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Effects of electrical field stimulation on the physicochemical and sensory attributes of aged chicken meat

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Abstract

Various physical, chemical, and biological practices have been adopted in the meat industry to enhance the tenderness of aged chicken meat. Among these, electrical field stimulation is used as an innovative tool in enhancing meat quality. Purposely, the present study was designed to evaluate the effectiveness of electrical stimulation (ES) on different quality attributes (chemical, physical, & sensory) of laying aged chicken (*Gallus domesticus*) carcasses. To assess the effect of ES on meat quality of aged chicken (1.5 years), a total of 54 birds were slaughtered and their respective carcasses were subjected to electric field strengths (EFSs) of 3.67 and 7.33 V/cm. Physicochemical and sensorial characteristics of the ES-treated groups (3.67 and 7.33 V/cm) and control group (without ES) meat were compared during the storage periods 0, 30, and 60 days. The results revealed that the electrical conductivity and specific energy consumption increased significantly with an increase in the EFS. ES significantly ($p < .05$) decreased peroxide number (by 12.62%), free fatty acids (FFA; by 13.46%), drip loss (by 4.25%), and cooking loss (by 50.85%), and increased pH (by 5.90%). Besides, ES-treated samples showed significant superiorities in terms of sensory characteristics in comparison with control samples. An artificial neural network (ANN) gave a good fitting to predict the development of peroxide value and FFA during storage.

Practical applications

Electrical stimulation (ES) has been studied as a means to reduce the time required for aging to prevent meat hardness. ES improves the tenderness of meat by reducing

Abbreviations: ANN, artificial neural network; B, number of millimeters of KOH smeared with the plank sample; CL, cooking loss (%); DL, drip loss (%); EFS, electric field strengths (V/cm); ES, electrical stimulation; FFA, free fatty acids (%); I, current (A); L, distance between electrodes (m); m, mass of chicken (kg); PV, peroxide value (meq/kg); R.L.S.D, revised least significant difference; S, cross-sectional area (m^2); SEC, specific energy consumption (kJ/kg); t, operating time (s); U, voltage (V); W, weight of sample (kg); W_1, sample weight after 48 h (g); W_{ac}, weight after cooking (g); W_{bc}, weight before cooking (g); W_o, original sample weight (g); σ, electrical conductivity (S/m); φ, number of milliliters of KOH swabbed with the oil or fat sample.

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cut values, increasing the sarcomere length, and reducing the diameter of muscle fibers. The application of ES helps in reducing the storage time, storage cost, de-feathering force, and microbial load on a chicken carcass. Aged chicken meat carcass can be treated by ES before storage to help meat processing industries for storing meat safely. This study aimed to investigate the use of ES to improve the qualitative and sensory characteristics of aged chicken meat carcass during storage periods.

1 | INTRODUCTION

Globally, the demand for poultry meat has escalated, and therefore poultry production has become a substantial economic business. Tenderness is one of the most important eating quality traits, which significantly influences customer purchase of a poultry product. Meat tenderness is dependent on several connective tissues in muscles, the content of muscle sarcomere contraction, and integrity/deterioration/degradation of myofibrillar structure (Ishamri & Joo, 2017). However, a trend of consumers is shifting toward the purchase and consumption of high-quality chicken. Consumer preference regarding aged chicken meat is low owing to their low tenderness, enhanced cooking time, poor physicochemical, and sensorial properties. Traditionally, meat tenderness is enhanced using certain chemicals and so is less preferred due to associated side effects and residual chemicals in meat. Therefore, electrical stimulation (ES) is considered a safe physical treatment used in the meat industry to enhance physicochemical and sensorial properties of meat as no chemicals are used in this method (Cetin, Bingol, Colak, & Hampikyan, 2012).

ES helps in enhancing the quality of poultry meat by decreasing muscle fiber diameter and increasing the sarcomere length. ES at 120 V (low-voltage) directly affects the nervous system, on the other hand, high voltage ES depolarizes and produces a large physical and chemical response in the directly affected muscles (Cetin et al., 2012). ES along with an injection of sodium chloride (NaCl) and calcium chloride ($CaCl_2$) into goat carcasses improves meat tenderization (Young & Buhr, 2000). Researchers found that ES accelerates the rigor mortis development (Lang et al., 2016). There is limited information about the effect of ES on other quality characteristics of poultry meat and the results differ according to varied experimental conditions. High AC voltage (higher than 120 V) led to better quality and reduced pH, while the use of voltage less than 120 V is safe for workers and gives the desired results commercially (Al-Hilphy, Al-Asadi, & Zhuang, 2020). ES reduces the maturation time after slaughter, speeds up the rigor mortis process, ripens the muscles within 2 hr instead of 6 hr or more eventually reducing the processing cost (Bakker, Underwood, Grubbs, & Blair, 2021; Bhat, Morton, Mason, & Bekhit, 2019; Warriss, 2000).

Commercially, ES has been studied as a means to reduce the time required for aging to prevent meat hardness. ES improves the tenderness of meat by reducing cut values, increasing the sarcomere length, and reducing the diameter of muscle fibers. The application of ES helps in reducing the storage time, storage cost, de-feathering force, and microbial load on the chicken carcass (Al-Hmedawy, Al-Asadi, & Al-Hilphy, 2018, 2019). Therefore, this study aimed to investigate the use of ES to improve the qualitative (physical and chemical) and sensory characteristics of aged chicken meat carcass during storage periods.

2 | MATERIALS AND METHODS

2.1 | Experimental birds

In this experiment, 54 laying's aged chicken Animal Selection Institute (ISA) brown hens (*G. gallus domesticus*) were used. Experimentally procured birds were nearly 1.5 years old having an average weight of 1.5 ± 0.10 kg. All the laying aged chickens were slaughtered manually and were left for 150 s to ensure complete depletion of blood. Afterward, the feathers and internal organs were removed manually. The birds (whole carcasses) were categorized into three treatments each comprising of six birds, and each treatment was repeated three times (total of 54 birds). Then, the ES process was conducted on the treatments except for the control treatment of carcasses. The treatment plan followed in this study consists of a control treatment (T_0: without ES), the first ES treatment (T_1: electric field of 3.67 V/cm), and the second ES treatment (T_2: electric field of 7.33 V/cm). A salt concentration of 1% NaCl was used, and the duration of the ES was 1 min for both treatments. Post 25 min of ES, experimental tests were performed on the chest cut followed by cooling of carcasses at a temperature of 4°C for 6 hr. Later, the carcasses were stored by freezing at −18°C for 0, 30, and 60 days until below mentioned tests were performed.

