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Original paper

Influence of high-voltage electric field thawing on frozen tilapia fillets quality

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Abstract In the food sector, high voltage electric field (HVEF) has recently been regarded as a novel thawing technique. The variance in the quality was compared between frozen tilapia fish fillets thawed by high voltage electrostatic field (HVE) and those thawed conventionally as control. Frozen tilapia fish fillets were thawed under HVEF and were exposed to three different corona voltages from 4.5 to 14 kV at electrode gaps of 3, 4.5, and 6 cm; the control was thawed at 20°C without HVEF treatment. Thawing rate, evaporation, thawing, and drip losses, as well as total volatile binding nitrogen (TVB-N), thiobarbituric acid reactive substances, protein solubility, and color variations, have been employed as the quality indicators. The results revealed that thawing under HVEF greatly enhances the thawing rates of frozen tilapia fish fillets. The greatest rate of thawing was 2.16 times that of the control specimen. However, thawing HVEF reduced the protein solubility and color of fish specimens. In comparison to the control, increasing the applied voltage reduced the protein solubility of the fish specimens High electrostatic field intensities caused frozen tilapia fish fillets to oxidize quicker than lower ones.

Keywords Thawing, High voltage electric field (HVEF), TVB-N, tilapia, Protein solubility

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Introduction

Fish is becoming a more essential source of food all around the world (Silva et al., 2011). The proportion of fisheries produce used for directly human consumption climbed from around 70% in the 1980s to more over 85% in 2012 (FAO, 2014).

Egypt is already one of the world's biggest aquaculture industry, which contributes significantly to income, jobs generation and food production. Nile tilapia was brought to undeveloped nations and sustenance cultivated to suit local protein demands (GAFRD, 2016). Nile tilapia, *Oreochromisniloticus*, is amongst the most significant fish species in tropical Africa's inland fisheries, particularly in the Great East African rift valley lakes.

Aside from its importance in caught fisheries, Tilapia is one of the most significant species for 21st-century aquaculture, with production in over 100 nations. Tilapias have become the world's 2nd most common cultured fish, trailing only carps (Elsebaieet al., 2021). Annual cultured tilapia output topped 2,002,087 metric tons (Yitayew, 2012). *O. niloticus* has a total length of 20 cm on average (FAO, 2012).

Egypt, China, Indonesia, and the Philippines are the top tilapia producers today. The benefits of tilapia include their quick growth, impedance against numerous illnesses and stresses, resilience to changing environmental circumstances, and readiness to breed in captivity (Shoemaker et al., 2000).

Freezing is a key intermediate stage in preparing fish for frozen storage, and among the most widely utilized ways is the air blast freezer. This technique eliminates heat out from fish via cycling cold air at temperatures ranging from-30 to - 40°C with speeds varying from 1.5 to 6ms-1 above the products (Ninan, 2018).

Freezing not only inhibits microbial growing but rather the chemical changes that cause quality degradation (Ordóez et al., 2005). This procedure is highly effective in retaining the nutritional and sensory properties of the fish, as long as the freezing, storage, and thawing stages are carried out correctly (Evangelista, 2008). The freeze-thawing process causes muscle proteins denaturation, resulting in undesirable textural changes in meat (Wang et al., 2015). Consequently, despite the effectiveness of freezing in ensuring either quality of meat and nutritional safety, various difficulties related to the freezing - thawing processes continue to be a major source of worry for the food consumers and manufacturers (Ali et al., 2015). A significant consideration when choosing the appropriate thawing procedure is that the technique is non-destructive, causing minimal damage to the fish quality. Various systems, including air, vacuum, water heat, radio frequency, high pressure, microwave, ultrasonic, and infrared have been used to thaw frozen fish, each of which has number of its issues, like as indolent rate, elevated weight losses, chemical spoilage, microbial spoilage, excessive heat, and expensive cost (Uyar et al., 2015 and Llave et al., 2015). As a result, it is critical to create a system capable of preserving quality while preventing unwanted changes in tilapia fish fillets.

