

Effect of Electrical Stimulation on Qualitative Characteristics of Aged Chicken Carcasses: A Comprehensive Review

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Abstract: The aim of this review was to summarize the histological, physical, chemical and microbial aspects and ways to stop the fluctuation in meat quality in addition to enhance its sensory quality using electrical stimulation. The low-voltage electrical stimulation and high-voltage electrical stimulation were employed. Electrical stimulation improves quality of poultry meat by reducing shear, increasing Sarcomere length, and reducing the diameter of muscle fibers. Low-voltage electrical stimulation affects voltages (120 volts directly in the nervous system, while high voltages were more than enough) to remove the polarization of the cover and produce a dense physio-chemical response in the muscles that had a direct effect. Electrical stimulation and injection with salts of sodium chloride and calcium chloride in the carcasses of female goats improved the tenderness of the meat. It was found that electrical stimulation accelerated the development of rigor mortis. Although electrical stimulation reduces breast meat shear, there was limited information about the effects of electrical stimulation on the other quality attributes of poultry meat and the results vary with quality attribute and differ from experimental conditions High voltage (higher than 120 volts) electrical stimulation improved meat quality and decreased the pH. Low voltages (below 120 volts) are used to ensure the safety of workers and give the desired results when used in commercial applications.

Keywords: Electrical stimulation, Physical, Chemical, Microbial characteristics, Meat tenderness.

Introduction

There are approximately 250 million of chickens worldwide, and about 85 millions of adult chickens marketed annually, including the laying hens that have finished their productive year (e.g. at age of 1.5 years), and

the birds from the foundation flocks, and parent flocks that are used in the processes of breeding (Al-Fayyadh *et al.*, 2011).

The adult chickens are characterized by the quality of hard meat, dry and low-trough.

These characteristics are considered one of the most important factors for palatability to the consumer and one of the first factors felt by humans when eating and cutting meat in the mouth into small pieces. It reflects how easy to cut meat into small segments and how easy that teeth penetrate a piece of meat when chewing. Also, this characteristic is affected by the degree of adhesion or connectivity between the muscle fibres with each other, or in other words strength of bonding tissues that surround the muscle fibres and bundles. The meat tenderness relates to the amount of connective tissues in the muscles and the degree of union of muscle proteins with water and the nature of muscle proteins. Besides, it depends on the amount of fat available at muscles (Jassim *et al.*, 2011; Agbeniga, 2018).

After slaughtering the animal and interruption of breath, pyruvic acid changes to lactic acid, which accumulation in muscles leads to reduce the value of pH, and there is not a sufficient amount of ATP released for expanding muscles leading to shrinking and spam of muscles. Therefore, it's preferable to ageing meat after 24 hours following slaughtering in chickens and ducks. This process is expensive for the plant. When the process of ageing is quick from 0-2 hours following slaughtering, 50-80% of meat is stiff. However, when ageing at 6 hours following slaughtering, 70-80% of chicken meat was tender (Asghar & Pearson, 1980; Mota -Rojas *et al.*, 2012).

One of the methods currently used to reduce the ageing time was the electrical stimulation after slaughtering for speeding rigor mortis, so that muscles can be matured within two hours instead of six or more, thus reducing the costs of processing, cooling, storage and energy discharged by the factory

(Warriss, 2000). Electrical stimulation has been studied as a means of reducing aging time and has currently been used commercially. Electrical stimulation is one of the novel methods that use to tenderize meat (Bhat *et al.*, 2019).

Electrical stimulation improves the meat tenderness through decreasing cut values and increasing the length of sarcomere and lowering diameter of muscle fibres. Moreover, there is a possibility of flanging meat at less than two hours of slaughtering at tenderness equivalent to tenderness of flanged and aged meat for four hours after slaughtering. Therefore, electrical stimulation decreases storage time to 50% or more and leads to lowering storing cost. Electrical stimulation leads to fast removing of feathers as well as the stimulation facilitates reducing microbial load on poultry (Thompson *et al.*, 1987; Adeyemi & Sazili, 2014). Different trends in the meat industry are factors that have contributed significantly to improving or maintaining the quality of products. Recently, the meat industry is in line with the consumer's needs for meat with health, safety, and nutritional values and good appearance. Therefore, the aim of this review is to assess the histological, physical, chemical and microbial properties and ways to stop the fluctuation in meat quality and enhance its sensory properties using electrical stimulation.

An Overview of Electrical Stimulation

Electrical Stimulation is the process of applying electrical voltage through a bird body directly after slaughtering and bleeding, resulting in a response in the nervous and muscular systems to voltages or amperes and leading to the occurrence of physiological or biological changes to the meat (Li *et al.*, 1993). The first man who used electrical

stimulation is the scientist named Benjamin Franklin who has worked on turkeys, dating back to 1947, and the meat has been tenderized. The mechanism responsible for the improvement of meat tenderness by electrical stimulation is due to the fact that the electrical stimulation reduces the phenomenon of short cooling since the probability of occurrence is greater when Ca^{+2} ions are released and ATP level stays high in muscles (Asghar & Pearson, 1980).

Low pH and high heat in the muscles immediately after slaughter tear off the membranes of the lysosomes, liberating the lysosomal enzymes to the cytoplasm. This impact can be caused by electrical stimulation that leads to a fast decrease in pH while the slaughtered bird's temperature is high (Asghar & Pearson, 1980). Also, a physical disruption in muscle fibres (Birkhold *et al.*, 1992; Birkhold & Sams, 1993, 1995).

Benefits of Electrical Stimulation

There are several benefits of electric stimulation of slaughtered birds are improve the tenderness of meat through decreasing values of cut (Li *et al.*, 1994a; Hirshler & Sams, 1998), increasing the length of the sarcomere (Birkhold & Sams, 1993), reducing the diameter of muscle fibre (Kannan *et al.*, 1991), and the possibility of flanging meat within less than two hours following slaughtering and with tenderness equivalent flanged and aged meat for four hours following slaughtering (Owens & Sams, 1998; Zocchi & Sams, 1999), then reducing time required for storage to 50% or more storage which leads to reduce the cost of storage. Low microbial load available on slaughtered birds could reduce efforts necessary to remove feathers.

