0047; 0,0687; 0,9762 y 0,0078, respectivamente. En general, estos resultados sugieren qu'el uso de un sistema basado en vision por computadora combinado con inteligencia artificial podría ser una técnica confiable y no destructiva para evaluar la calidad de la carne durante su tiempo de almacenamiento.

Palabras clave: Carne de res; modelado ANN; parámetros de color; tiempo de almacenamiento

Received: 15/05/2023 Accepted: 06/06/2023 Published: 25/06/2023

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INTRODUCTION

Across the world, meat occupies a central place in diet. It is used in the preparation of a variety of dishes, from the most traditional to the most modern. It is associated with moments of pleasure and celebration, with family or friends. In this regard, freezing meat is a common and widespread practice in most families and is part of their preservation habits. However, even when frozen, meat is not an inert material; it is subject to changes in organoleptic properties (texture, taste, appearance), nutritional properties (oxidation of lipids and proteins), or structural changes during the freezing process itself [1].Sensory analysis provides a fast and reliable non-destructive alternative to analyze meat quality and shelf life. The main sensory attributes analyzed in such analysis are texture, flavor, and color. When determining shelf life during sensory analysis, color profiling is of particular importance [2].

Color analysis is a vital component in assessing food quality, and it can be performed through sensory evaluation by trained inspectors or using instrumental methods such as colorimeters. However, the subjectivity of human inspectors in evaluating color can lead to discrepancies between observers. To overcome this limitation, the International Commission on Illumination (CIE) proposed a standard color space known as CIELAB in 1976 [3]. This color space defines colors in terms of three coordinates: L* for brightness, a* for the red-green component, and b* for the yellow-blue component. L* ranges from 0 to 100, while a* and b* range from positive to negative. The adoption of the CIELAB color space allows for a more reliable and objective evaluation of food matrix colors. It is particularly useful for detecting color changes during storage and processing, making it a crucial tool for quality control in the food industry.

To predict meat storage time, mathematical models such as Logistic, Baranyi, modified Gompertz, square-root, Arrhenius model, interaction models, and generic models are used to analyze changes in bacterial growth with temperature fluctuations, according to Hansen *et al.* [4]. These mathematical models are precise and effective in forecasting meat storage time. However, in recent years, artificial neural networks (ANNs) have become increasingly popular in predicting changes that occur in meat quality and evaluation. For example, Zhu *et al.* [5] used a neural network to predict various qualities of dry-cured ham based on protein degradation. Similarly, Kaczmarek and Muzolf-Panek [6] used the ANN modeling technique to simulate variations in TBARS levels in the intramuscular lipid fraction of raw beef enriched with plant extracts. Additionally, Xu *et al.* [7] presented a neural network-based approach to anticipate changes in the quality of frozen shrimp (*Solenocera melantho*). In their recent work, Kaczmarek and Muzolf-Panek [8] used predictive models to monitor changes in the levels of the thiol group (SH) in raw and thermally processed ground chicken meat that had been enriched with selected plant extracts during storage at different temperatures. Other researchers, including Taheri-Garavand *et al.* [9] and Lalabadi *et al.* [10], have also used various ANN models to analyze the quality, production optimization, and sensory freshness of various food products. However, the use of computer vision systems as a non-invasive method for quality control of meat during its conservation is relatively new. For this reason, the aim of this research is to ascertain the potential of color values as a reliable method in the evaluation of frozen meat quality and to develop an ANN-based model for predicting meat storage time based on color values.

MATERIALS AND METHODS

Samples preparation

One hundred twenty samples weighing approximately 600 g were selected from the beef biceps femoris muscle slaughtered at the Municipal Slaughterhouse of Batna, in North Eastern Algeria, and the beef used was less than two years old. These 120 samples were taken 24 h after the slaughter. The fresh meat samples were analyzed on the same day, while the remaining samples were divided into six portions corresponding to the six freezing periods (2, 4, 6, 8, 10, and 12 months), with each period containing 20 samples. Noting that these samples have been vacuum packed in bags made of polyamide and polyethylene using vacuum packaging machine (Sealer Machine, China) and frozen at -23 ± 1.5°C (CRF-NT64GF40, Condor, Algeria). Temperature monitoring throughout the frozen storage period was conducted three times a day using a thermometer (TIA 101, China). Prior to photography, each frozen sample was thawed in a refrigerator (CRF-NT64GF40, Condor, Algeria) at a cool and constant temperature of 4 ± 0.6°C for 24 h.