Today, nonthermal systems have been used as a novel methods to prevent the negative effects of heat on food color, flavor, and nutritional content (Orlowska et al., 2014), such asohmic thawing and HVEF thawing Ohmic thawing is based on electricity flow via a food product with electrical resistance (Bozkurt and Icier, 2012). Heat is produced instantaneously within the foodstuff. Meanwhile, in HVE thawing, air is ionized by passing high voltage electricity between a needle electrode and a ground electrode, and the produced ions are propelled around the electrodes. Then, the bulk of the ionized fluid moved on the sample's surface by transferring momentum from air ions to neutral air molecules (Zhang and Ding, 2020).

Besides, its low power consumption, the HVEF retains food at freshness state, which has lately made it appealing for the production of high-quality products (Singh et al., 2012 and Dinani et al., 2014). Previous researches have shown that HVEF can cut the time required to thaw chicken (-3°C) and frozen pork (20°C) to two-thirds of the time required in still air (He et al., 2013). Thawing frozen eggs and beef with this novel process took 25–30% less time than the conventional procedures under the identical temperature (Orlowska et al., 2014). The HVEF method has been reduced the time required to thaw frozen pork tenderloin meat by raising voltage and reducing the distance between electrodes (He et al., 2014). Some researchers investigated the influence of an electrostatic field on the frozen items quality and discovered that electrostatic thawing process can restrict microbiological growth and minimize microbial loads; thus, the quantity of volatile nitrogen in thawed items via this way is lowered and storage duration is increased (He et al., 2013).Based on the foregoing, it appears that implementing an adequate technique for frozen fish thawing can be a significant achievement for food manufacturers. The current work is part of an ongoing investigation into the use of HVEF thawing for frozen tilapia fish fillets, with the goal of investigating the changes that may occur in the quality of the product throughout thawing beneath HVEF and storage duration, as well as comparing it to the traditional still air technique. Hence, it offers for the first time the practical and theoretical groundwork for using high-voltage electric field thawing technologies to thaw frozen tilapia fillets.

Materials and Methods

Materials

Nile tilapia fish

Nile tilapia (Orechromisniloticus) fish specimens (average weight = 300-450 g) were acquired on the same day of harvesting from a fish market in Kafr El-Shiekh City, Egypt.

All chemical used in this work of HPLC grade (99.9% purity) were obtained from Sigma company of chemicals and drugs, St. Louis, MO, USA.

HVE experimental apparatus included high voltage output from -50 to 50 kV and maximal electrical current (5 mA), a processing chamber and a high-voltage generator regulated by a multi-point plate electrode system. The ground electrode is a rectangular 20 x 15 cm^2 copper plate. A sharp 16-tip (0.4 mm diameter) connected to the positive pole of high voltage power supply creates a corona discharge electrode. The chamber was positioned in a low temperature incubator. Via varying the voltages and distance amidst the used electrodes, the intensity of the electric area is changed. The experiential device for applying the HVEF method is demonstrated in Figure 1.

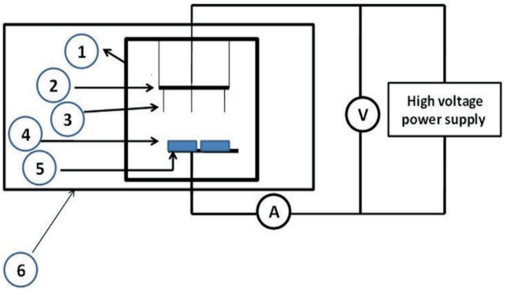

Figure 1. Schematic diagram of experimental set-up employed for HVE thawing process. Where, 1 is chamber, 2 is Aluminum, 3 is point electrode, 4 is frozen tilapia fish fillets, 5 is plate electrode (Copper) and 6 is incubator

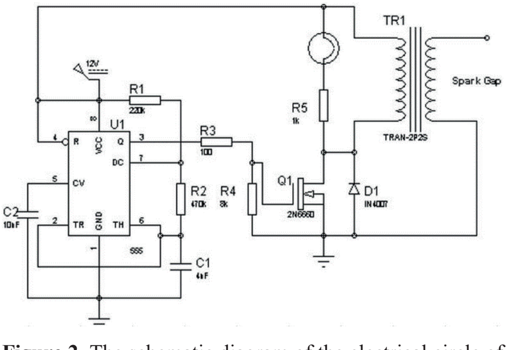

Figure 2. The schematic diagram of the electrical circle of the high voltage powersupply.