Mechanism of Electrical Stimulation

The use of electrical stimulation on the slaughtered bird and the flow of electric current cause severe contraction in muscles. It was similar to what happens in the living muscle when shrinking with the difference that the flowing current is very large in the case of electrical stimulation compared with those supplied through the nervous system during the life of the animal. The stimulus (the force of action) moves from the surface of the axon to the neuron fibre through synapses and reaches surface of the neuromuscular connectives or what's called neuromuscular connectivity. When a stimulus arrives at an end plate causes a release of Acetyl Choline (ACH) of small vesicles found in the branches of end nerves through Synapses, and ACH is in contact with the ACH membrane, therefore the sodium ion permeability changes as the Sarcolemma cover becomes more permeable to the sodium ions, and then there will be a change in electric voltage from negative into positive inside the cell membrane. This stimulus is transferred to (tubule L) system, nearby (Z-line) and then the effect reaches the longitudinal tubes (L-system) in the sarcoplasmic system. As a result, the associated calcium ions are released and the concentration of free calcium ions increases from 10^{-7} mole to 10^{-5} mole, which spread through via vacuum among muscular fibres. The process of contraction commences by using electrical stimulation. Electrical stimulation is not allowed to delay because the amount of change in pH during a certain period decreases. The temperature of the slaughtered bird begins to decline after bleeding and all these causes affect the rate of glycolysis in muscle (Asghar *et al.*, 1983; Polidori & Vincenzetti, 2017; Agbeniga, 2018). Therefore, it should be carried out early, such as 15-20 minutes following after

slaughtering, because the nervous system and nerves remain effective during this period. This observation is important in the case of the use of low-voltage stimulation as it works through its effect on the nervous system directly. While high-voltage stimulation, which was more than 200 V, gives intense current enough to remove the polarization of the cover and produces a physiochemical response affecting muscles directly (Warriss, 2000).

Electrical Stimulation Systems

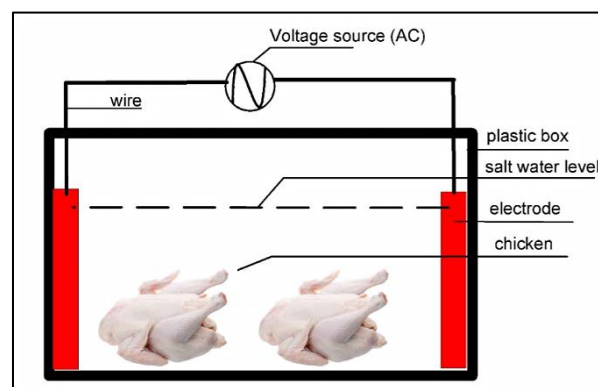
There are many electrical stimulation systems used in the poultry industry, which are classified mainly into two basic systems :

A-Low voltage electrical stimulation (Fehrman *et al.*, 2019).

B-High voltage electrical stimulation (Mombeni *et al.*, 2013; López-Campos *et al.*, 2018).

High voltage electrical stimulation

In this system, voltages higher than 120 volts are used, which is considered common compared with the other systems. Maki & Froning (1987) referred to the fact that the stimulation by using (800 V, AC, 340 milliAmpere, 4 s ON, 5 s OFF, for 36 seconds) led to a significant decrease in the value of pH for thigh muscles after 15 minutes of slaughtering, and cut values of the chest muscles fallen compared with chest muscles resulting from slaughtered birds without electrical stimulation. Mombeni *et al.* (2013) stated that the use of high voltage electrical stimulation was success to decrease the pH of meat and concluded that high voltage electrical stimulation improved meat quality. Thompson *et al.* (1987) indicated that the high voltage was led to an improvement in the tenderness of flanged cuts directly after slaughtering.



Kannan *et al.* (1991) worked on stimulating slaughtered chickens electrically (220 and 330 V, 4 s, 6 s ON: OFF, for 110 s) at the age of 60 weeks. Researchers found that there's no impact of electrical stimulation on the pH after passing 24 h from slaughtering or length of Sarcomere. However, the diameter of fibres decreased after 24 h from slaughtering from 71.11 to 63.05 micron, and from 66.66 to 59.17 micron in the muscle electrically stimulated with a voltage of 220 and 330 V, respectively.

Hirshler & Sams (1998) pointed out that electrically stimulating chickens with an electric current amounting to 450 milliamp caused reduction in the cutting values by 50% when measured Lyon (1991) methods. The results of these two devices were consistent with sensory evaluation results. Zocchi & Sams (1999) noticed that muscles of a flanged broiler, following two hours of slaughtering and resulting from slaughtered birds electrically stimulated (450 volts, 450 milliamper, 2 s ON, 1s OFF, 5 pulses) had the same values of cuts of flanged muscles after four hours of slaughtering which resulted from slaughtered chickens not electrically stimulated (Sams, 1995).

Alvarado & Sams (2000) brought to light that electrical stimulation (370 V for broiler meat, 580 mA for ducks, 60 Hz, 2 s ON, 1 s OFF, 5 pulses) led to a significant reduction in the pH of the muscles an hour after

slaughter and an increase in the cut-off values after 1.25 h of slaughter.

Low voltage electrical stimulation

In this system, voltages below 120 volts are used to ensure the safety of workers. There's a tendency towards this system if low voltages give the desired results when used in commercial applications (Eikelenboom *et al.*, 1985). Froning & Uijttenboogaart (1988) made it clear that stimulation of broiler meat (100 V, 1 s ON, 0.5 s OFF, for 90 sec) did not improve the tenderness of flanged muscles after removing internal guts, or following 15 minutes after that. On the other hand, the electrical stimulation resulted in a significant improvement in the elasticity of the flanged muscles after two or four hours of removing internal guts. Stimulation of electrically slaughtered boiler meat with a voltage of 50 didn't improved tenderness of flanged muscles when cuts values as well as values of tenderness and juiciness were measured (Lyon *et al.*, 1989).