The computer vision system for image capture consisted of a box and two lamps located 50 cm above the samples at an angle of 45°, whose purpose was to obtain a uniform light intensity on the sample. A digital camera (Canon DS126621,China) was also placed on top at a distance of 30 cm from the sample. To reduce the background light, the inner walls of the box are covered with an opaque black cloth [11]. Using Adobe Photoshop CS3, the color's clarity (L*), redness (a*), and yellowness (b*) were numerically assessed (FIG.1).

Application of Artificial Neural Networks for modeling

In order to create and utilize ANNs, certain characteristics were chosen. While there are numerous types of ANNs to choose from, a multilayer perceptron (MLP) was selected. FIG. 2 illustrates the schematic representation of MLP networks consisting of three layers: the input layer, hidden layer(s), and output layer [12]. Neurons in the input layer display three color variables for frozen/thawed meat. The output layer, which contains time storage, is complemented by one or more neurons in the hidden layer. The number of nodes in these layers is determined by trial and error, so there is no fixed rule for how many hidden layers or neurons are necessary (FIG. 2). The MATLAB interface was used during the design phase and optimization. During this study, well-known variable statistical indicators, namely R, MSE, MAD MAE, and RMSE, were utilized to evaluate the network's efficiency. To ensure a good fit between model approaches and target data points, the R value was employed. Meanwhile, MSE is a dependable measure to assess the accuracy of a developed procedure, especially when it comes to predicting errors for an external set of samples. Additionally, the MAD can be applied as a scale measure to account for individual differences and elucidate any correlations. Finally, both MAE and RMSE are used as evaluation metrics in prediction tasks to assess the accuracy of the predictions. Lower values of both MAE and RMSE indicate better prediction accuracy.

Statistical analysis

Statistical analysis was performed on the observed values using variance analysis (ANOVA) with SPSS software version 22 (IBM SPSS Statistics v22). The means were compared using the Tukey method. The difference was considered significant if the probability ($P<0.05$). Otherwise, the difference was considered insignificant ($P\geq0.05$).