2.2 | Electric field stimulator and ES treatment

The ES device (Figures 1 and 2) was designed and manufactured in the Food Engineering Laboratory, Food Sciences Department, College of Agriculture, University of Basrah. The device consists of a basin made of plastic (11) and insulated by a cork. The thickness of the insulation was 2.0 cm and was covered with an outer layer of plastic. The inner dimensions of the sink were 55 × 33.5 × 32 cm (length × width × depth), and it contained a plastic cover (1) and voltage regulator (12) for regulating (0–250 V AC) intensity of the electric field inside the basin. To ensure the exposure of the electric field, an eccentric column (8) made of plastic was installed at the top of the basin, which helped in raising and lowering (13) from and to the basin,

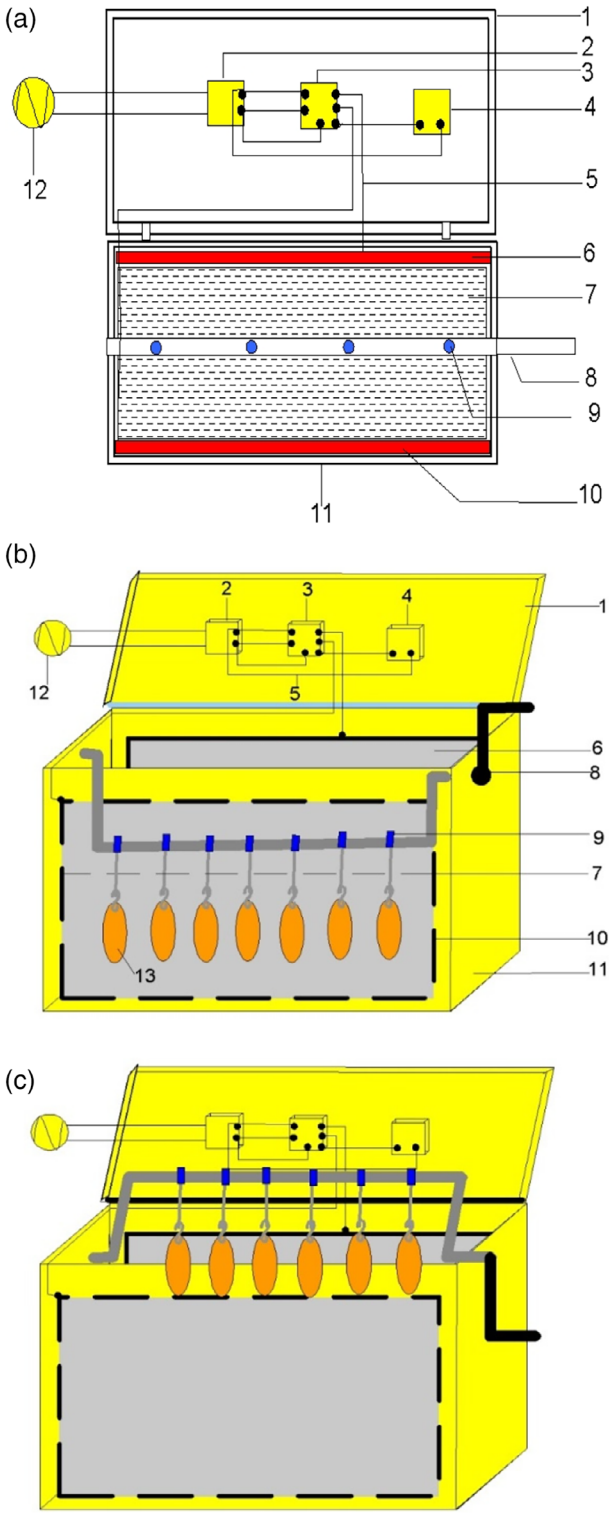

FIGURE 1 Scheme of the electrical stimulating device for poultry carcasses: (a) top view, (b) during stimulation, and (c) after stimulation. (1) Plastic cover, (2) starter switch, (3) electrical connector, (4) timer, (5) wires, (6, 10) electrodes, (7) insulators, (8) Eccentric shaft, (9) levers, (11) plastic basin, and (12) regulator

and the carrying capacity of the device was four birds. Electro stimulating electrodes (6 and 10) were made of stainless steel having dimensions of 50 × 30 cm.

2.3 | Temperature measurement of the carcass

The temperature of the carcass during ES treatment was measured by a digital infrared thermometer (MCP, German). For this purpose, the thermal camera was directed at the carcass, and the temperature was recorded.

2.4 | Electrical conductivity

Electrical conductivity was calculated from the following formula (İçier, Yildiz, & Baysal, 2008; Wang & Sastry, 1993).

$$\sigma = \frac{IL}{US} \quad (1)$$

where σ is the electrical conductivity (S/m), I is the current (A), U is the voltage (V), S is the cross-sectional area (m^2) and $L$is the distance between electrodes (m).

2.5 | Measuring voltage and current

The voltage was measured using a voltmeter provided with a voltage regulator (Neutral, 0 V s/day 250 V AC). The current was measured using an AC Digital clamp meter (Kyoritsu 2127R AC Digital Clamp Meter). To measure the current passing to electrodes, a clamp meter is put around the wire and the wire put in the center of the clamp for maximum measurement accuracy.

2.6 | Specific energy consumption

The specific energy consumption was calculated by the following equation (Gavahian & Chu, 2021):

$$SEC = \frac{UIt}{m} \quad (2)$$

where U is the voltage (V), $t$is the operating time (s), I is the current (A), m is the mass of chicken (kg), and SEC is the specific energy consumption (kJ/kg).

2.7 | Chemical properties

2.7.1 | Peroxide value

The peroxide value (PV) of meat samples for all treatments was calculated according to the method of Nielsen, Qian, and Pike (2017). Purposely, 5 g extracted fat from the meat sample was taken in a volumetric flask (250 ml), and 30 ml of an acetic acid-chloroform mixture (containing three volumes of glacial acetic acid and two volumes of chloroform (Sigma-Aldrich Co. LLC, Germany) was added in it