Methods

Nile tilapia fish fillets (NTFFs) preparation and freezing

Each fish was gutted, deheaded, cleaned, and filleted into two pieces weighing roughly 90 g each. The specimens were then wrapped in sterile polyethylene bags and sent immediately to the food technology laboratory, faculty of agriculture, Kafrelshiekh University using an icebox, where they were immediately frozen at -18°C in a freezer (Kiriazi, Egypt) for 24 hours to prepare for the thawing experiment.

Thawing

Frozen NTFFs(7 cm diameter × 1 cm thickness) thawing process were carried using HVE for each treatment. Frozen NTFFs was positioned over rectangular platelet electrode and an electrical area was formed between the positive and negative electrodes. Control sample thawing process was carried out by poisoning it into HVE room over the identical platelet electrode in the absence of the electric field. Fiber optic thermocouple (Digi-Sense® Traceable® Kangaroo) was used to regulate the temperature pending this process. To stabilize the thermocouple prior to freezing, a hole was formed in the geometric middle of each processed NTFFs via plurality of needles, and by finishing the freezing period, needles were pulled out of the sample. The optic fibers were put in the geometric middle of every one and keep it fixed in NTFFs. When the NTFFs internal temperature reaches up 0°C, the thawing is deemed finished. The applied voltages for the experimental groups were 4.5, 7.5, and 10.5 kV; 6, 10.5 and 13.5 kV; and 7.5, 10.5, and 14 kV for electrode gaps of 3, 4.5 and 6 cm.He et al. (2014) stated that both the geometric center and surface temperatures increased rapidly with increased applied voltages, and there was no significant difference in the inside and outside temperatures of frozen pork tenderloin meat from different HVEF treatments or in the control. Therefore, the temperature measured at the geometric center of the samples was taken as object of study. The experiments were triplicated.

Thawing rate measurement

The period needed for promoting the temperature in the position of frozen NTFFs from -18ºC to 0ºC, was possessed in consideration as thawing period. The thawing rate of frozen NTFFs was calculated by dividing the NTFFs weight by the thawing period (g/s)

Evaporation, thawing, and drip losses measurement

Evaporation, thawing, and drip losses values were measured using the procedure explained according to Ding et al. (2018). The results were calculated from the following equations:

$$\textbf{Evaporation loss (\%)} = \frac{M_F - M_{TB}}{M_F} \times 100$$

$$\textbf{Thawing loss (\%)} = \frac{M_F - M_{TA}}{M_F} \times 100$$

$$\textbf{Drip loss} = \frac{M_{TB} - M_{TA}}{M_F} \times 100$$

Where M_F, M_{TB}, and M_{TA} are the frozen weight, the thawed weight before removing surfacewater, and the thawed weight after surface water removal, respectively

Cooking and total losses determination

Ten grams of thawed samples were put in a polyethylene bag and cooked for 25 minutes in a water bath at 75°C until the temperature was reached 72°C. The following formulas were used to calculate cooking loss and total loss:

$$\text{Cooking loss (\%)} = \frac{\text{Raw weight - Cooking weight}}{\text{Raw weight}} \times 100$$

$$\text{Total loss} = \text{Thawing loss} + \text{Cooking loss}$$

Total Volatile Binding Nitrogen (TVB-N)

The TVBN of the tha wed NTFFs samples was measure dinstantly after 6 days of storage at 4±1Cusing a colorimetric method as defined by Mousakhani-Ganjeh*et al.* (2015).

Thiobarbituric acid reactive substances determination

The thawed NTFFs' thiobarbituric acid reactive substances content were measured using a colorimetric system, as described by Zeb and Ullah (2016).

Protein solubility

The protein solubility of the thawed NTFF was determined using the procedure stated byHe *et al.* (2015).

Color differences of NTFFs:

The thawed NTFFs sample color spacers were calculated in line with the CIE Lab method using the Hunter Lab Colorimeter in L* (lightness), a* (redness–greenness), and b* (yellowness-blue) (Colorflex, Hunter Associates laboratory, USA).

Thawing energy consumption and specific thawing energy consumption

Thawing energy consumption and specific thawing energy consumption calculated using following equations (Niazmand et al., 2020):

$$Thawing\ energy\ consumption\ (kW.h) = V \times I \times t \qquad (1)$$

$$Specific\ thawing\ energy\ consumption\ (kW.h.kg^{-1}) = \frac{Thwaing\ energy\ consumption}{sample\ weight} \qquad (2)$$

Where V is working electrical potential (in Volts), I is electrical current (A), t is thawing time (h)

Statistical analysis

ANOVA was conducted using the general linear regression model of SPSS (Ver.16.0, 2007) to assess variations between values. The probability degrees of $P \leq 0.05$ were significantly considered for statistical tests. All measurements and experiments were conducted in triplicate.

