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EFFECT OF ELECTROLYZED WATER ON PHYSICO-CHEMICAL AND SENSORY QUALITIES OF BEEF

Gourpada Biswas[1]*, Md. Shafiqul Islam[1], S. M. Mahbubur Rahman[2], S. M. Abdullah Al Mamun[1]
[1] Agrotechnology Discipline, Khulna University, Khulna, Bangladesh
[2] Biotechnology and Genetic Engineering Discipline, Khulna University, Khulna, Bangladesh

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Abstract
During beef processing, contamination by microorganisms from diverse sources poses a significant risk to its quality and safety. This contamination can lead to reduced shelf life, compromised meat quality, and increased health hazards. In recent years, electrolyzed water (EW) has emerged as a promising solution for sanitizing and cleaning beef. The purpose of this study was to evaluate the physicochemical and sensory qualities of beef that had been treated with EW. In this experiment, there were three replications with a factorial Randomized Complete Block Design (RCBD). Factor-A: consisted of six (06) treatments concentrations: T_0 *= Control sample (fresh water);* T_1 *= 10 ppm electrolyzed water;* T_2 *= 20 ppm electrolyzed water;* T_3 *= 30 ppm electrolyzed water;* T_4 *= 40 ppm electrolyzed water;* T_5 *= 50 ppm electrolyzed water; Factor-B: consisted of three (03) durations:* TM_1 *= 5 minutes;* TM_2 *= 10 minutes;* TM_3 *= 15 minutes. The findings showed that the moisture content (%), crude protein (%), ether extract (%) and ash content (%) of beef samples ranged from 72.31 ± 0.29 to 73.93 ± 0.30, 19.95 ± 0.16 to 21.91 ± 0.19, 4.28 ± 0.09 to 5.06 ± 0.09, 1.29 ± 0.09 to 1.76 ± 0.07 respectively. Beef's proximate composition (moisture, crude protein, ether extract, dry matter, and ash) and physical analyses (cooking yield, cooking loss, and pH) were not significantly affected by the EW treatments (*$p > 0.05$*). However, drip loss and beef color showed substantial significant effects (*$p < 0.05$*). Findings suggest that EW treatments with concentration up to 50 ppm can effectively decontaminate beef while maintaining its nutritional and sensory properties.*

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Introduction

Red meat and poultry stand out as the primary sources of high-quality protein in the human diet. In addition, meat products are the concentrated sources of vitamins of B group, notably vitamin B_{12}, which is lacking in plant meals, and the meat is a reasonably rich source of iron that is easily absorbed. Pork makes about 40% of the world's meat consumption, with beef and poultry coming in close behind at roughly 25% and 30%, respectively [1].

Fresh beef is easily contaminated by naturally occurring microorganisms from a variety of sources during processing of all edible carcass tissues [2]. This might lead to a decrease in the quality and shelf life of beef during its storage, and increase health risks. Therefore, it is necessary to develop an effective preservation method that can prolong the shelf life of fresh beef during its storage. Recently, various sanitizing processes have been adopted to improve the safety and quality of fresh meat and meat products before refrigeration [3,4]. The most widely used chemical decontaminants in the meat and poultry industries are organic acid solutions [5,6]. While chlorine rinses are generally used during processing of poultry for pathogens reduction [7], other various processes have been proposed as alternatives to eliminate or substantially decrease bacterial population on poultry carcasses. However, most of these processes are not completely acceptable due to the chemical residues, discoloration of chicken carcasses, high costs, or limited effectiveness. Chlorine solution was usually used for fresh meat refrigeration. But the excessive use of chlorine (Cl_2) can lead to several environmental problems [8]. Furthermore, the consumers are concerned about the use of these chemicals because they may potentially provide undesirable effects on human health. Therefore, most studies on the decontamination of fresh meat or vegetables have focused on sanitizing agent alternative to chlorine [9,10]. Electrolyzed water with a pH of 5.0–6.5 is well recognized as an alternative sanitizer, containing a high concentration of hypochlorous acid [11]. It is produced by the electrolysis of diluted salt (sodium chloride) solution. Compared to conventional disinfectants, the use of EW offers a number of benefits, including cost effectiveness, simplicity of application, efficient disinfection, on-the-spot production, and environmental and human safety. A few studies on electrolyzed water for decontamination and shelf life extension of beef are currently being carried out [2]. The study mostly focused on the reduction of microbial population and did not consider physicochemical and sensory properties of beef. Tango et al. [2] evaluated the changes in color, odor and texture of the EW-treated fresh beef compared to the control sample of beef by the sensory index (SI) and pH. Rahman et al. [12] showed that there was no adverse effect of slightly acidic electrolyzed water (pH 5–6.5) on the poultry meat. Notably, the use of EW on raw meat in Bangladesh has never previously been the subject of a above-specified research.