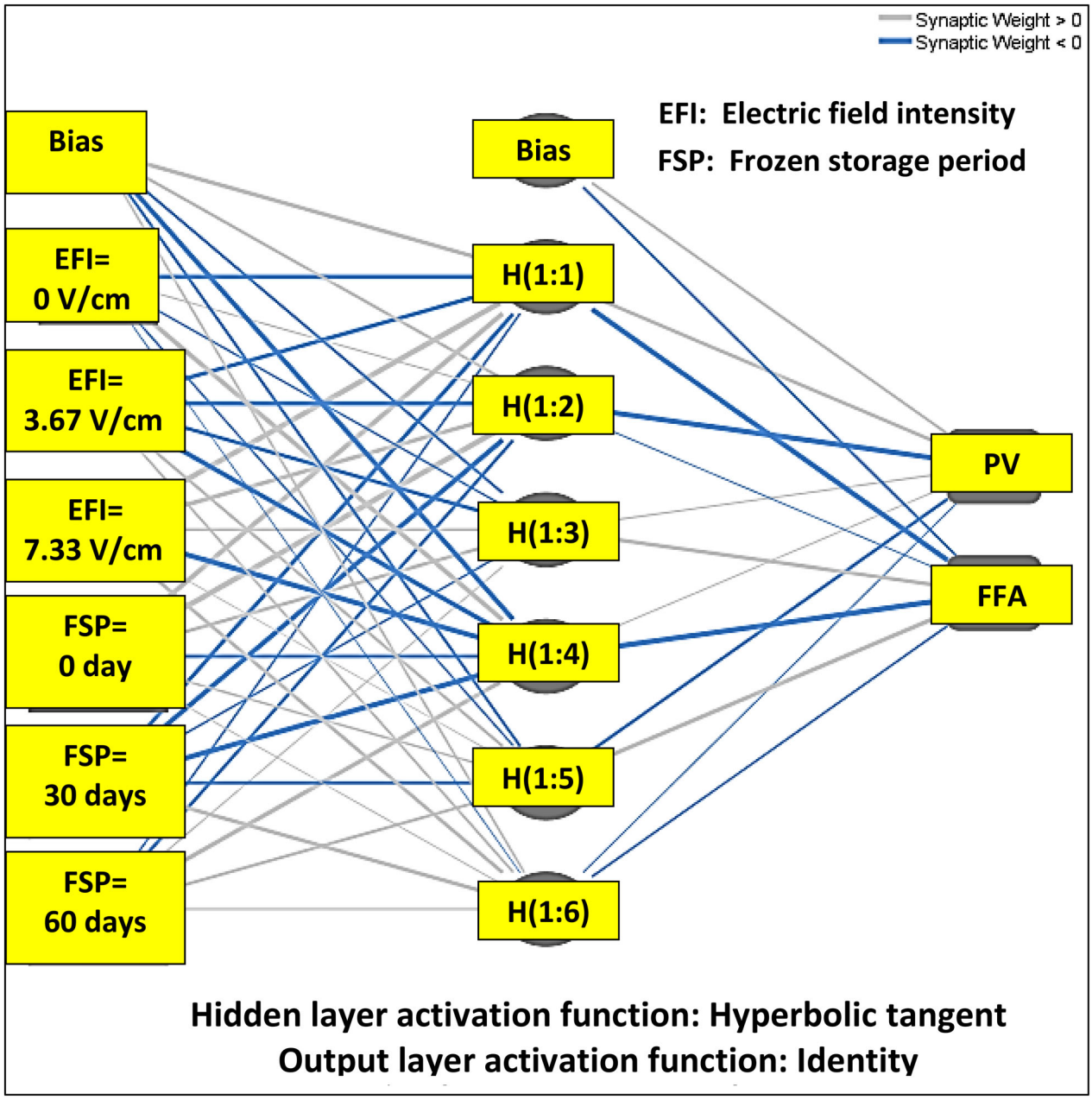

FIGURE 2 Design of artificial neural network (ANN)

followed by swirling. Afterward, 0.5 ml of saturated potassium iodide solution and 20 ml of distilled water were added. This solution was then titrated against 0.1 N sodium thiosulfate solution with continuous shaking till the disappearance of yellow color. Further, 0.5 ml of starch indicator solution (1%) was added and titrated again till the blue color disappeared and the peroxide number was estimated by the following equation:

$$\mathrm{PV} = \frac{\tau \times N}{W} \tag{3}$$

where W is the weight of the sample (kg), PV is the peroxide value, and τ is the quantity of $Na_2S_2O_3$ (ml).

2.7.2 | Free fatty acids

The free fatty acid (FFA) was calculated based on the method of Nielsen et al. (2017). Initially, 3 g of fat extracted from meat samples was mixed with 50 ml of ethyl alcohol (Sigma-Aldrich Chemie GmbH, German) followed by the addition of a few drops (2 ml) of phenolphthalein indicator. Afterward, the mixture was mixed thoroughly and titrated with 0.1 N sodium hydroxide solution until the color of the solution changed to light pink. The percentage of FFA was estimated by the following equation:

$$\mathrm{FFA} = \frac{\mathrm{Titration}(\varphi - B) \times N \times 282 \times 100}{1000 \times W} \tag{4}$$

where W is the weight of the sample (g), φ is the number of milliliters of KOH swabbed with the oil or fat sample, B is the number of millimeters of KOH smeared with the plank sample, and 282 is the molecular weight of oleic acid.

2.8 | Physical properties

2.8.1 | pH of meat samples

The pH of meat samples taken from the chest of aged laying hen carcasses was measured using a pH Meter (Jenway 3505, England). The minced meat samples (10 g) were mixed in distilled water (100 ml) in a glass beaker and left for 5 min. Later, the device was inserted into this mixture and values were taken.

2.8.2 | Drip loss

In this experiment, the meat samples were weighed and suspended in the refrigerator for 48 hr at a temperature of 4 °C by tying them with a thread made of cotton and placing them in small nylon bags. After 48 hr, the samples were dried using a filter paper and again weighed (Alvarado & Sams, 2000). Drip loss (DL) was calculated using the following formula:

$$DL = \frac{W_o - W_1}{W_o} \quad (5)$$

where W_1 the sample weight is after 48 hr (g) and W_o is the original sample weight (g).

2.8.3 | Cooking loss

To calculate cooking loss, the method of Belitz, Grosch, and Schieberle (2009) was adopted. Cooking loss was calculated by weighing the breast meat before and after roasting the samples in an oven at a temperature of 200°C for 15 min by using the following equation:

$$CL = \frac{W_{bc} - W_{ac}}{W_{bc}} \times 100 \quad (6)$$

where W_{bc} is the weight before cooking (g), W_{ac} is the weight after cooking (g), and CL is the cooking loss.

2.9 | Artificial neural network modeling

A multilayered perception artificial neural network (ANN) trained using algorithm backpropagation was chosen to develop the model of prediction. A neural network in the SPSS version 25 software was used. Data were randomized and divided into three subsets are, 88.9% is for utilized training and 11.1% for testing. Input variable were electric field intensity (0, 3.87, and 7.33 V/cm) and period of frozen storage (0, 30, 60, and 90 days). The output variables were PV and FFA of spent hen meat. The activation function used in the hidden layer was a hyperbolic tangent and the identity activation function was used in the output layer, and the type of training was batch. The optimization algorithm was scale conjugate gradient. Sum of square error and average overall relative error were calculated to compare between the predicted and experimental data. The better results that gave a lower sum of square error and relative error. Figure 2 illustrates the design of an ANN. The predicted data by ANN was drawn by using design expert version 7 software.

2.10 | Sensory assessment

The meat was cut into cubes for all treatments, and then the electric oven was used at a temperature of 200°C for 15 min. The sensory evaluation was conducted by 15 (10 men and 5 women) trained experienced arbitrators (they trained according to ISO standards (International Organization for Standardization (ISO) 8586, 2012; International Organization for Standardization (ISO 8589), 2007) in the Department of Food Sciences to evaluate the samples in terms of color, tenderness. Flavor, juiciness, and overall acceptance on the 9-score scale (no intensity (1)–high intensity (9). Analysis of sensory descriptive was performed according to generic descriptive analysis (Lawless & Heymann, 2010) and ISO standard (International Organization for Standardization (ISO 13299), 2016).

2.11 | Statistical analysis

A two-factor factorial experiment with a completely randomized design was used and the results were compared using the revised least significant difference (R.L.S.D) at the probability level ($p < .05$) using the SPSS ver. 25 statistical program. Three replicates were used in the experiments.

3 | RESULTS AND DISCUSSION

3.1 | Electrical conductivity, temperature, and SEC

Table 1 shows the electrical conductivity in brine during the treatment of chicken carcasses by ES at the EFS 3.67 and 7.33 V/cm. The results showed that the electrical conductivity increased significantly ($p < .05$) with the increase in the EFS due to the increase in the current flow, that is, electrical conductivity increased from 0.11 to 0.15 S/m. Xu, Zhang, Wang, and Bhandari (2021) stated that the electrical conductivity depends on the orientation of the electrical field, the composition of food materials (fat, salt, and fiber direction), and temperature. The temperature in the saline solution during treatment

TABLE 1 Effect of EFS on the σ, temperature, and SEC

EFS (V/cm)	σ (S/m)	Temperature (°C)	SEC (kJ/kg)
3.67	0.11 ± 0.01[a]	13.20 ± 0.34[a]	4.80 ± 0.11[a]
7.33	0.15 ± 0.02[b]	22.00 ± 0.45[c]	26.8 ± 0.75[b]
Control	N/A	12.00 ± 0.67[b]	N/A

Note: The different letters in the same column refer to significant effect at $p < .05$ level.
Abbreviations: σ, electrical conductivity; EFS, electrical field strength; SEC, specific energy consumption.

ranged from 13.2 to 22°C. The SEC increased significantly ($p < .05$) with the increase in the EFS, and this is a result of the increase in the consumed power because there was an increasing current with the same processing time for all treatments. For example, when the EFS is increased from 3.67 to 7.33 V/cm, the SEC increased from 4.80 to 26.8 kJ/kg due to the increase of power consumption due to the increase of current at constant processing time (1 min). Moreover, from a combination of Equations (1) and (2), its can derive the following Equation:

$$\mathrm{SEC} = \frac{t\sigma U^2 \mathrm{S}}{\mathrm{m\,L}} \tag{7}$$

Based on Equation (3), when U increased in two times and σ increased on 1.36 times or 36% (from 0.11 to 0.15 S/m), SEC increased on $4 \times 1.36 = 5.44$ times (444%).