Gault *et al.* (2000) came to point that stimulation of electrically slaughtered boiler meat with a low voltage (100) decreased the pH for chest muscles with an amount of 0.5 units following 20 minutes of slaughter, whether pH was measured by using Iodoacetate or direct connection of an electrode to the muscle .

Salts Used in Electrical Stimulation

Salts alone have been used extensively in softening poultry meat, especially laying hens. On this basis, a number of researchers had studied the effect of using electrical stimulation and salts together. Young & Lyon (1997) disclosed that electrical stimulation (450 mA bird^{-1} , 2 s ON, 1 s OFF, 5 pulses) resulted in the fall of pH of meat treated with sodium chloride.

Hirschler & Sams (1998) found that it is possible to obtain flanged meat after two hours of slaughter and with a tenderness equivalent to the tenderness of the flanged and aged meat through using the two techniques; electrical stimulation (450 mA bird^{-1} , 7 pulses, 2 s ON, 1 s OFF) and an injection using 10% of (3%STPP) together.

The researchers found that the application of these two treatments together gave meat tenderness higher than that of electrically stimulated meat only, and the results of measuring the method were similar when measured with cutting devices or sensory evaluation. Young *et al.* (1999) studied the effect of using electrical stimulation (200 V, 115-125 mA, 1s OFF: 2s ON, AC, for one minute) with triple sodium phosphate salts (4% STPP) on changes in the quality of chest meat in broilers after cooling, they noted that the use of these techniques combined gave more tender meat immediately after cooling compared to electrically stimulated meat or treated with salt separately or electrically non-stimulated and non-salt treatment (control). The cut values for these treatments were 4.44, 5.88, 8.15 and 6.02 kg, respectively. Tenderness of meat after 2, 4 and 6 hours of cooling was not significantly different in all treatments from the control treatment.

Young & Buhr (2000) used sodium chloride salts with or without polyphosphate triple sodium salts (4% STPP) in a possibility to enhance the effect of electrical stimulation (200 V, 115-125 mA bird^{-1} , AC, 2 s ON: 1 s OFF). The researchers observed that only the cuts treated by electrical stimulation, and treated with sodium chloride salts separately gave less liquid loss compared to the electrically motivated cuts and treated with both sodium chloride and STPP salts.

Histological characteristics

Effect of electrical stimulation on the length of sarcomere

Fibroblasts are synthetic tissue proteins consisting of strands that are responsible for directly diminishing and extending the muscle cells, these proteins include actin, myosin, and tropomyosin, and troponin protein of types T, C, I, Actinin: β , α , protein (M-line) of all types: M-protein, Myomesin and Creatin Kinase), C-protein and Desmin. The most proteins that suffers decomposition and breakdown are seven types including tannin, desmin, paranemin napolin, synemin, filamin and T- troponin. These proteins are classified as clico-proteins and have a significant role in the synthesis of sarcomere and considered basic materials for kalpin enzyme (Robson *et al.*, 1997). There is an association between actin and mycin and increase thickness of the muscle fibres leads to reduce of tenderness (Taylor *et al.*, 1995).

Electrical stimulation has the effect of increasing the length of the sarcomere. One possible reason for increasing the length of the sarcomere as a result of the stimulation may be the breakage of the accidental bridges, or shortage of energy components in the muscle and allow it to shrink (Owens & Sams, 1997).

As for the muscle type, the sarcomere in the white muscle fibres is shorter than the sarcomere of the red muscle fibres that they reached 1.85 and 2.00 micron respectively. These variations are attributed to nature, type and diameter of prevailing fibresin each type of muscles (Haj-Saeed, 2004).

Al-Rubaiya *et al.* (2006) showed that the length of sarcomere was due to high voltage electrical stimulation. There is no difference in the length of sarcomere due to the increase of the stimulation time within one voltage. In another study, Apparao *et al.* (2009) observed

a significant effect in increasing sarcomere length when treated with only 220V at storage time of 1 h after electrical stimulation). There was no significant difference between the control treatment and the second treatment 110V for both times (1 and 24 h).

Al-Hmedawy (2019) disclosed that the length of sarcomere had been affected significantly ($p < 0.05$) by the electric stimulation where length of sarcomere was decreased from 1.89-1.87 when electrical field strength increased from 3.67-7.33 $V \cdot cm^{-1}$. The results showed the length of sarcomere at an intensity of the electrical field 7.33 $V \cdot cm^{-1}$ (220 V) in chicken as time progresses .

Effect of electrical stimulation on muscle fibre diameter

Kannan *et al.* (1991) studied the effect of electrical stimulation on diameter of muscle fibres, where he found a fall in the diameter of muscle fibres for laying hens electrically stimulated with a voltage of 220 or 330 V. In a study carried out by Naveena & Mendiratta (2001) on boiler meat of aged chickens raised 52 weeks, there's no effect on the diameter of muscle fibres caused by electrical stimulation.

Effect of electrical stimulation on MFI

There the effect of electrical stimulation on muscle fibres breakage through its effect on breaking down the structural composition of muscle and on rupture and breakdown in the Z-line (Hopkins & Thompson, 2001). Apparao *et al.* (2009) came to a point that there was a significant fall ($p < 0.01$) in the manual of muscle fibres' breakage compared with the control treatment, but there was not a significant effect between a control treatment and the second treatment at 110V.

Al-Hmedawy (2019) stated that the manual of muscle fibres' breakage was significantly affected ($p \leq 0.05$) by electrical stimulation.

The results showed an increased evidence of muscle fibres breakage when the electric field intensity 7.33 V.cm^{-1} (220 V) in chickens at time progressing, and slowness reflected a significant difference from chickens in the manual of muscle fibres' breakage. Al-Rubaiya *et al.* (2010) stated that the use of electrical stimulation and injection with salts of sodium chloride and calcium chloride in the carcasses of female goats improved the tendency of the meat .