Results and discussion

Thawing rate

The effect of various voltages and electrodes gaps used in the HVEF process on the thawing rate is shown in Table 1. As the voltages increased, the thawing rate obviously increased for each electrode gap (P≤0.05). But at the other hand, increasing the gaps between electrodes, the thawing rate decreased at a constant voltage (10.5 kV). Thawing rate at the electrical field strength of 3.5 kV/cm (3cm electrodes gap and 10.5kV), was 2.16 times higher than that the control sample under conventional conditions (0.069 g/s and 0.032 g/s, respectively). It is worth noting that even at the low electrical field strength (1.25 kV/cm, 6cm electrodes gap and 7.5kV), an increase of approximately 1.34 times than that the control was reported. Hence, thawing beneath HVEF had a favorable influence on the process via enhancing the thawing rate, since the quality of tilapia fish fillets is less impacted by thawing time and much more quality is retained. These results are consistent with what has been stated in the previous investigations (He et al., 2013, Mousakhani-Ganji et al., 2016).

Table 1. Influence of voltage and gap on *the* thawing rate, thawing loss, drip loss, evaporation loss, cooking loss and total loss of tilapia fish fillets

Gap (cm)	Voltage (Kv)	Electrical field strength	Thawing rate (g/s)	Evaporation loss (%)	Drip loss (%)	Thawing loss (%)	Cooking loss (%)	Total loss (%)
3	4.5	1.5	0.049 ± 0.01^{bc}	0.68 ± 0.15^{d}	0.56 ± 0.09^{cd}	1.46 ± 0.32^{c}	18.60 ± 1.21^{c}	20.06 ± 1.03^{c}
	7.5	2.5	0.058 ± 0.02^{ab}	1.09 ± 0.42^{b}	0.74 ± 0.12^{b}	1.98 ± 0.29^{b}	20.74 ± 0.97^{a}	22.72 ± 1.44^{a}
	10.5	3.5	0.069 ± 0.01^{a}	1.27 ± 0.58^{a}	0.72 ± 0.16^{b}	2.14 ± 0.33^{b}	20.05 ± 1.16^{a}	22.19 ± 1.65^{a}
4.5	6.0	1.33	0.045 ± 0.03^{c}	0.76 ± 0.21^{c}	0.49 ± 0.10^{d}	1.53 ± 0.39^{c}	18.13 ± 1.33^{c}	19.66 ± 1.32^{d}
	10.5	2.33	0.056 ± 0.02^{b}	1.06 ± 0.53^{b}	0.76 ± 0.19^{b}	1.96 ± 0.46^{b}	20.69 ± 0.99^{a}	22.65 ± 1.39^{a}
	13.5	3.00	0.066 ± 0.03^{a}	1.19 ± 0.44^{a}	0.71 ± 0.08^{b}	2.03 ± 0.52^{b}	19.92 ± 1.32^{b}	21.95 ± 0.99^{b}
6.0	7.5	1.25	0.043 ± 0.04^{c}	0.64 ± 0.21^{d}	0.61 ± 0.13^{c}	1.51 ± 0.38^{c}	18.11 ± 1.52^{c}	19.62 ± 1.29^{d}
	10.5	1.75	0.051 ± 0.01^{b}	0.65 ± 0.19^{d}	0.62 ± 0.16^{c}	1.54 ± 0.29^{c}	20.62 ± 1.12^{a}	22.16 ± 1.38^{a}
	14.0	2.33	0.055 ± 0.02^{ab}	1.07 ± 0.54^{b}	0.76 ± 0.14^{b}	1.97 ± 0.51^{b}	20.35 ± 1.08^{a}	22.32 ± 1.52^{a}
Control		---	0.032 ± 0.01^{d}	0.65 ± 0.11^{d}	1.73 ± 0.63^{a}	3.31 ± 0.63^{a}	16.04 ± 1.66^{d}	19.35 ± 1.40^{d}

Means in same column with different small letters are significantly different ($P \leq 0.05$)

The ions formed in the tiny region surrounding the needle electrodes are accelerated by the electrical field, and the generated movement is transferred from the ionized air particles to uncharged air molecules and generates the corona winds, which propels the bulk fluid to the surface. In this instance, the bulk fluid interferes with the surface, causing disturbance on the surface's boundary layer and, as a result, increasing the heat transfer coefficient (Goodenough et al., 2007). As a result, the time necessary for thawing the frozen tilapia fish fillets is reduced.