This observation was in line with that reported in a recent study by Gavahian and Chu (2021). Besides, Al-Hilphy, Abdulstar, and Gavahian (2021) pointed that the SEC increased by 344% when the EFS increased from 8.33 to 20.8 V/cm for the milk treated with the electric field at constant time of processing. Similarly, Al-Hilphy et al. (2021) found that the SEC increased by 113.88% when the EFS increased from 4.28 to 15.71 V/cm. The researchers attributed the reason for this as an increase in the consumed power with the increase in the EFS when treating the mixture of wheat brans and water with Ohmic heating. In addition, the increase in the current was higher than the reduction in heating time.

3.2 | Chemical properties

3.2.1 | Peroxide value

Figure 3a shows the effect of ES and the frozen storage period on the PV of carcasses of aged chicken. There were significant ($p < .05$) effects of ES and the period of frozen storage on the PV of chicken carcasses, where the second treatment at a time of 60 days recorded an increase in the PV, which amounted to 1.50 meq/kg. The reason for the high PV may be due to chemical changes (oxidative rancidity) because fat contains unsaturated fatty acids, so it is easy to get exposed to oxidative rancidity, especially since fatty tissues contain the enzyme lipoxygenase, which acts as a catalyst in adding oxygen to fatty acids, so the viscosity increases. The factors that help this

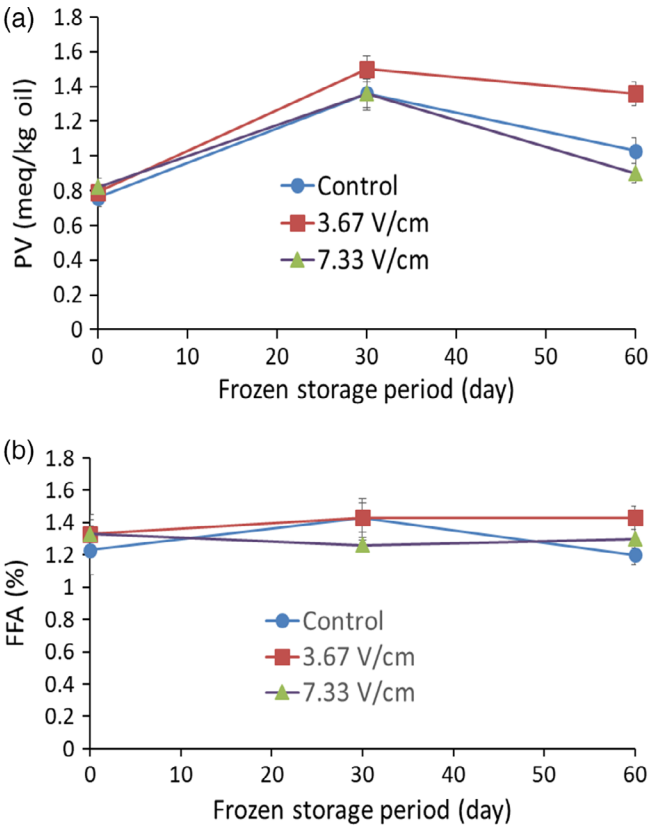

FIGURE 3 Effect of electric field strength and period of frozen storage on experimental. (a) Peroxide value (PV) and (b) free fatty acids (FFA) of spent hen meat

reaction are light energy, especially infrared or atomic rays, so enough energy is collected to separate a proton from the hydrocarbon chain of the unsaturated fatty acid, so free compounds called Free radicals are formed. This reaction is catalyzed in the presence of this enzyme, which adds oxygen to the acids, so peroxides are formed, then these peroxides break down into short-chain fatty acids eventually combining with hydrogen to form hydroperoxides (Kleopatra, 2018). In oxidative events, free radicals act on the unsaturated bonds of fatty acids especially essential fatty acids (linoleic and linolenic) (Shahidi & Zhong, 2005).

3.2.2 | Free fatty acids

Figure 3b shows the effect of ES and the period of frozen storage on FFA. The Table shows a significant ($p < .05$) effect of ES and the period of frozen storage on the percentage of FFA in meat. It is noted that the FFA in the control treatment increased when the storage period was 30 days, as it amounted to 1.4% and then decreased with the progression of the storage period. While it is noted from the figure that the treatments 3.6 and 7.33 V/cm had a slight increase with the progression of the storage periods, and the reason for this may be due to Hydrolysis in the presence of lipase enzyme to fatty acids + glycerol. This process may occur due to some microorganisms that

grow on fat and decompose it more rapidly during humid storage and occurs mainly in the cell where the foul-smelling butyric acid separates. Furthermore, this enzyme can be eliminated by thermal treatment (Al-Asadi, 2020), as the ES worked to break down the enzyme lipase, thus preventing the separation of butyric acid.

3.2.3 | ANN modeling of PV and FFA

Figure 4 illustrates the effect of EFS and FSP on PV, and FFA obtained from ANN modeling. The results showed that the PV and FFA were varied with EFS and FSP. For instance, when EFS increased from 0 to 7.33 V/cm at FSP of 0 days, the PV reduced from 0.806 to 0.80 meq/kg (Figure 4a), and FFA increased from 1.239 to 1.326% (Figure 4b), respectively. The maximum values of PV and FFA were 1.468 meq/kg and 1.430%, respectively at 3.670 V/cm of EFS and 30 days of FSP. But, the minimum values were 0.7803 meq/kg at 3.670 V/cm of EFS and 30 days of EFS, and 1.239% at 0 V/cm of EFS and 0 days of FSP, respectively. The determination coefficient between experimental and predicted values using ANN for PV, and FFA reached 0.994 and 0.991, respectively as depicted in Figure 5. Sum of Squares Error reached 0.066 and 0.007 for training and testing, respectively, as shown in Table 2. Also, the relative error reached 0.007 and 0.012 for PV and FFA, respectively. Fit statistics of the model were $SD = 0.039$, C.V. % = 3.559, $R^2 = .995$, adjusted $R^2 = .981$, predicted $R^2 = .856$, and Adeq precision = 21.272 for PV, and for FFA were $SD = 0.013$, C.V. % = 1.002, $R^2 = .997$, adjusted $R^2 = .978$, predicted $R^2 = .500$, and Adeq precision = 19.880. According to fit statistics, PV and FFA can be predicted by Equations (3) and (4) as follows:

$$\mathrm{PV}\left(\frac{\mathrm{meq}}{\mathrm{kg}}\right) = 0.8046 - 0.0234E + 0.0330t + 0.0035Et + 0.0034E^2 - 0.00048t^2 - 0.00051E^2t \quad (8)$$

$$\mathrm{FFA}(\%) = 1.2414 + 0.0290E + 0.01264t - 0.00106Et - 0.00234E^2 - 0.00023t^2 - 0.00018E^2t + 4.14805 \times 10^{-5}Et^2 \quad (9)$$

where E and t are electric field strength and the frozen storage period, respectively.