Effect of Electrical Stimulation on pH

The pH had an effect toward the physical properties of meat. One of these effects are dark or light colour. High pH values (5.8 and above) increase the water load capacity, showing a darker colour and stiff construction and providing suitable conditions for rot. Low pH value (5.5 or less) leads to different changes from the high pH value, such as showing transparent colour and smooth muscle structure with an increase in the length of storage period (Taher, 1990). The pH values of the stored meat are affected by the conversion of glycogen to lactic acid. Whenever there was an increase in conversion process, pH decreases and then storage life of meat increases. The range of pH fall after slaughtering and occurrence of rigor mortis have a significant role in some sensory characteristics (such as tenderness) and enzymatic degradation (Lawrie, 1958). The fall in pH values might be affected by physiological status of a bird before slaughtering, which in turn affects nature of interactions after slaughtering. This means that there is a relationship between the efficacy of the bird's body before and after slaughter, and the relationship is direct between the effectiveness of muscles after slaughter and the quality and traits of meat produced (Davey & Winger, 1988).

Offer (1991) studied the rise of pH value a one degree from normal limits leads to denaturation of protein 12 times.

A study conducted by Khan & Nakamura (1970) noted the low pH due to an increase in the stimulation time within one voltage. It was shown by the pH values that the electrical stimulation accelerated the development of rigor mortis by lowering the pH due to the accumulation of lactic acid in the muscles as a result of the process of diabetic decomposition. Most researchers noted that there was a significant fall in pH values when electrical stimulation was applied to laying hens (Gault *et al.*, 2000), turkeys (Kannan *et al.*, 1991) and broiler and ducks (Alvarado & Sams, 2000).

In another study, no a significant effect was observed on the pH values of meat (Young & Buhr, 2000). Haj-Saeed (2004) on a study conducted on elderly laying hens, it was found there was a significant effect of electrical stimulation ($p < 0.01$) on decreasing pH value. Moreover, researchers found a sort of fall in pH as long as there is an increase in stimulation time within a single voltage .

Sams (1990) didn't find any significant effect of increasing the stimulation time on the pH. The use of electrical stimulation in the slaughtered speeds up the rate of pH. Glycogenolysis is accelerated after slaughter which is due to stimulation of the effectiveness of glycogenolysis. Al-Hmedawy (2019) found significant differences in pH values and slaughtered bird temperature during electrical stimulation at 3.67 and 7.33 V.cm^{-1} electric field intensity. Postmortem glycolysis was accelerated production of lactic acid by using electrical stimulation which led to reduce meat pH lower than 6 before the temperature of muscle to arrive 10 °C (Lang *et al.*, 2016).

Effect of Electrical Stimulation on the liquid loss during storage

Exuding fluid is a liquid-like liquid that comes out of fresh meat during being stored and from frozen meat during being melted (Al-Fayyadh & Naji, 1989). The increase of exuded liquid and an increase in proportion of nutrients lost with the growing age of the bird and the thickness of the muscle. As long as a muscle is thick, an amount of exuding liquid increases. Kim *et al.* (2008) concluded that amount of loss from exuded fluid of chicken meat increased by 29.2%, while the rate of loss in duck meat was 34.5%. The percentage of protein in exuded fluids also rises due to the protein denaturation (den Hertog-Meishke *et al.*, 1997).

Chemical characteristics

Effect of electrical stimulation on lipid oxidation

A few studies were conducted on red meat and just recently done to understand the relationship between lipid oxidation and eating quality of meat treated with electrical stimulation. Cheng & Ockerman (2013) evaluated the effects of electrical stimulation on rate of lipid oxidation and warmed-over flavour in precooked roast beef after refrigerated storage and reheating, they showed that electrical stimulation had no significant effect on lipid oxidation or formation of thiobarbituric acid reactive substances in pre-cooked roast beef. However, there was an increased undesirable warmed-over flavour for both electrical stimulation and non- electrical stimulation treatments over refrigerated storage time. Riffin *et al.* (2019) investigated the effect of electrical stimulation on the oxidation of alpaca (*Vicunga pacos*) meat and showed that although electrical stimulation increased lipid oxidation within the longissimus, overall

oxidation levels were extremely low and could not be detected by the consumers. For poultry, there is no published study on the effect of electrical stimulation on lipid oxidation .

Physical characteristics

Effect of electrical stimulation on the chicken temperature

There is a lack of study on the effect of electrical stimulation on the temperature of poultry carcasses. For red meat, Carse (1973) reported that beef carcass temperature dropped from 40° to 37°C during electrical stimulation. However, Bendall (1980) reported that mean temperature of whole beef carcasses rose by approximate 0.04 °C. The increases in carcass temperature treated with electrical stimulation have been attributed to accelerate glycolysis after passage of electricity through carcasses.

Effect of electrical stimulation on the colour

Many researchers have reported that electrical stimulation has a significantly affect colour in red meat (Asghar *et al.*, 1983, Adeyemi & Sazili, 2014; Polidori & Vincenzetti 2017), although the results varied with study. Similar results are also reported with electrical stimulation of poultry carcasses. Maki & Froning (1987) studied the quality effect of post-mortem electrical stimulation (after bleeding and prior to scalding) on turkey breast meat. They reported that electrical stimulation significantly increased meat redness (Hunter Lab values) in uncooked breast muscle and decreased lightness in the cooked breast muscle. Froning & Uijttenboogart (1988) treated broiler carcasses with post-mortem intermittent electrical stimulation for 60 s (100 V immediately after bleeding) and breast meat

were deboned at various times (0 to 240 min) after evisceration. They found that there was the significant method of deboning time interaction. Raw breast muscle from electrical stimulation muscle was significantly darker in colour (lower L* value) when the meat was hot-boned at 60 min or earlier. However, there were no significant differences in lightness (L* values) of the treatments beyond the 60-min deboning time. Electrical stimulation resulted in the meat lighter (greater L* values) in non-deboned muscle at all times after evisceration. In addition, the electrical stimulation significantly increased redness (a* values) at all deboning times except 30 min. However, non-deboned electrical stimulation muscle appeared redder (greater a* values) at all times. Electrical stimulation did not consistently affect yellow (b* values) compared with those of untreated birds .