Evaporation, drip, thawing, cooking, and total losses

In this work, five types of losses were calculated to investigate the impacts of varying voltages and electrode gaps on the quality of HVEF-thawed NTFFs.The results revealed that as the applied voltage was raised, evaporation loss rose; however, when the electrode gap was reduced for a fixed voltage, evaporation loss increased. The samples thawed in HVEF at 1.75 kV/cm (6cm electrode gap and 10.5kV) revealed the same evaporation loss as the ones thawed under ordinary conditions (control specimen). At 4.5 and 6 cm electrode gap, raising the voltage resulted in a small increase in evaporation loss. The thawing and drip losses values reduced by increasing the electric field intensity from 1.25 to 1.5 kV/cm, and then marginally raised at 3.5 kV/cm. However, at the same voltage, there were no significant variations between the electrode gaps of 3 cm and 4.5 cm. As may be observed, the control showed greater losses than the HVEF treatment (Table 1).

Cooking loss was smaller in the control group compared to the HVEF treatments. It increased considerably ($P \leq 0.05$) with increasing electric field strength, with 2.5 kV/cm electric field strength showing the greatest cooking loss at each electrode gap. Cooking and total losses rose as voltage rose, but there were no substantial increases at any of the electrode gaps. The increased water release during heating in the HVEF-treated samples is thought to be due to protein denaturation (Bouton and Harris, 1972). Protein solubility was observed to decrease with increasing voltage at all electrode spacing and decreasing electrode distance at a constant voltage (Mousakhani -Ganjeh et al., 2015). Denatured proteins lose their capacity to hold water, with a tiny fraction lost after thawing process and a significant percentage lost during cooking.

TVB-N

Bacteria and enzymes breakdown proteins in animal-derived foods, producing amines, ammonia, and other alkaline nitrogenous compounds that may be measured using the TVB-N content. As a result, the TVB-N value is a useful measure of fish freshness. TVB-N at a concentration of 20mg N/100g fish meat is suggested for rejection.The findings show that as the electric field strength increased, the rate of TVB-N changes decreased (Fig. 3). The control sample's changes in TVB-N values were slightly higher (81.17 percent) than those in the HVEF-thawed samples (Fig. 3). Changes in TVB-N values after 6 days of storage decreased with increased voltage at all electrode distances, as seen in Fig. 3. At a constant voltage (10.5 kV), narrower electrode gaps resulted in lower increases in TVB-N values. The removal of microbial load, as well as the formation and release of negative ions in the air, are some of the processes by which the corona influences product quality(MousakhaniGanjeh et al., 2015).

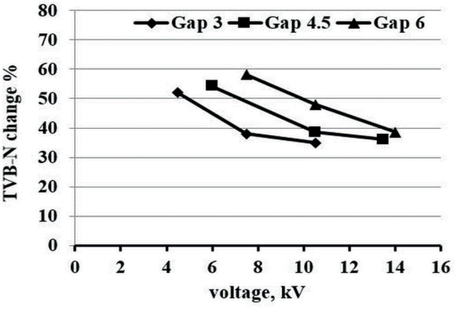

Figure 3. Changes in TVB-N of frozen tilapia fish fillets after thawing in different voltages and gaps.

The HVEF corona might have an impact on product quality by reducing microbial contamination as well as producing and releasing air ions negative charge (IANC) and ozone (Song et al., 2000). Ozone and IANC would prevent or eliminate spoilage and harmful bacteria, resulting in less degradation of fresh items (Starik et al., 2016 and Papachristodoulou et al., 2018). HVEF treatment will minimize TVB-N yield, allowing thawed Tilapia fillets to be stored for longer.