Figure 6 clarified the importance of independent variables in the effect on the PV and FFA. The results demonstrated that the frozen storage period has importance higher than EFS in the development of PV and FFA, that is, the importance and normalized importance EFS were 0.438 and 78.1%, respectively, for FSP were 0.562 and 100%, respectively.

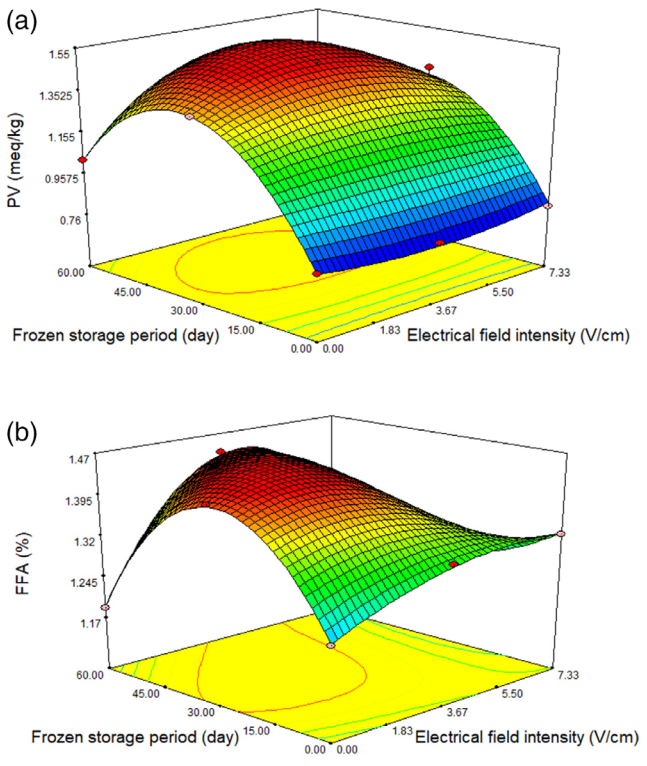

FIGURE 4 Effect of electric field strength and frozen storage period on (a) peroxide value and (b) free fatty acids resulting from artificial neural network modeling

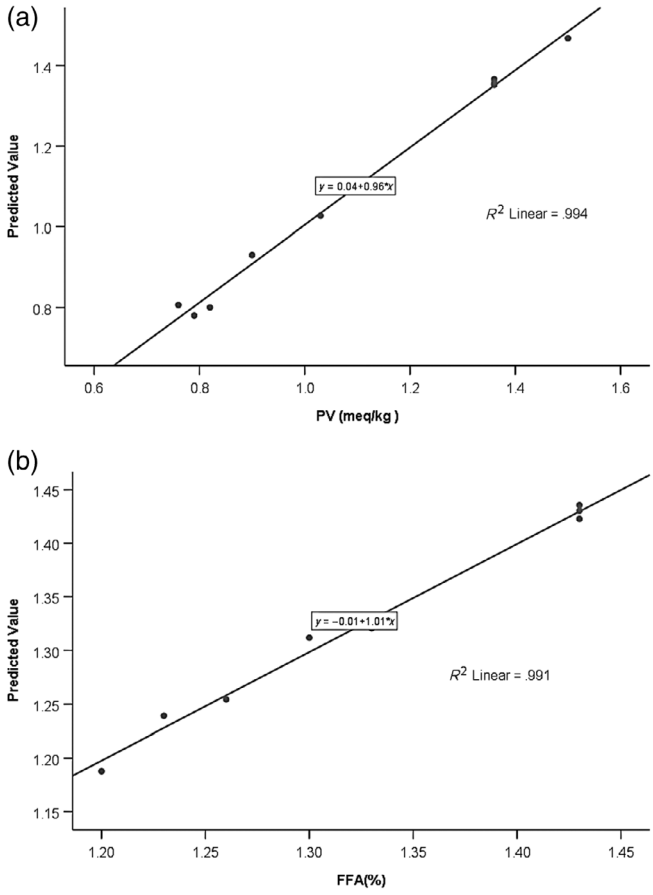

FIGURE 5 Experimental and predicted values using ANN (a) peroxide value and (b) free fatty acid

3.3 | Physical properties

3.3.1 | pH

Figure 7a illustrates a significant ($p < .05$) effect of ES and the period of frozen storage on the pH of carcasses of aged chicken. It is noticed from the Figure that the pH values increased with the progress of the frozen storage periods in the control treatment and the ES treatment 7.33 V/cm, as they reached 6.3 and 6.5, respectively. It is further noticeable that the control treatment pH decreased significantly at the 60th day frozen storage period, which amounted to 6, while there was no decrease in the third treatment. The Figure shows that the pH at ES treatment 3.67 V/cm was not affected by the progression of the frozen storage periods, as this treatment maintained the pH, that is, remained below 6. The reason for the high pH in the electrically stimulated at 7.33 V/cm may be due to the slowing down of the glycogenolysis process in the muscles. As the high-voltage ES affects the internal environmental balance processes of the muscles, which in turn affects most of the enzymes involved in the environmental balance owing to its sensitivity to the temperature of the medium in which it operates. This causes a reduction in the lactic acid content that result in the rise of the pH. It has been observed that the rapid decrease in pH during the first hours of slaughter leads to a decrease in the quality of meat. It was observed from the figure that the pH values naturally decreased in the ES 3.67 V/cm, and this natural decrease does not lead to denaturation of muscle proteins. Mainly due to the low temperature of the carcass and during the period of storage by freezing to a point where the temperature does not affect the properties of muscle proteins (Abdel-Naeem, Zayed, & Mansour, 2021; Ahmed, 2021).

TABLE 2 Model summary

Training	Sum of squares error	0.066
	Average overall relative error	0.009
	Relative error for scale dependents	
	PV (meq/kg)	0.007
	FFA (%)	0.012
Testing	Sum of squares error	0.007

3.3.2 | Carcass temperature

Figure 7b shows the effect of ES and the period of frozen storage on the temperature of the carcass. It is noted from the figure that the carcass temperature decreased with the progression of the frozen storage periods. There were no significant differences between the ES treatments (3.67 and 7.33 V/cm) and the control treatment in the average carcass temperature. The reason for the decrease in the temperature of the carcass with the progress of the frozen storage periods may be because the natural decrease in the temperature of the carcass does not lead to denaturation of muscle proteins. Other factors affecting the temperature of the carcass include the length of the frozen storage period, the condition of the bird before slaughtering, and the pH, as the slow decrease in pH is followed by a rapid decrease in the temperature of the carcass (Abdel-Naeem et al., 2021).