Owens & Sams (1997) evaluated the effects of electrical stimulation on muscle metabolism and breast meat quality in turkeys. turkey hens were electrically stimulated at the neck in a saline bath (570 V, 450 mA, AC, 60 Hz, 2 s on 1 s off for 10 pulses). Their results showed that there was no significant difference in raw meat redness between treatments and no significant effect on meat lightness of the fillets between treatments at boning time at 24 h postmortem. Owens & Sams (1998) further evaluated the effects of electrical stimulation on broiler pectoralispectoralis major harvested at 1 h post-mortem and individually quick frozen or aged on ice. In experiments, birds were treated with similar electrical stimulation parameters at the neck in a saline bath. The researchers found that there was no significant difference in lightness and redness in raw breast meat between the electrical

stimulation treatments or control at 1 or 24 h. Sams & Dzuik (1999) found that the combination of argon gas and electrical stimulation resulted in redder meat.

Craig *et al.* (1999) studies the combined effects of antemortem electrical stunning and postmortem electrical stimulation on broiler breast muscle rigor development and meat quality attributes. The researchers found that here were no significant interactions between trial, stunning, stimulation, or deboning time. Electrical stimulation with 440 V resulted in darker, less yellow (lower b* value) and redder raw meat in the breast samples. Castaneda *et al.* (2005) evaluated the functionality of broiler breast meat of electrically stimulated carcasses with and without normal rapid chilling and found no differences in lightness of raw breast meat between the treated and non-treated samples regardless of carcass chilling method. Lyon *et al.* (1989) evaluated the effects of the combination of electrical stimulation and marination on colour of both raw and cooked frozen/thawed broiler breast meat deboned at four post-mortem times (0, 0.5, 1.0, and 1.5 h post-mortem). The results showed that raw muscles from stimulated carcasses were significantly redder than muscles from non-stimulated carcasses, while the raw meat lightness and yellowness between stimulated and non-stimulated carcasses were not significantly different. Cooked meat from stimulated carcasses was darker and redder than meat from non-stimulated carcasses. Young *et al.* (1999) also investigated the effects of interaction between electrical stimulation and marination on interior colour of cooked muscle and showed that meat lightness, redness and yellowness (CLEL*a*b*) were not significantly affected by the interactions. However, electrical stimulation resulted in significantly greater

lightness and less redness (a^*) of cooked breast meat. Aging time and electrical stimulation significantly affected colour measurements. Marinated treatment only affected b^* values. Perlo *et al.* (2012) found significant interactions of electrical stimulation, marination, and aging time. In both marinated and non-marinated fillets, electrical stimulation treatment increased meat lightness. Aging times increased lightness in fillets aged 8 h compared to 0 h in all treatments (electrically-stimulated and non-electrically-stimulated, marinated and non-marinated). There were also significant differences in redness and yellowness with aging time. Marinated treatment decreased yellowness in both electrical stimulation and non-electrical stimulation fillets. The differences between these studies have been ascribed to differences in stimulation, aging time, or measurement methods (Owens & Sams, 1997, 1998).

The effects of electrical stimulation on meat colour have been attributed to a fast drop in pH and the oxidation of myoglobin (Ledward *et al.*, 1986) and may be its capability to reduce metabolites of surviving oxidative pathways in the muscle (Contreras & Harrison, 1981; Lawrie & Ledward, 2006). In broiler breast meat, although the impact of electrical stimulation on meat quality is not consistent, most studies demonstrate that electrical stimulation results in rapid pH decline. In addition, it is inconclusive about the effects of electrical stimulation on incidence rate of pale, soft and exudative (PSE) in both red meat and poultry breast meat, even though it enhances the rate of glycolysis in muscle (Adeyeni & Sazili, 2014; Castenoda *et al.*, 2005; Polidori & Vincenzetti, 2017). Hafid *et al.* (2018) declared that the electrical stimulation period had a significant effect on the colour of

Muscovy duck meat and the period of 20 min. was better than the other periods. Al-Hmedawy *et al.* (2019). Stated that the Electrical stimulation had a significant ($p < 0.05$) effect on the color compounds (lightness, redness and yellowness)

Effect of electrical stimulation on water-holding capacity

The effects of electrical stimulation on water-holding capacity (WHC) of poultry meat differ from study to study. With turkey, Maki & Froning (1987) did not note any differences in cook loss of whole carcasses and in expressible moisture of both turkey breast and thighs between electrically-stimulated and non-electrically-stimulated samples. Owens & Sams (1998) also measured the effects of electrical stimulation on expressible moisture and cook loss of turkey pectoralis major. The data showed that there was no consistent effect of electrical stimulation on expressible moisture or cook loss. Both of them varied with postmortem harvest time and replications. Froning & Uijttenboogaart (1987) found that cooking losses of the cold deboned groups were significantly greater from electrically-stimulated muscle than from muscle of non-treated controls except at the 0-min, 15-min, and 60-min deboning times. The electrical stimulation produced significantly greater cooking losses in hot deboned meat at deboning times of 120 and 240 min than in controls. However, expressible moisture of breast muscle was not significantly affected by electrical stimulation or deboning methods. Castenoda *et al.* (2005) did not note any differences in cook loss and expressible moisture of broiler breast meat regardless of carcass chilling method.

Alvarado & Sams (2000) investigated the effects of electrical stimulation on postmortem physiology and quality of both

broiler and duck breast meat. The pectoral muscle was harvested from the carcasses after 0.25, 1.25, and 24 h postmortem. The researchers found that that electrical stimulation decreased cook loss in meat harvested at 1.25 h postmortem in broiler pectoralis major, whereas no differences were noted at 0.25 and 24 h. However, electrical stimulation did not affect percentage cook loss of duck muscle for any postmortem deboning time. Dickens & Lyon (1995) studied the effects of stimulating broilers on biochemical reactions and objective texture of the meat deboned after 1, 2, or 3 h in the chiller and did not find any cook loss differences in breast meat from the unstimulated and stimulated carcasses. Young & Lyon (1997) reported that electrical stimulation did not affect moisture absorption during chilling. However, cooking loss was dependent upon time of aging and electrical stimulation. For the unstimulated carcasses, cooking loss remained constant regardless of aging time, but was elevated for those electrical stimulation carcasses that were aged more than 30 min. Zocchi & Sams (1999) compared cook loss of meat treated with electrical stimulation and deboned at 2 h postmortem with cook loss of meat deboned at 4 h postmortem and found no difference due to electrical stimulation or deboning time for either thaw loss or cook loss .