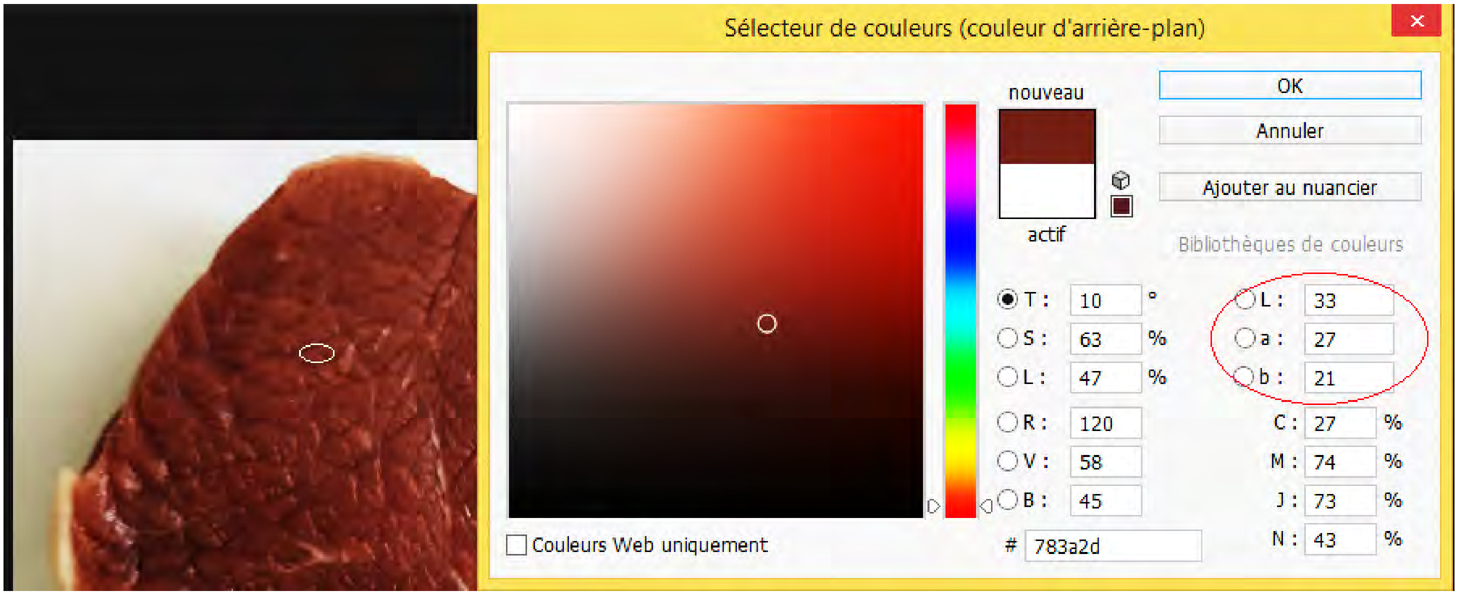

FIGURE 1. Utilization of Adobe Photoshop CS3 software for image analysis

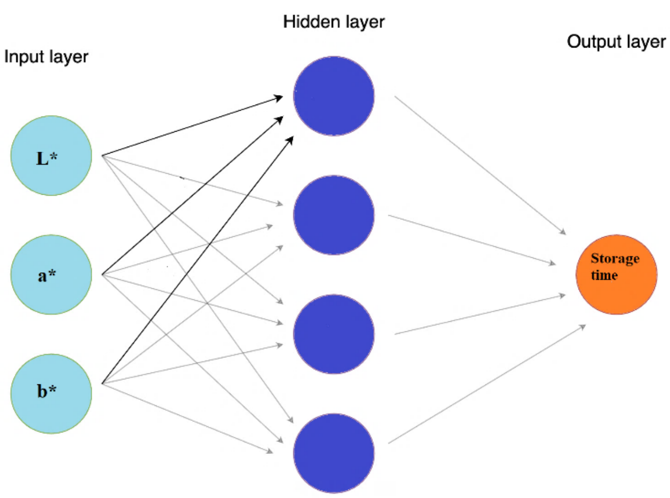

FIGURE 2. Schematic of the training process of the ANN

RESULTS AND DISCUSSION

Color evaluation

The color of meat has a significant influence on its appearance and market acceptability [13]. As shown in FIG. 3A, the L* value decreased significantly after 4 months of storage ($P<0.05$). Similar results have been reported by Muela *et al.* [14] and Muela *et al.* [15], where the L* values tended to decrease with prolonged storage time. The content and chemical state of myoglobin are important factors in determining meat color [15, 16]. Increased sensitivity to myoglobin oxidation during freezing could darken the meat color, resulting in decreased L* values [17, 18]. Other factors may also influence meat color, especially after long periods of storage, by promoting marked darkening with decreased luminance (L*), such as dehydration of the meat surface layer during long-term storage [20] or temperature fluctuation during the storage process [21].

By observing FIG. 3B, it was able to deduce that the (a*) values showed a significant decrease after 10 months of frozen storage ($P<0.05$), which is consistent with the findings of Hansen *et al.* [4] who noted a decrease in (a*) values after 30 months of frozen storage. Medić *et al.* [22], on the other hand, discovered decreasing (a*) values up to the 4th month of frozen storage, but an increase at the 6th month. Alonso *et al.* [23] suggested that denaturation of myoglobin during freezing could be the cause of the decrease in (a*) values. In contrast to the current results, Daszkiewicz *et al.* [24] did not detect any differences in (a*) values of frozen Kamieniec sheep (*Ovis aries*) meat samples for a period of 12 months.