3.3.3 | Drip loss

Figure 7c indicates a significant ($p < .05$) effect of ES and the frozen storage period on the amount of DL in carcasses of aged laying hens. It is noted from the figure that the DL values increased with the progress of the frozen storage periods in the control treatment and the electrical field intensity of 7.33 V/cm treated meat samples, as they

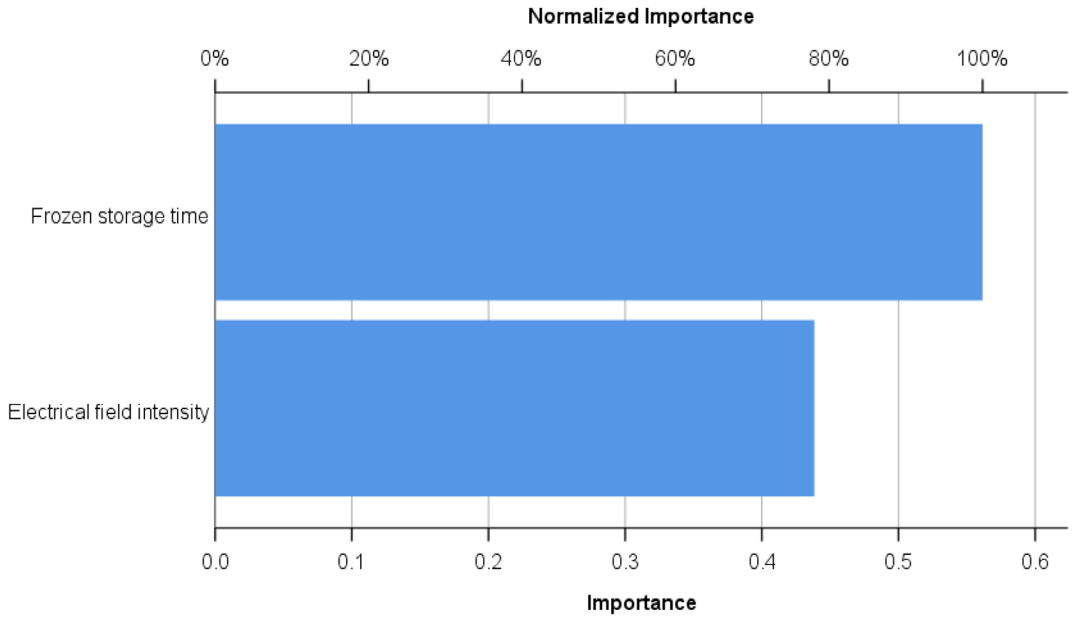

FIGURE 6 The importance of independent variables in the effect on the PV and FFA

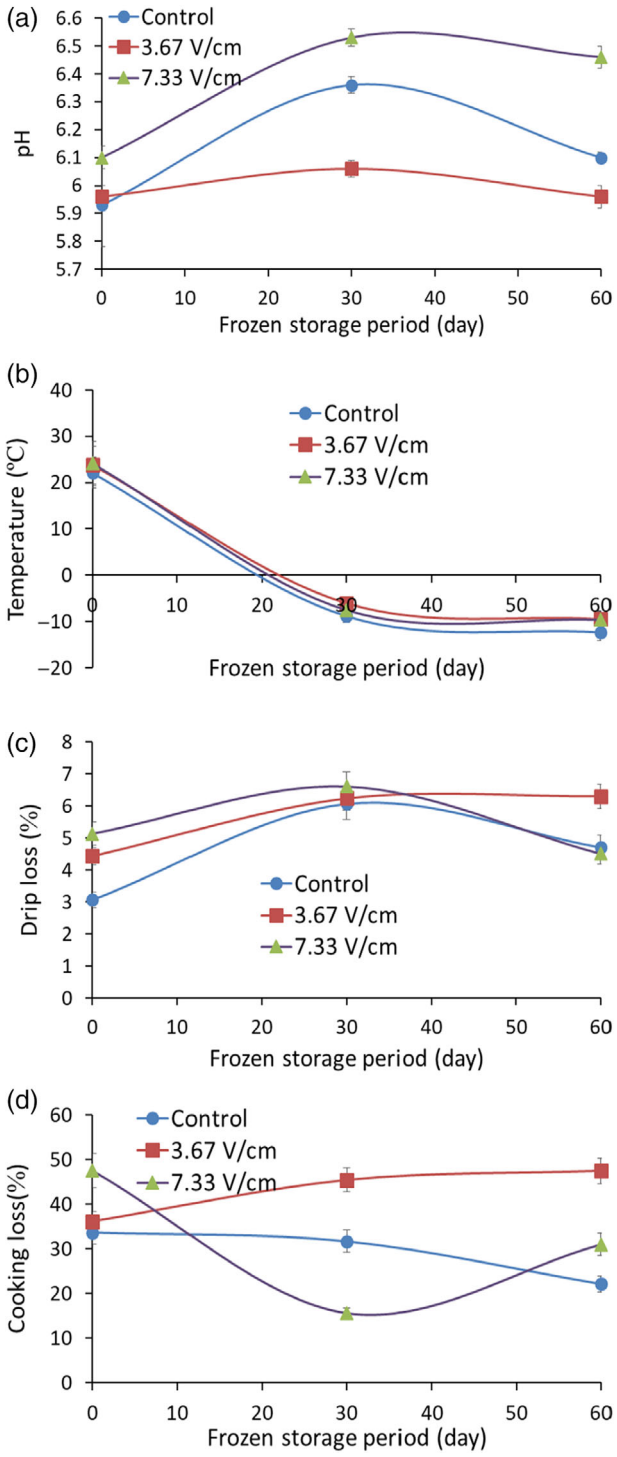

FIGURE 7 Effect of electric field strength and duration of frozen storage on (a) pH, (b) carcass temperature, (c) drip loss, and (d) cooking loss

reached 3.3 and 5.5%, respectively. Then it is noted that the DL in control treatment increased significantly on the 30th day of the frozen storage period, as it reached 5%. While a slight increase in the electrical field intensity of 7.33 V/cm resulted in an increase of DL at the 30th day of storage, which reduced to 4% at the 60th day of storage. The figure shows that the DL at EFS 3.67 V/cm treatment maintained that the DL, as it remained within the normal levels. DL values observed in the ES 3.67 and 7.33 V/cm remain within the normal rates. The natural increase in DL due to the progression of the frozen storage period may be because the amount of fluid lost during the frozen storage period may be due to the lack of denaturation of proteins in the muscles and thus increasing the ability of the proteins to bind water within the muscles (Al-Asadi, 2020).

3.3.4 | Cooking loss

Figure 7d indicates a significant ($p < .05$) effect of ES and the period of frozen storage on the amount of cooking loss of carcasses of aged chicken. The figure reveals that the values of cooking loss in the EFS 7.33 V/cm treated meat decreased 7%. At the 30-day frozen storage period, as it reached 15%, after which it is noted that it increased at the 60-day frozen storage period. While there was a slight decrease in the control treatment with the progression of frozen storage periods. While it is noticed that there is an increase in the amount of cooking loss with the progression of the frozen storage periods in the EFS 3.67 V/cm. The reason for the increase in the amount of cooking loss in ES treatments may be due to the lack of denaturation of proteins in the muscles of carcasses and thus increasing the capacity of proteins on the binding of water inside the muscles at zero storage period. But the reason for the high amount of cooking loss in meat samples stored in freezing may be due to a decrease in the carrying capacity of water during storage and an increase in the decomposition of proteins, which leads to a decrease in water retention and then an increase in the cooking loss. ES plays a major role in stimulating the activity of glycogenolytic enzymes, which work to higher the pH and lower the water carrying capacity (Al-Asadi, 2020; Al-Hilphy, Al-Asadi, & Zhuang, 2020). Armila, Hafid, and Ananda (2019) stated that the ES has a significant effect ($p < .05$) on the cooking loss of mal chicken, and it is average ranged between 21.0 and 23.5%.