This study aimed to evaluate the effectiveness of electrolyzed water on physicochemical (moisture, crude protein, ether extract, ash, pH, drip loss, cooking loss), and sensory qualities of fresh beef.

Materials and methods

Collection of raw materials

Beef sample was obtained from a retail meat shop in Gollamari market, Khulna, Bangladesh. The sample was placed in a sterile polythene bag and promptly transported to the laboratory for analysis within one hour.

Experimental design

All of the beef samples were measured and divided into five experimental groups and one control group. The studies were conducted in a factorial RCBD with three replications. Factor-A: consisted of six (06) treatments concentrations: T_0 = Control sample (fresh water); T_1 = 10 ppm electrolyzed water; T_2 = 20 ppm electrolyzed water; T_3 = 30 ppm electrolyzed water; T_4 = 40 ppm electrolyzed water; T_5 = 50 ppm electrolyzed water; Factor-B: consisted of three (03) durations: TM_1 = 5 minutes; TM2 = 10 minutes; TM_3 = 15 minutes. The effect of EW on the nutritional quality (proximate analysis, pH, drip loss, cooking yield, cooking loss and sensory analysis) of beef meat was studied.

Preparation of electrolyzed water (EW) solution

Electrolyzed water with pH of 2.3, available chlorine concentration (ACC) of 70ppm, and oxidation reduction potential (ORP) of 1100 mV was used for the preparation of EW (electrolyzed water) solution of varying concentrations like 10 ppm, 20 ppm, 30 ppm, 40 ppm and 50 ppm. Electrolyzed water was diluted with distilled water of varying volume and the pH, ORP and ACC of each solution was measured. The pH and ORP were measured using a dual scale pH/ORP meter CON60 (Trans-Wiggens, Singapore). The ACC was determined using a digital chlorine test system RC-2Z (Kasahara Chemical Instruments Co., Saitama, Japan). The final pH of the solution was 5.8, 5.3 5.0, 4.2, 3.5 for 10 ppm, 20 ppm, 30 ppm, 40 ppm and 50ppm of EW solution respectively.

Determination of proximate composition

Using the method of [13], the proximate composition of beef was evaluated in terms of moisture, crude protein, ether extract, dry matter, and ash content.

Moisture content

Drying oven (SH Scientific, Korea) was used to determine the moisture content. For this, 50 g of ground meat samples from each treatment concentration mode were oven dried at 75 °C for 24 hours till a constant weight was obtained and thus calculated:

$$\text{Moisture (\%)} = \frac{(W_1 - W_2)}{W_1} \times 100 \tag{1}$$

$$\text{Dry matter (\%)} = \frac{W_2}{W_1} \times 100 \tag{2}$$

Where,
W_1 = Initial weight of sample (g);
W_2 = Final weight of sample (g).

Crude protein

Semiautomatic digestion and distillation unit (VELP Scientifica, Italy) was used to determine the crude protein of meat samples by Kjedahl method. The actual crude protein values of the meat samples were obtained by converting nitrogen content of meat with constant 6.25.

$$\text{Crude protein (\%)} = (6.25 \times N\%) \tag{3}$$

Ether extracts (Fat)

Semiautomatic solvent extractor (VELP Scientifica, Italy) was used to determine the ether extracts by Soxhlet method.

$$\text{Ether extract (\%)} = \frac{W_2}{W_1} \times 100 \tag{4}$$

Where,
W_1 = Weight of sample (g);
W_2 = Weight of fat (g).