The b* value was lowest in fresh samples and increased significantly with time, starting from the 6th month ($P<0.05$), reaching its highest value at 12 months of storage (FIG.3C). Studies have reported similar results, where meat (b*) value increased as the freezing period became longer, such as Hansen *et al.* [4]; Vieira *et al.* [25]; Fernandes *et al.* [19] and Coombs *et al.* [26]. It may be related to the accumulation of metmyoglobin and the increase in lipid oxidation as freezing time increases [13, 27].

ANN prediction model

Constructing an ANN model requires careful consideration when determining its topology. In this particular investigation, after many tests of different models, : it was considered considered the multilayer perceptron (MLP) with 60 hidden layers. FIG.4 shows the symbolic notation of the ANN-optimized model. The optimal number of neurons required to maximize R^2 and minimize MSE was identified through careful evaluation. R^2 and MSE values varied with the number of neurons up to 50, but adding 55 and 60 neurons produced the same R^2 value of 0.97. Similarly, MSE values varied independently of the number of neurons. A high correlation coefficient of 0.97 indicates a significant correlation between the variables used in the model development and optimization process (FIG. 4). The lowest MSE values were obtained with 60 and 55 neurons, while neuron 1 had the highest MSE of 0.070. Although the main goal of optimizing the topology is to maximize R^2 and minimize MSE, the highest R^2 and lowest MSE were