3.4 | Sensory assessment

Figure 8 shows the effect of ES and the frozen storage period on the organoleptic characteristics of tenderness, juiciness, flavor, color, and general acceptance of carcasses of aged chicken. The results showed that there were significant ($p < .05$) effects of ES and the period of frozen storage on the freshness and juiciness (Figure 8a,b) of chicken carcasses, where the EFS 3.67 and 7.33 V/cm at a time of 60 days have recorded an increase in the values of freshness and juiciness, which reached 6.5 and 7.5, respectively, compared to the treatment of chicken carcasses (control), which amounted to 6. While there were no significant differences in the flavor, color, and general acceptance (between the ES treatments and the control treatment). Many researchers depicted that ES has a significant effect on the red meat color (Adeyemi & Sazili, 2014; Asghar, Henrickson, & Kastner, 1983; Polidori & Vincenzetti, 2017). The reason for improving the freshness and juiciness (Figure 8c–e) may be due to the high pH in the ES

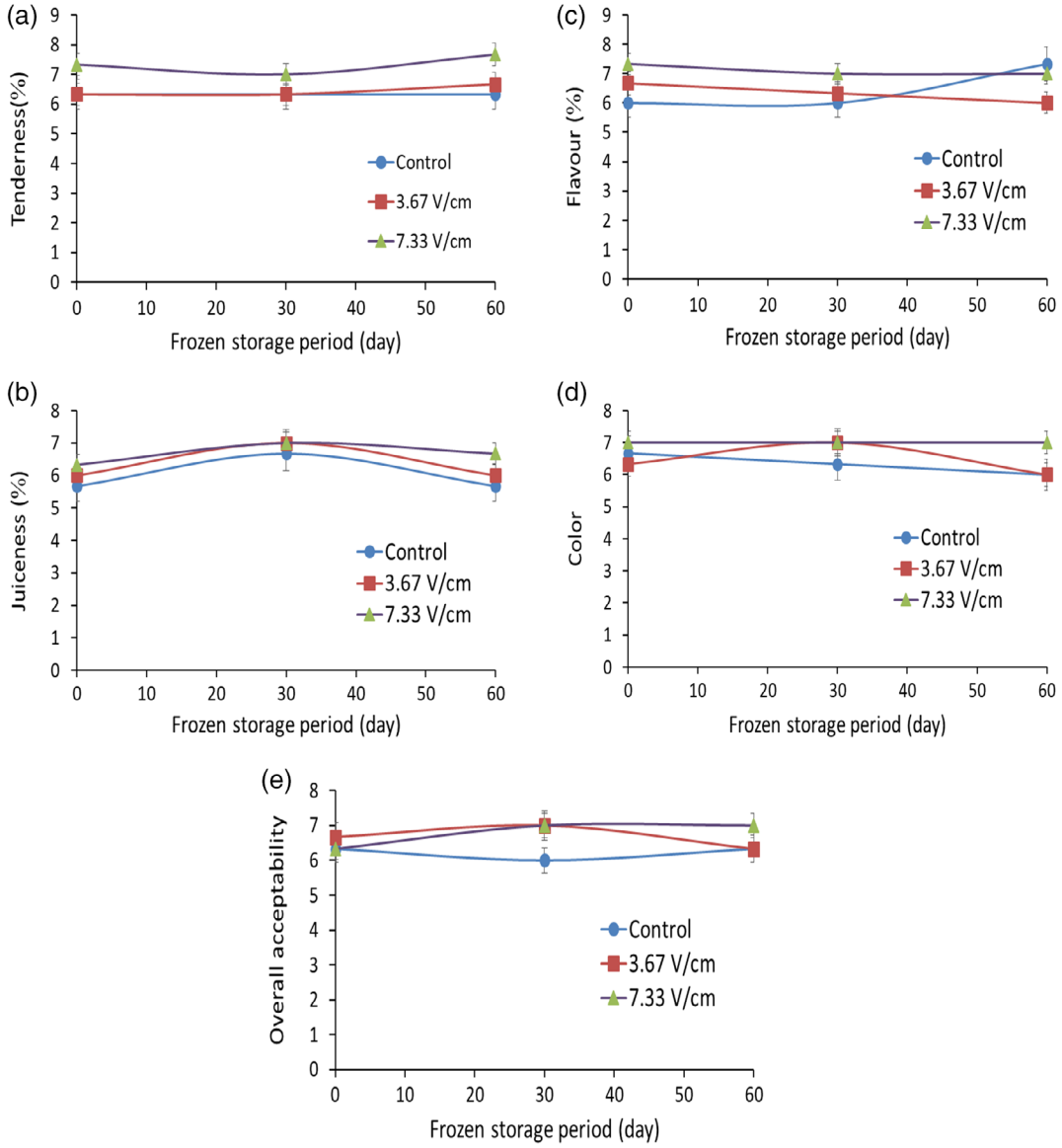

FIGURE 8 Effect of electric field intensity and period of frozen storage on sensory characteristics of spent hen meat

treatments to slow the decomposition process of the glycogen in the muscles, as the high-voltage ES reduces the lactic acid, which causes the pH to rise. There is a positive correlation between the water carrying capacity and the pH, so it is noticed that the juiciness of the meat of the carcasses improves and thus reflects positively on the improvement of tenderness (Abdel-Naeem et al., 2021; Al-Hilphy, Al-Musafer, & Gavahian, 2020). The native chicken meat texture was significantly (p < .01) affected by the ES and ranged between 1.91 and 3.13 (Armila et al., 2019).

4 | CONCLUSIONS

Both electrical conductivity and SEC increased with the increase in EFS. The characteristics of the chemical and physical carcass treated with ES and during the FSPs of 0, 30, and 60 days were improved compared to the control treatment. The ES treatment at 7.33 V/cm increased the sensory characteristics (freshness, juiciness, flavor, and general acceptability) at all FSPs. ANN was used to predict the development of PV and FFA during FSPs, and the poly nonlinear model has described the development of PV and FFA during FSP. To include ES technology in meat processing industry, should manufacturing big ES apparatuses to treat meat by a continuous method.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Asaad R. Saeed Al-Hilphy: Conceptualization; data curation; formal analysis; writing – original draft. **Majid H. Al-Asadi:** Data curation; formal analysis. **Noora K. Al-Hmedawy:** Data curation; formal analysis. **Anees Ahmed Khalil:** Writing – review and editing. **Ume Roobab:** Writing – review and editing. **Muhammad Modassar Ali Nawaz Ranjha:** Data curation; software. **Muhammad Faisal Manzoor:** Writing – original draft; writing – review and editing.

ETHICS STATEMENT

All national and international guidelines in place for the care and use of animals have been followed.

DATA AVAILABILITY STATEMENT

The dataset supporting the conclusions of this article included within the article.