Young *et al.* (1999) found that cooking loss was not significantly affected by interactions among aging time, marination and electrical stimulation and the electrical stimulation resulted in significant increases in cook loss of broiler breast meat, although electrical stimulation improved marinade absorption. Young *et al.* (2005) conducted experiments to determine the effects of carcass electrical stimulation and alternative carcass chilling methods on yield of early-harvested boneless

broiler pectoralis major and reported that either the electrical stimulation treatment or chilling method did not influence harvest breast meat weight and cooked meat weight. However, meat cooked yield was significantly impacted by both the electrical stimulation treatment and chilling method. Breast meat from treated carcasses exhibited significantly greater cooked yields than the meat from non-treated carcasses. Perlo *et al.* (2012) found that cook loss was significantly influenced by aging time, electrical stimulation, marination, and electrical stimulation \times aging time interaction. In non-marinated pectoralis major, the electrical stimulation treatment reduced cook loss in meat aged for 0, 2 and 4 h. In marinated fillets the electrical stimulation treatment decreased cook loss at 2, 4, 6 and 8 h of aging. Marination decreased cook loss of treated meat aged for 4, 6 and 8 h compared to non-marinated control, while no marination effect was observed in non-stimulated breast meat.

Kranen (2003) reported no significant differences in tissue fluid loss due to applying electrical stimulation after feather removal and concluded that the electrical treatment did not negatively affect water-holding capacity of the meat. Lyon *et al.* (1989) evaluated three electrical potentials (50, 200 and 350 V AC) in stimulation of broilers during bleeding. Pectoralis major from broilers subjected to the 350 V stimulation treatment exhibited the lowest cooked yield and the greatest percentage of fluids and solids lost during heating than samples from broilers subjected to 50 V stimulation. There was no significant difference in cooked yield or percentage loss of fluids and solids for breast meat from carcasses subjected to the 50 or 200 V. Gault *et al.* (2000) investigated the influence of different rates of wing flapping on the rate of post-mortem glycolysis in the

pectoralis major of commercially-processed broilers. Broiler carcasses were treated with 300 pulses of low voltage electrical stimulation shortly after slaughter at various frequencies and pulse widths. Results showed that pulse frequency had no effect on cooking loss of breast meat compared to controls.

Effect of electrical stimulation on meat shelf life during storage

No research has been carried out to evaluate shelf life of poultry meat products treated with electrical stimulation. In red meat, quality examination showed some difference in surface discolouration and overall appearance of the retail cuts from electrically stimulated and control lamb carcass (Riley *et al.*, 1980). Previous studies also demonstrated that electrical stimulation enhanced retail case life or meat acceptability of cut steaks (Savell *et al.*, 1977). Rashid *et al.* (1983) did not measure any significant difference in colour of ovine muscle, which were wrapped in oxygen permeable film and displayed under commercial conditions, between stimulated and unstimulated samples .

Effect of electrical stimulation on the microorganisms

Mechanism of microorganism's inactivation using electrical stimulation

Electroporation theory suggests that the high electrical field intensity leads to increase cell membrane permeability due to occur holes in the membranes. Moreover, an imbalance occur in osmotic balance during electroporation due to the leakage of ions and small particles into the cell and thus the membrane becomes preamble for the water that causes the swelling and disruption cell as shown in fig. (2) (Tsong, 1990). Castro *et al.* (1993) reported that the electroporation causes an instability of the binary layer (fat

and protein) in the cell membranes and the small particles and water penetrate it and causes collapsing cell.

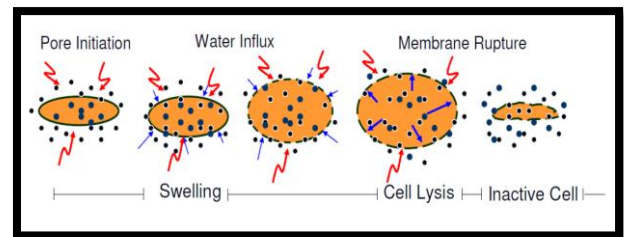


Fig. (2): Stages of electroporation in the cell membrane (Tsong, 1990).

The reduction of microorganisms during applying the electrical field can be calculated by equation 1 (Food & Drug Administration, 2000):

$$\log \left[\frac{D}{D_R} \right] = \frac{-(E - E_R)}{z} \quad (1)$$

Where, D is the time required to reduce microorganisms by 90% through one logarithmic cycle, D_R is the time of decimal reduction at intensity of specific electrical field (E_R) and z is the increment in the intensity of electrical field to decrease of D by one logarithmic cycle . E is the electric field intensity.

Although the effect of electrical stimulation on the microbiology of meat has been widely investigated in red meat (Asghar *et al.*, 1983,; Palaniappan & Sastry, 1990; Adeyemi & Sazili, 2014,; Polidort & Vincenzetti, 2017), there is only very limited information available in poultry (Li *et al.*, 1993) and the research was exclusively limited to *Salmonella typhimurium* and carried out in the same laboratory .

Slavik *et al.* (1990) evaluated electrical stimulation for eliminating or reducing the number of *S. typhimurium* attached to chicken legs and the effect of electrical stimulation on bacteria in an electrolyte solution for

preventing cross-contamination of poultry carcasses during processing. Their data showed that electrical stimulation was effective in killing bacteria in the electrolyte solution and in reducing the number of *Salmonella* attached to chicken legs when legs are attached to anodes. Li *et al.* (1991) reported that low-voltage, low current pulsed electrical signals was effective for killing bacteria in various electrolyte solutions and in poultry chiller water. Their study further showed that *S. typhimutium* attached to chicken skins were reduced by 90% or more after electrical treatment in the electrolyte solutions for 10 min and the effectiveness varied with composition of solution. The researchers concluded that the combined electrical and chemical treatments reduced variation in bacterial reduction and electrical stimulation in combination with a food additive in solution can be used as an alternative method for reducing *S. typhimurium* attached to chicken carcasses as well as tenderization of meat (Li *et al.* 1994b).