TBA

Malone aldehyde difference in thawed frozen tilapia fish fillets during cold storage is seen in Fig. 4. The findings show that as the applied voltage was increased, Malone aldehyde increased dramatically ($P \leq 0.05$). MDA levels have increased as storage time in the refrigerator at 4°C increased. Furthermore, the entire voltage electrode distances studied showed a growing pattern in these improvements. As a result of the reduced electrode distance, lipid oxidation during storage was more severe with rising voltage. However, when the electrode gap was raised with a constant voltage (10.5 kV) during the trial, lipid oxidation decreased. On days 0, 2, 4, and 6, the highest TBA values were 1.59, 1.81, 2.24, and 2.55 times greater than those recorded for the control at a voltage of 10.5 kV and a distance of 3 cm, respectively. It's possible that the high energy released during HVEF thawing causes lipid oxidation to occur. Lipid oxidation, as well as the formation and release in negative ions of air, are all involved in the influence of corona on product consistency. High levels of negative ions in the environment cause oxidation of the sample surface and taste degradation. The effect of electrical voltages producing air ionization may be the reason for this phenomenon.

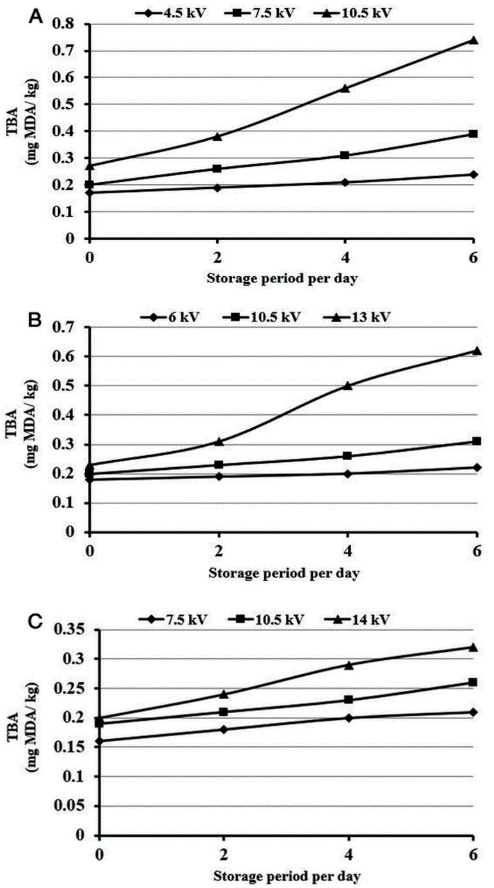

Fig. 4. Changes in TBA values during storage of frozen tilapia fish fillets thawed with different voltages, 3cm (A), 4.5cm (B), and 6cm (C) gaps.

Protein solubility

Protein denaturation can be assessed using a variety of measures. Measuring protein solubility is one of the most general. As seen in Table 2, protein solubility decreased as voltage increased, suggesting that higher voltages resulted in further protein denaturation. With a starting voltage of corona equal to that of air thawed samples (80.02 mg protein/g sample), the highest protein solubility was obtained. The effect of electrode distance on protein denaturation is also seen in the results. Reduced electrode gap has a detrimental effect on protein solubility, resulting in increased denaturation of proteins at constant voltage due to the lower effect of corona at higher electrode gaps. As a result, voltages greater than 10.5 kV generated the greatest influence of corona on protein solubility. The development of negative ions in the air during the application of HVEF appears to be a major factor in protein denaturation.Protein secondary and tertiary structures may be altered, resulting in decreased protein solubility. The thiol group of cysteine is converted to disulfide by the negative ions in the air. Disulfide crosslinks form, which denature the protein and alter its solubility (Cataldo, 2003). Protein solubility is reduced to a greater degree at lower electrode distances and higher voltages when more negative ions of the air are released.

Color differences of NTFFs

Consumers generally equate color with product freshness, improved taste, and higher quality, according to studies of seafood products. L* (lightness), a* (redness–greenness), and b* (yellowness–blueness) values were used to measure fish color in this analysis (He et al., 2013). Table 2 illustrates how variations in voltage and electrode difference affect the color parameters L*, a*, and b*. With increases in applied voltage and electrode distance, the values of a* and b* decreased. The L* values in the test sample were slightly smaller than those in the samples thawed at voltages greater than 10.5 kV. The changes in color parameters can in any way be linked to the development of ozone during the HVEF phase. The results of ozonation on the color parameters of Mackerel surimi were studied by Jiang et al. (1998). They also discovered that ozonation improved the L* value in surimi because the porphyrin ring was oxidized.