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REFERENCES

Abdel-Naeem, H. H., Zayed, N. E., & Mansour, H. A. (2021). Effect of chitosan and lauric alginate edible coating on bacteriological quality, deterioration criteria, and sensory attributes of frozen stored chicken meat. *Lebensmittel-Wissenschaft und Technologie*, *150*, 111928. https://doi.org/10.1016/j.lwt.2021.111928

Adeyemi, K. D., & Sazili, A. Q. (2014). Efficacy of carcass electrical stimulation in meat quality enhancement: A review. *Asian-Australasian Journal of Animal Sciences*, *27*(3), 447–456. https://doi.org/10.5713/ajas.2013.13463

Al-Asadi, M. H. (2020). The use of electrical stimulation technique to influence the quality and quantity of accumulated fat and cholesterol in duck meat. *Plant Archives*, *20*(1), 443–448. Retrieved from. http://www.plantarchives.org/SPECIAL%20ISSUE%2020-1/88__443-448_.pdf

Al-Hilphy, A. R., Abdulstar, A. R., & Gavahian, M. (2021). Moderate electric field pasteurization of milk in a continuous flow unit: Effects of process parameters, energy consumption, and shelf-life determination. *Innovative Food Science & Emerging Technologies*, *67*, e102568. https://doi.org/10.1016/j.ifset.2020.102568

Al-Hilphy, A. R., Al-Asadi, M. H., & Zhuang, H. (2020). Effect of electrical stimulation on qualitative characteristics of aged chicken carcasses: A comprehensive review. *Basrah Journal of Agricultural Sciences*, *33*(1), 135–158. https://doi.org/10.37077/25200860.2020.33.1.11

Al-Hilphy, A. R., Al-Musafer, A. M., & Gavahian, M. (2020). Pilot-scale ohmic heating-assisted extraction of wheat bran bioactive compounds: Effects of the extract on corn oil stability. *Food Research International*, *137*, e109649. https://doi.org/10.1016/j.foodres.2020.109649

Al-Hmedawy, N. K., Al-Asadi, M. H., & Al-Hilphy, A. R. (2018). Destruction of bacteria using electric stimulation of old duck and chicken carcasses. *Basrah Journal of Agricultural Sciences*, *31*(2), 31–35. https://doi.org/10.37077/25200860.2018.97

Al-Hmedawy, N. K., Al-Asadi, M. H., & Al-Hilphy, A. R. (2019). Effect of electric stimulation on histological traits and color of carcasses in old duck and chicken [In IOP Conference Series]. *Earth and Environmental Science*, *388*(1), 012024. https://doi.org/10.1088/1755-1315/388/1/012024/meta

Alvarado, C. Z., & Sams, A. R. (2000). The influence of postmortem electrical stimulation on rigor mortis development, calpastatin activity, and tenderness in broiler and duck pectoralis. *Poultry Science*, *79*(9), 1364–1368. https://doi.org/10.1093/ps/79.9.1364

Armila, I., Hafid, H., & Ananda, S. H. (2019). Quality of chicken meat which is given treatment of electric stimulation. *Journal of Physics*, *1364*(1), 012072. https://doi.org/10.1088/1742-6596/1364/1/012072

Asghar, A., Henrickson, R. L., & Kastner, C. L. (1983). Post-mortem stimulation of carcasses: Effects on biochemistry, biophysics, microbiology, and quality of meat. *CRC Critical Reviews in Food Science and Nutrition*, *18*(1), 1–58. https://doi.org/10.1080/10408398209527356

Bakker, C., Underwood, K., Grubbs, J. K., & Blair, A. (2021). Low-voltage electrical stimulation of beef carcasses slows carcass chilling rate and improves steak color. *Food*, *10*(5), 1065. https://doi.org/10.3390/foods10051065

Belitz, H.-D., Grosch, W., & Schieberle, P. (2009). *Food chemistry* (4th ed.). Berlin, Heidelberg: Springer. Retrieved from. http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10271951

Bhat, Z. F., Morton, J. D., Mason, S. L., & Bekhit, A. E. D. A. (2019). Current and future prospects for the use of pulsed electric field in the meat industry. *Critical Review of Food Science and Nutrition*, *59*(10), 1660–1674. https://doi.org/10.1080/10408398.2018.1425825

Cetin, O., Bingol, E. B., Colak, H., & Hampikyan, H. (2012). Effects of electrical stimulation on meat quality of lamb and goat meat. *The Scientific World Journal*, *2012*, 1–9. https://doi.org/10.1100/2012/574202

Gavahian, M., & Chu, R. (2021). Design, development, and performance evaluation of an ohmic extractor to valorize fruit by-products based on Taguchi method: Reduced energy consumption and enhanced total phenolics. *Journal of Food Process Engineering*, e13825.

İçier, F., Yildiz, H., & Baysal, T. (2008). Polyphenoloxidase deactivation kinetics during ohmic heating of grape juice. *Journal of Food Engineering*, *85*(3), 410–417. https://doi.org/10.1016/j.jfoodeng.2007.08.002

International Organization for Standardization (ISO 13229). (2016). *Sensory analysis—General guidance for establishing a sensory profile* (p. 41 p. Retrieved from). Geneva, Switzerland: International Organization for Standardization. https://www.iso.org/standard/58042.html

International Organization for Standardization (ISO 8586). (2012). *Sensory analysis—General guidance for selection, training and monitoring of selected sensory assessors and expert assessors* (p. 28p. Retrieved from). Geneva, Switzerland: International Organization for Standardization. https://www.iso.org/standard/45352.html

International Organization for Standardization (ISO 8589). (2007). *Sensory analysis—General guidance for the design of test rooms* (p. 16 p. Retrieved from). Geneva, Switzerland: International Organization for Standardization. https://www.iso.org/standard/36385.html

Ishamri, I., & Joo, S. T. (2017). Poultry meat quality in relation to muscle growth and muscle fiber characteristics. *Korean Journal of Food Science and Animal*, *37*(6), 873–883. https://doi.org/10.5851/kosfa.2017.37.6.873

Lang, Y., Sha, K., Zhang, R., Xie, P., Luo, X., Sun, B., & Liu, X. (2016). Effect of electrical stimulation and hot boning on the eating quality of Gannan yak *Longissimus lumborum*. *Meat Science*, *112*, 3–8. https://doi.org/10.1016/j.meatsci.2015.10.011

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food—Principles and practices* (p. 819. Retrieved from). Berlin, Germany: Springer. https://link.springer.com/book/10.1007/978-1-4419-6488-5?fbclid=IwAR0YgBrMkl0Vy2dlFzQnPMe-ifkuvmZQ8rwfmdllAwFPGQO4bpnjvlMQiWE

Nielsen, S. S., Qian, M. C., & Pike, O. A. (2017). Fat characterization. In S. Nielsen (Ed.), *Food analysis laboratory manual* (pp. 185–194). Cham: Springer. https://doi.org/10.1007/978-3-319-45776-5_36

Polidori, P., & Vincenzetti, S. (2017). The use of electrical stimulation in meat production. In D. B. McCarthy (Ed.), *Meat and meat processing*

(pp. 133–153). Hauppauge, NY: Nova Science Publishers, Inc. pp. Retrieved from. https://novapublishers.com/shop/meat-and-meat-processing/

Shahidi, F., & Zhong, Y. (2005). Antioxidants: Regulatory status. In F. Shahidi (Ed.), *Bailey's industrial oil and fat products* (pp. 491–512). Hobeken, NJ: Wiley-Interscience.

Wang, W. C., & Sastry, S. K. (1993). Salt diffusion into vegetable tissue as a pretreatment for ohmic heating: Determination of parameters and mathematical model verification. *Journal of Food Engineering*, *20*(4), 311–323. https://doi.org/10.1016/0260-8774(93)90081-T

Warriss, P. D. (2000). *Meat science: An introductory text* (2nd ed., p. 223). Wallingford, UK: CABI Publishing.

Xu, J., Zhang, M., Wang, Y., & Bhandari, B. (2021). Novel technologies for flavor formation in the processing of meat products: A review. *Food Reviews International*, 1–25. https://doi.org/10.1080/87559129.2021.1926480

Young, L. L., & Buhr, R. J. (2000). Effect of electrical stimulation and polyphosphate marination on drip from early-harvested, individually quick-frozen chicken breast fillets. *Poultry Science*, *79*, 925–927. https://doi.org/10.1093/ps/79.6.925

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