Ash content

Ash content was determined by igniting 3g of ground meat samples in a muffle furnace SH-FU-5MGE (SH Scientific, Korea) at 600 °C for 5 hours until ashes were formed.

$$\text{Ash (\%)} = \frac{W_2}{W_1} \times 100 \tag{5}$$

Where,
W_1 = Weight of sample (g);
W_2 = Weight of ash (g).

Measurement of pH

The pH was determined with a digital pH-meter (Seven Easy pH, Mettler-Toledo GmbH, Switzerland). For this, the beef sample was homogenized with a Polytron blender (Brinkman Instrument, New York) at 1000 rpm for 30 seconds. A 10 g of homogenized sample was weighed into a beaker along with 50ml of distilled water. Next, the sample was added to 5 different beakers containing 10, 20, 30, 40, and 50 ppm EW solution. A control experiment was also conducted without the addition of EW solution. A stir bar was placed in the homogenized solution and pH was measured while stirring.

Determination of cooking yield and cooking loss

The cooking loss was calculated as the percentage difference between the weights before and after cooking, as described in the reference [14]. Initially, fresh samples were sliced and weighed to obtain their initial weight and then cooked using a dry heat method. Briefly, the meat was placed on a water bath with a beaker containing the meat extending above the water surface. Traditional cooking times were adhered to determining cooking loss and cooking yield. It is important to note that it took 20 minutes to reach a temperature of 100 °C. Subsequently, the meat was removed from the beaker, dried, and weighed. Cooking loss was measured in duplicate. Following this, the meat sample was cooked for an additional 10 minutes at 100 °C (totaling 30 minutes), surface dried, and weighed. Finally, the meat sample was cooked for another 10 minutes at 100 °C (totaling 40 minutes, the traditional cooking time for beef in Bangladesh), surface dried, and weighed again. Cooking loss was then determined in duplicate.

$$\text{Cooking loss (\%)} = \frac{W_1 - W_2}{(W_1)} \times 100 \quad (6)$$

$$\text{Cooking yield (\%)} = \frac{(W_2)}{(W_1)} \times 100 \quad (7)$$

Where

Weight of sample before cooking = W_1;

Weight of sample after cooking = W_2.

Determination of drip loss

Drip loss was determined by the standard bag method [15]. Approximately 40 g of meat sample was utilized for assessing drip loss. The sample was then ensconced in netting and suspended within an inflated bag to prevent contact with the bag, or placed in a container on a supporting mesh, and sealed securely. Following a chilling period of 24 hours, the samples were reweighed. The same samples were used for subsequent drip loss measurements for up to 3 days, with the initial weight serving as the reference point per each experimental trial. When measured, samples were promptly removed from the containers, gently blotted dry, and then weighed.

$$\text{Drip loss (\%)} = \frac{W_1 - W_2}{(W_1)} \times 100 \quad (8)$$

Where

Weight of sample before thawing = W_1

Weight of sample after thawing = W_2

Sensory evaluation

The sensory evaluation study was conducted following the procedures [16]. Six panelists participated in the sensory evaluation which was carried out at Animal Husbandry Laboratory of Agrotechnology Discipline, Khulna University, Bangladesh. In order to minimize bias, three samples were coded before being evaluated by a sensory panel based on how similar the samples were in terms of appearance, texture, scent, and general acceptability. Panelists were served in their separate locations. A nine-point hedonic scale was used, with nine being the lowest score (dislike extremely) and one representing the greatest score (like extremely).

Color analysis

For color analysis of the samples, a CM (Minolta Chromometer CR-400, Osaka, Japan) with a 1 cm aperture, illuminant C and a2 viewing angle was used. A white calibration plate was used to calibrate the device prior to data collection. Evaluations were made of lightness (L*), redness (a*), and yellowness (b*). Readings were obtained close to each core's center. Color coordinates (*L**, *a** and *b**) were observed on the surface exposed by cutting. Coordinate a* ranged from red (+a*) to green (–a*) and coordinate *b** from yellow (+*b**) to blue (–*b**) [17]. Three readings of *L**, *a**, *b**values were obtained at different sites.