Table 2. Influence of voltage and gap on the protein solubility and colour parameters of tilapia fish fillets

Gap (cm)	Voltage (Kv)	Electrical field strength	Protein solubility (%)	Colour parameters		
				L*	a*	b*
3	4.5	1.5	81.03±1.02^{a}	49.44±1.82^{c}	2.60±0.49^{b}	18.43±1.06^{b}
	7.5	2.5	77.96±1.32^{d}	50.46±1.62^{b}	2.55±0.56^{c}	16.69±1.14^{d}
	10.5	3.5	71.84±1.41^{e}	51.50±1.10^{a}	2.52±0.82^{c}	15.03±1.27^{e}
4.5	6.0	1.33	82.16±1.33^{a}	49.26±1.94^{c}	2.61±0.99^{b}	18.96±1.22^{ab}
	10.5	2.33	79.35±1.46^{c}	50.23±1.77^{b}	2.56±.45^{c}	17.24±1.39^{c}
	13.5	3.00	72.15±1.52^{e}	50.98±1.40^{a}	2.54±0.71^{c}	15.75±1.20^{e}
6.0	7.5	1.25	82.19±1.30^{a}	48.61±1.71^{cd}	2.63±0.64^{b}	19.14±1.18^{a}
	10.5	1.75	80.0±1.51^{b}	49.69±1.66^{c}	2.58±0.50^{bc}	17.82±1.32^{c}
	14.0	2.33	79.35±1.29^{c}	50,21±1.58^{b}	2.56±0.62b^{c}	17.23±1.51^{c}
Control		---	80.02±1.73^{b}	50.58±1.79^{b}	2.94±0.55^{a}	19.07±1.98^{a}

Means in same column with different small letters are significantly different ($P \leq 0.05$)

Specific thawing energy consumption

Table 3 shows the influence of high voltage and gap on the energy consumption and specific energy consumption during frozen tilapia fish fillets thawing process. The results indicate that specific thawing energy consumption (Watt.h/kg) significantly increased with increasing applied voltage (P≤0.05). Furthermore, these changes took an increasing trend for all the voltage electrode distances examined. The highest specific thawing energy consumption values obtained at a voltage of 14 kV and a gap of 6 cm was 37.94 Watt.h/kg, combared with other investigated samples.

Table 3. Influence of high voltage and gap on the energy consumption and specific energy consumption

Gap, cm	High voltage, kV	Input power to power supply, Watt	Thawing time, h	Thawing energy consumption Watt.hr	Specific thawing energy consumption Watt.h/kg
3	4.5	2.55f	0.57ab	1.45f	14.54f
	7.5	3.96d	0.48c	1.90e	19.01e
	10.5	5.46c	0.40c	2.18d	21.84d
4.5	6	3.04e	0.62a	1.88e	18.85e
	10.5	5.46c	0.50b	2.73c	27.30b
	13.5	6.9b	0.42c	2.90b	28.98b
6	7.5	3.96d	0.65a	2.57c	25.74c
	10.5	5.46c	0.54b	2.95b	29.48b
	14	7.44a	0.51bc	3.79a	37.94a

Means in same column with different small letters are significantly different ($P \leq 0.05$)

Conclusion

In the food sector, high voltage electric field (HVEF) has recently been regarded a novel thawing technique. The variance in the quality was compared between frozen tilapia fish fillets thawed by high voltage electrostatic field (HVE) and those thawed conventionally as control. The results revealed that thawing under HVEF greatly enhances the thawing rates of frozen tilapia fish fillets and their TVB-N values. In general, thawing frozen tilapia fillets using a high voltage electrostatic field can not only speed up the process, but also improve the quality of the fish..HVEF achieved at a voltage of 10.5 kV and an electrode gap of 3 cm is the optimum choice based on thaw rate and quality parameters.

Author contributions

Atef Mohamed Elsbaay: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing.
Asmaa A. Elattar: Conceptualization, Data curation, Formal analysis, Investigation,Methodology, Writing - original draft.
Rowida Younis Essa: Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing - original draft, Writing - review & editing.

Conflict of Interest

The authors have declared no conflicts of interest for this article.

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