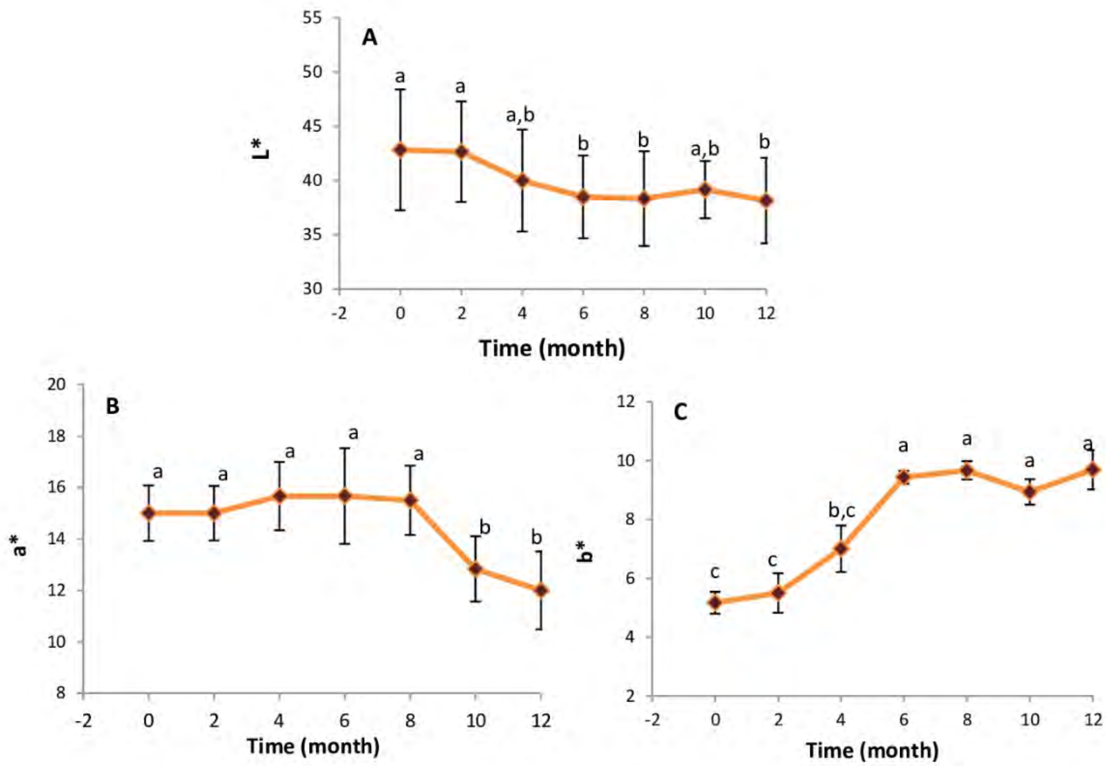

FIGURE 3. Effect Effect of time freezing on meat colorof freezing on meat color

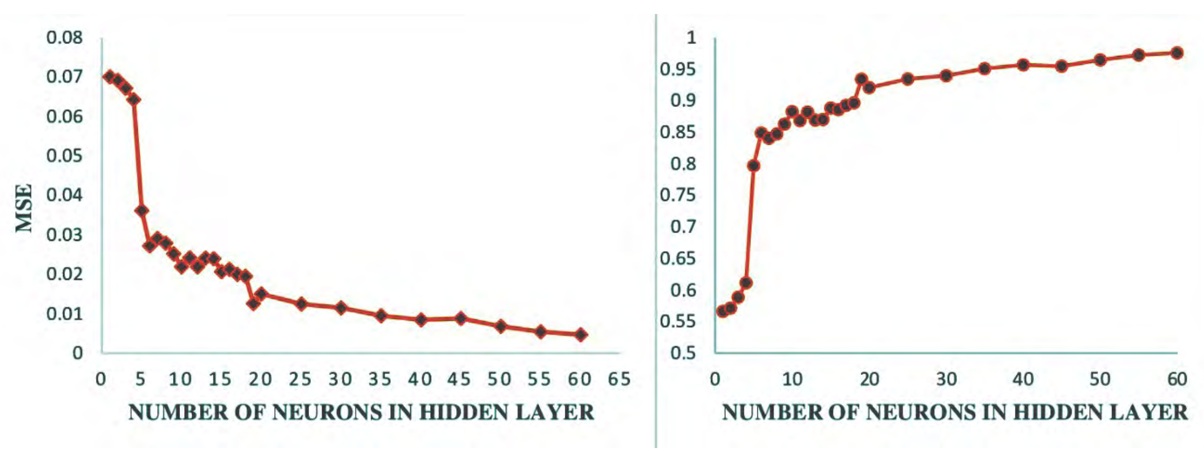

FIGURE 4. The variations in MSE and R^2 values in reacting to variations in the number of neurons in the hidden layer

achieved with 60 neurons, with the MSE value of 60 neurons being slightly lower than that of 55 neurons.

Previous studies have also shown similar results with a lower number of neurons. For example, Zhang *et al.* [28] reported that MSE values reached their minimum after adding 11 nodes to the hidden layer when constructing an ANN model for the hydrolysis of Newfoundland shrimp waste. The MSE values remained stable when adding additional neurons. In another study, Liu *et al.* [7] used an ANN model to predict changes in the quality of rainbow trout (*Oncorhynchus mykiss*) fillets. They built an ANN model and observed the lowest MSE values and highest R^2 values using only 6 neurons.

The ANN model developed in this study includes 60 neurons in the hidden layer. The model's performance is evaluated using several measures, such as MAD, MSE, RMSE, R^2, and MAE. All of which are measures of error or precision. The values of these measures for the test data are presented in TABLE I.

TABLE I
Assessing the Effectiveness of Artificial Neural Networks (ANN)

MAE	R^2	RMSE	MSE	MAD
0.0078	0.9762	0.0687	0.0047	0.0344

MAE: Mean absolute Error, R^2: Correlation Coefficient, RMSE: Residual Mean Squared Errors, MSE: Mean Squared Errors, MAD: Mean Absolute Deviation.

The results show that the developed ANN model has been successfully validated according to performance criteria, indicating that the model's predictions are in good agreement with the observed data.

CONCLUSION

Using color values (L*, a*, and b*) to predict the storage time of frozen meat through an artificial neural network has been proven to be an accurate method. The results of the study validate the developed ANN model, as it has shown good agreement with observed data based on performance criteria. Unlike physico–chemical and microbiological analysis, color measurements are non–destructive, less time–consuming, and do not require preliminary training for evaluation. Hence, this study utilized color measurements to estimate the storage time of frozen meat for a period of 12 months. It is important to note that the combination of ANN models and color parameters as inputs has great potential to accurately and quickly predict the storage time of meat, providing a reliable method for predicting the shelf life of meat.

Conflicts of interest

The authors declare no competing interests.

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