Statistical analysis

Data entry was conducted using Microsoft Excel, and subsequent analysis was performed using Statistix-10 software. The impact of electrolyzed water on the physicochemical and sensory qualities of beef was assessed through analysis of variance. The least significant difference (LSD) test was used to compare treatment means in cases where significant differences were identified, with $p < 0.001$ being considered statistically significant.

Results and discussion

Proximate composition of beef meat

The findings of the proximate composition are summarized in the Table 1. Moisture content gradually increased along with the increase of concentration of EW, whereas dry matter content, crude protein, ether extract and ash content gradually decreased. Crude protein content, ether extract and ash content were negatively correlated with moisture content [18]. Fat and moisture content are inversely proportional [19], as was observed in this study as well. There was no significant (NS) difference($p > 0.05$) among the treatments.

Drip loss and pH

The drip loss of beef samples was evaluated in 24 hours, 48 hours, and 72 hours, corresponding to day 1, day 2, and day 3, respectively. The results are listed in the Table 2. Drip loss is a critical aspect in the meat industry, particularly from a financial standpoint [20]. Generally, beef with high drip loss has an unattractive appearance. It also decreases meat tenderness and juiciness. Drip loss (%) was increased along with advancement of storage time. It was found that drip loss gradually decreased with the increase of concentration of EW. The treatments resulted in a significantly different drip loss of meat ($p < 0.001$).

Table 1. Proximate composition of beef treated with electrolyzed water

Treatment combination mode	Moisture (%)	Dry matter (%)	Crude protein (%)	Ether extract (%)	Ash (%)
$T_0 \times TM_1$	72.31 ± 0.29	27.68 ± 0.29	21.91 ± 0.19	4.55 ± 0.16	1.48 ± 0.16
$T_0 \times TM_2$	72.68 ± 0.28	27.32 ± 0.28	21.90 ± 0.31	4.65 ± 0.17	1.29 ± 0.09
$T_0 \times TM_3$	72.42 ± 0.30	27.58 ± 0.30	21.74 ± 0.16	4.86 ± 0.18	1.72 ± 0.17
$T_1 \times TM_1$	73.17 ± 0.36	26.82 ± 0.36	20.33 ± 0.34	5.06 ± 0.09	1.55 ± 0.08
$T_1 \times TM_2$	72.96 ± 0.35	27.04 ± 0.35	20.70 ± 0.35	4.72 ± 0.11	1.49 ± 0.17
$T_1 \times TM_3$	72.90 ± 0.36	27.11 ± 0.36	20.31 ± 0.27	5.0 ± 0.19	1.76 ± 0.07
$T_2 \times TM_1$	73.11 ± 0.30	26.89 ± 0.30	20.41 ± 0.27	4.69 ± 0.25	1.44 ± 0.08
$T_2 \times TM_2$	73.23 ± 0.32	26.77 ± 0.32	20.19 ± 0.19	4.60 ± 0.10	1.47 ± 0.03
$T_2 \times TM_3$	73.05 ± 0.36	26.94 ± 0.36	20.52 ± 0.16	4.54 ± 0.12	1.60 ± 0.14
$T_3 \times TM_1$	73.51 ± 0.30	26.49 ± 0.30	20.23 ± 0.27	4.51 ± 0.16	1.48 ± 0.10
$T_3 \times TM_2$	73.63 ± 0.32	26.37 ± 0.32	20.30 ± 0.18	4.33 ± 0.14	1.36 ± 0.13
$T_3 \times TM_3$	73.35 ± 0.35	26.65 ± 0.35	20.29 ± 0.19	4.46 ± 0.09	1.56 ± 0.08
$T_4 \times TM_1$	73.60 ± 0.30	26.39 ± 0.30	20.26 ± 0.14	4.37 ± 0.14	1.35 ± 0.04
$T_4 \times TM_2$	73.69 ± 0.31	26.30 ± 0.31	20.11 ± 0.15	4.27 ± 0.09	1.49 ± 0.10
$T_4 \times TM_3$	73.42 ± 0.35	26.58 ± 0.35	20.02 ± 0.16	4.34 ± 0.06	1.45 ± 0.04
$T_5 \times TM_1$	73.84 ± 0.30	26.16 ± 0.30	19.95 ± 0.16	4.29 ± 0.10	1.40 ± 0.04
$T_5 \times TM_2$	73.93 ± 0.30	25.96 ± 0.30	20.02 ± 0.15	4.28 ± 0.09	1.40 ± 0.05
$T_5 \times TM_3$	73.72 ± 0.35	26.28 ± 0.35	19.98 ± 0.15	4.31 ± 0.11	1.36 ± 0.06
Significant Level	NS	NS	NS	NS	NS