The mechanisms bacterial death by electricity may be due to mechanical, chemical, or thermal effects, or to their combination, but they are not yet determined clearly and are not fully understood (Palaniappan & Sastry, 1990). The antimicrobial effects have been attributed to the electrical stimulation deleterious effect on either the bacterial cells by affecting the viability or on the meat as a growth medium by fast reduction in pH value (Riley *et al.*, 1980). Another hypothesis was that the proteolytic enzymes released during electrical stimulation may be destroying the bacteria. The change in redox potential and presence of free radicals may also be responsible for inactivating bacterial cells in meat from electrically stimulated carcasses (Mrigadat et

al., 1980). Al-Hmedawy *et al.* (2018) disclosed that the effect of electrical stimulation (110 and 240 volts) on the number of Psychrophiles, lipolysis and proteolysis was significant ($p < 0.05$), and 240 volts gave higher reducing the microorganisms in both chicken and duck.

Effect of electrical stimulation on poultry meat organoleptic

Unlike red meat (Asghar *et al.*, 1983; Adeyemi & Sazili, 2014; Polidori & Vincenzetti, 2017), there was very limited study on the effects of electrical stimulation on sensory quality of poultry meat. In study on the influence of commercial-scale electrical stimulation on tenderness and meat yield production costs, Hirschler & Sams (1998) evaluated sensory quality of electrically-stimulated chicken breast using a 9-member panel and a 5-point scale. Sensory panel responses indicated that more treated meat was perceived "slight tender" than the 2h non-stimulated controls. Electrical stimulation combined with the injection treatment resulted in meat as tender as that deboned from control carcasses at 8 h post-mortem. Dickens & Lyon (1995), based on the data of the relationship between sensory perception of tenderness and instrumental shear measurements from a separate experiment (Lyon & Lyon, 1991), predicted that the non-treated breast meat was consistently less tender than the treated samples regardless of postmortem deboning time. Young & Lyon (1997) also predicted that unstimulated broiler breast was undesired by the consumers compared with stimulated muscles, and concluded that electrical stimulation in combination with NaCl₂ increased quality of meat and it was desired by the consumers. Table (1) summarized the

effect of electrical stimulation on the qualitative properties of poultry meat.

Table (1): Summarizes the effect of electrical stimulation on the qualitative properties of poultry meat.

Sample description	Stimulation parameters (voltage/Ampere / time)	Effects of stimulation	References
Broiler breast	240, 530, 820V and low voltage 45V/2-3 min.	High voltage significantly increased shear values, declined sarcomere length and acceptance tenderness of chill boned fillets. low voltage improve tenderness of hot boned fillets.	Thompson <i>et al.</i> (1987)
Turkey Meat	800V/430 mA/ 36s/pules (4sec ON, 5sec OFF)	Decreased pH and shear force. No significant effect on the cooking loss, breast moisture and tight moisture. No significant effect on the L-value (lightness)	Maki & Froning (1987)
broiler meat	100 V/ pulse (1 sec ON, 0.5 sec OFF, for 90 sec)	Did not improve the tenderness of flanged muscles. Enhanced elasticity of the flanged muscles. Decreased lightness.	Froning & Uijttenboogaart (1988)
boiler meat	50 V	Did not improve tenderness.	Lyon <i>et al.</i> (1989).
Spent chicken carcasses.	220 or 330 V	Decreased the diameter of muscle fibers.	Kannan <i>et al.</i> (1991)
chicken breast	450 mA/bird/ 2 sec ON, 1 sec OFF, 5 pulses)	Decreased pH	Young & Lyon (1997)
Turkeys	570 V/450 mA/60Hz/(2s on, 1 sec off for 10 pulses)	Reduced pH, accelerated rigor mortis.	Owens & Sams (1997)
breast meat	450 mA/bird, 7 pulses, 2 sec ON, 1 sec OFF)	Improved tenderness	Hirschler & Sams (1998)
Broilers meat	200 V/115-125 mA/ 1sec OFF: 2sec ON, AC, for 1 min.)	Gave more tenderness (stimulation after cooling). No significant effect (only stimulation).	Young <i>et al.</i> (1999)
Broiler breast	56 V/35 mA/2 sec	Decreased toughness, acceptable	Zocchi & Sams

fillets	on, 1 s off	tenderness, reduced the required time by 50%.	(1999)
broiler meat	370V/ 580 mA/pulse (2 sec ON, 1 sec OFF)	Reduced pH and increased the cut-off values after 1.25 hours of slaughter.	Alvarado & Sams (2000)
boiler meat	100 V	Decreased pH	Gault <i>et al.</i> (2000)
chicken breast fillets	200 volts, 115-125 mA/bird, AC, 2 sec ON: 1 sec OFF)	Reduced liquid loss. No effect on the pH.	Young & Buhr (2000)
Broiler	370 V/ 450 mA/60Hz/(2on, 1 off pules)	Reduced pH of muscles, shear values. and gravimetric fragmentation index. Increased cut-off values.	Alvarado & Sams (2000)
Broiler meat	450 mV/ 450 mA/2 s./7 pulse/s	Enhanced meat tenderness, decreased ATP, pH and muscle fibre physical rupture. not any differences in cooking loss	Canstaneda <i>et al.</i> (2005)
Spent Rabbit	110-220V AC.	220V increased sarcomere length higher than 110 V. reduced the manual of muscle fibres' breakage. No significant effect in 110 V.	Apparao, <i>et al.</i> (2009)
Beef carcasses	800 V/2.5 A/ 25s.	Decreased pH, Changed the colour. Rigor mortis was accelerated.	Mombeni <i>et al.</i> (2013)
yak meat	21 V/0.25 A/50 Hz/ 60s	Reduced pH. Accelerated production of lactic acid	Lang <i>et al.</i> , 2016)
Muscovy duck meat	20 V/0-20 min/	Reduced cooking loss, pH. Increased tenderness.	Hafid <i>et al.</i> (2018)
Chicken meat	110-220 V/20s	Significantly reduced Psychrophiles, lipolysis and proteolysis.	Al-Hmedawy <i>et al.</i> (2018)
Chicken meat	110-220V (7.33 V/cm)/length 60Hz/20 s	Significantly effected on the length of sarcomere. Increased muscle fibre breakage. Significant differences in pH values	Al-Hmedawy (2019)