The pH of samples was analyzed within 24 hours, and the findings are presented in the Table 2. pH levels ranged from 5.42 to 6.11. As the concentration of EW increased, there was a gradual decrease in pH. However, no significant difference ($p > 0.05$) in pH was observed among the treatments.

Table 2. Drip loss and pH of the beef treated with electrolyzed water

Treatment combination mode	pH	Drip loss–day 1 (%)	Drip loss–day 2 (%)	Drip loss–day 3 (%)
$T_0 \times TM_1$	6.11 ± 0.007^a	3.31 ± 0.05^a	3.77 ± 0.05^a	4.92 ± 0.02^a
$T_0 \times TM_2$	6.10 ± 0.007^a	3.29 ± 0.08^a	3.54 ± 0.009^b	4.76 ± 0.02^b
$T_0 \times TM_3$	6.10 ± 0.006^a	3.28 ± 0.03^a	3.48 ± 0.007^c	4.67 ± 0.06^c
$T_1 \times TM_1$	5.84 ± 0.003^b	3.18 ± 0.02^b	3.44 ± 0.003^{cd}	4.13 ± 0.03^d
$T_1 \times TM_2$	5.80 ± 0.007^c	3.14 ± 0.006^{bc}	3.41 ± 0.04^d	3.91 ± 0.02^e
$T_1 \times TM_3$	5.75 ± 0.01^d	3.10 ± 0.04^{cd}	3.40 ± 0.02^d	3.85 ± 0.04^f
$T_2 \times TM_1$	5.72 ± 0.007^e	3.06 ± 0.02^d	3.23 ± 0.009^e	3.77 ± 0.06^g
$T_2 \times TM_2$	5.69 ± 0.006^f	3.05 ± 0.03^{de}	3.16 ± 0.03^f	3.70 ± 0.03^{hi}
$T_2 \times TM_3$	5.69 ± 0.009^f	3.06 ± 0.05^d	3.11 ± 0.003^f	3.69 ± 0.006^{hi}
$T_3 \times TM_1$	5.66 ± 0.009^g	2.98 ± 0.04^{ef}	3.11 ± 0.009^f	3.67 ± 0.006^i
$T_3 \times TM_2$	5.64 ± 0.003^h	2.90 ± 0.06^{fg}	3.01 ± 0.007^g	3.74 ± 0.05^{gh}
$T_3 \times TM_3$	5.63 ± 0.007^h	2.89 ± 0.01^g	3.03 ± 0.02^g	3.70 ± 0.06^{hi}
$T_4 \times TM_1$	5.60 ± 0.003^i	2.86 ± 0.07^g	2.90 ± 0.01^{hi}	3.11 ± 0.01^j
$T_4 \times TM_2$	5.58 ± 0.009^i	2.88 ± 0.09^g	2.94 ± 0.01^h	3.05 ± 0.05^k
$T_4 \times TM_3$	5.56 ± 0.007^j	2.84 ± 0.04^g	2.85 ± 0.03^i	2.98 ± 0.006^l
$T_5 \times TM_1$	5.56 ± 0.003^j	2.47 ± 0.006^h	2.51 ± 0.02^j	2.63 ± 0.006^m
$T_5 \times TM_2$	5.53 ± 0.007^k	2.31 ± 0.02^i	2.43 ± 0.03^k	2.55 ± 0.02^n
$T_5 \times TM_3$	5.52 ± 0.006^k	2.27 ± 0.05^i	2.32 ± 0.009^l	2.49 ± 0.006^o
Significant level	***	*	***	***