Pulsed electric field stimulation

Pulsed electric field (PEF) is an emerging non-thermal technique and it considered as a

very promising technology of preservation foods and enhancement of food quality. In this technology, the pulsed electric field with

short duration ranged between several nanosecond to milliseconds using electrical field intensity from 0.1 to 80 kV. cm⁻¹ is applied, and PEF pass through food put between two electrodes (Koubaa *et al.*, 2015; Puértolas & Barba, 2016; Barba *et al.* 2018). PEF depends on the electric field intensity, delivered energy and temperature of treatment (Toepfl *et al.*, 2014). Foods treated by PEF had a less degradation of nutrition and sensory compared to the conventional thermal processing (Buckow *et al.*, 2013). The advantage of PEF are lower temperature and processing time (Walkling-Ribeiro *et al.*, 2011). PEF was used to solid food processing (Aguiló-Aguayo *et al.*, 2017; Liu *et al.* 2017) and it is use in meat is considered an emerged technique (Bekhit *et al.*, 2016; Ma *et al.*, 2016; Khan *et al.*, 2017;).

Gudmundsson & Hafsteinsson (2001) and O'Dowd *et al.* (2013) reported that the literatures for using PEF in meat is very little. The meat qualitative characteristics treated by PEF was modified as well as curing and brining were improved. Bhat *et al.* (2018) disclosed that the PEF improves meat tenderness in pre-rigor and post-rigor during aging muscle. There are not literature available about the use of PEF in poultry meat treatment.

The energy density during PEF application is given in equation (2) as follows (Zhang *et al.*, 1995; O'Dowd *et al.*, 2013):

$$Q = \frac{V^2 t}{Rv} \quad (2)$$

Where, Q is the energy density (kJ. kg⁻¹), t is the time of treatment (µs) (pulses number × duration pulse), V is the voltage (V), v is the sample weight (g) and R is the resistance (Ohm).

For reduction of microorganism using PEF, equation (3) is used to calculate reduction of microorganism (Hulsheger *et al.*, 1981):

$$\frac{N}{N_o} = \left[\frac{t}{t_c} \right]^{-(E-E_c)/k} \quad (3)$$

Where, $\frac{N}{N_o}$ is the survival rate, k is the constant, t is the time of treatment, t_c is the critical time (under the time of treatment that no inactivation of microorganisms happens), E is the electric field strength (V.cm⁻¹), E_c is the critical electric field strength (the highest electric field strength which does not inactivation of microorganism).

Conclusions

The meat industry is in line with the consumer's needs for meat with health, safety, and nutritional values and good appearance. Electrical stimulation is one of the novel methods that used to tenderize meat. There are two kinds of electrical stimulation are: low voltage electrical stimulation and high voltage electrical stimulation. Using electrical stimulation and salts together improve meat tenderness more than that of electrically stimulated meat only. Electrical stimulation has the effect of increasing the length of the sarcomere. There was a significant fall (p < 0.01) in the manual of muscle fibre' breakage compared with the control treatment. The low pH is due to an increase in the stimulation time within one voltage. The electrical stimulation had no significant effect on lipid oxidation. Moreover, the electrical stimulation period had a significant effect on the colour of meat. Cooking losses of the cold deboned groups were significantly greater from electrically-stimulated muscle than from muscle of non-treated controls. In addition, electrical stimulation eliminates microorganisms.

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Conflict interest

The authors declare that they have no conflict .of interests

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تأثير التحفيز الكهربائي على الخصائص النوعية لذبائح الدجاج المسنة: مراجعة شاملة

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المستخلص: هدفت هذه المراجعة الى تلخيص الجوانب النسيجية والفيزيائية والكيميائية والميكروبية وطرق وقف التذبذب في جودة اللحوم بالإضافة إلى تعزيز جودتها الحسية باستخدام التحفيز الكهربائي. تم استخدام التحفيز الكهربائي منخفض الجهد والتحفيز الكهربائي عالي الجهد. يعمل التحفيز الكهربائي على تحسين جودة لحوم الدواجن من خلال تقليل القصر وزيادة طول Sarcomere وتقليل قطر ألياف العضلات. يؤثر التحفيز الكهربائي بالجهد المنخفض الفولتية (120 فولت) مباشرة في الجهاز العصبي، بينما الفولتية العالية كافية لإزالة الاستقطاب وإنتاج استجابة فيزيائية وكيميائية كبيرة في العضلات التي تتأثر بشكل مباشر. أدى التحفيز الكهربائي والحقن بملاح كلوريد الصوديوم وكلوريد الكالسيوم في ذبائح الماعز إلى تحسين تطرية اللحم. وجد أن التحفيز الكهربائي يسرع من تطور التيبس الرمي. على الرغم من أن التحفيز الكهربائي يقلل من قوة قص لحوم الصدر إلا أن هناك معلومات محدودة حول تأثير التحفيز الكهربائي على سمات الجودة الأخرى للحوم الدواجن والنتائج تختلف باختلاف سمة الجودة وتختلف عند اختلاف الظروف التجريبية. الجهد العالي (أعلى من 120 فولت) أدى إلى تحسين الجودة وانخفاض درجة الحموضة. يتم استخدام الفولتية المنخفضة (أقل من 120 فولت) لضمان سلامة العمال وإعطاء النتائج المطلوبة عند استخدامها في التطبيقات التجارية.

الكلمات المفتاحية: التحفيز الكهربائي، الخصائص الفيزيائية، الكيميائية، الميكروبية، تطرية اللحم.