Means with different superscripts within same column differ significantly; * = Highly significant ($p < 0.001$), * = Significant ($p < 0.05$).**

Cooking loss and cooking yield

The Table 3 presents the cooking yield and cooking loss of beef treated with varying concentrations of electrolyzed water. Cooking loss, measured at 20 minutes, 30 minutes, and 40 minutes, represents the reduction in weight of beef during cooking [21]. Due to the possibility of moisture loss and soluble nutrients loss, this parameter is crucial for the meat processing sector [22]. The percentage of cooking loss varied from 33.86% to 35.82% [14]. The cooking loss that we observed in our results, which varied between 38.70% and 47.51%, was slightly greater than what was previously reported [14]. Cooking loss (%) decreased gradually with the increase of concentration of EW but yet increased along with advancement of cooking time. Meat's pH value has a significant impact on cooking loss; if the meat's pH is higher or lower than its isoelectric point (5.0–5.1), the amount of cooking loss will be decreased [23]. Elevated cooking temperatures may be linked to increased cooking loss because they denaturize collagen and actin protein (over 60 °C), which shrinks muscle fibers parallel to their axis and extracts water from the space between them [24]. No significant (NS) difference was observed among the treatments.

Sensory evaluation

Table 4 summarizes the results of the tasting panelists' evaluation of the beef's appearance, aroma and texture among other quality criteria. The highest values were found in the trial $T_2 \times TM_2$ for appearance and aroma. Beef samples treated with 20 ppm EW solution was chosen as the most desirable appearance and aroma. As the addition of 50 ppm EW solution treated with meat, appearance got worse but texture improved. No significant difference (NS) was observed among the treatments in case of appearance, aroma and texture. The findings of our study showed that the meat

Table 3. Cooking loss and cooking yield of beef treated with electrolyzed water

Treatment combination mode	Cooking loss-20 minutes (%)	Cooking yield-20 minutes (%)	Cooking loss-30 minutes (%)	Cooking yield-30 minutes (%)	Cooking loss-40 minutes (%)	Cooking yield-40 minutes (%)
$T_0 \times TM_1$	43.27 ± 0.10	56.73 ± 0.10	45.79 ± 0.15	54.21 ± 0.15	47.51 ± 0.12	52.48 ± 0.12
$T_0 \times TM_2$	43.10 ± 0.01	56.89 ± 0.01	45.70 ± 0.16	54.54 ± 0.16	47.49 ± 0.11	52.50 ± 0.11
$T_0 \times TM_3$	43.07 ± 0.06	56.92 ± 0.06	45.60 ± 0.11	54.19 ± 0.11	47.48 ± 0.10	52.52 ± 0.10
$T_1 \times TM_1$	42.73 ± 0.19	57.26 ± 0.19	43.91 ± 0.03	56.08 ± 0.03	45.12 ± 0.10	54.88 ± 0.10
$T_1 \times TM_2$	42.71 ± 0.18	57.28 ± 0.18	43.74 ± 0.15	56.25 ± 0.15	45.20 ± 0.28	54.80 ± 0.28
$T_1 \times TM_3$	42.72 ± 0.20	57.28 ± 0.20	43.68 ± 0.08	56.32 ± 0.08	45.03 ± 0.14	54.96 ± 0.14
$T_2 \times TM_1$	41.59 ± 0.17	58.40 ± 0.17	42.67 ± 0.16	57.32 ± 0.16	44.04 ± 0.14	55.96 ± 0.14
$T_2 \times TM_2$	41.59 ± 0.14	58.40 ± 0.14	42.55 ± 0.15	57.44 ± 0.15	44.03 ± 0.16	55.99 ± 0.16
$T_2 \times TM_3$	41.54 ± 0.12	58.45 ± 0.12	42.52 ± 0.12	57.47 ± 0.12	43.91 ± 0.16	56.09 ± 0.16
$T_3 \times TM_1$	40.89 ± 0.02	59.11 ± 0.02	42.34 ± 0.04	57.62 ± 0.04	43.18 ± 0.16	56.81 ± 0.16
$T_3 \times TM_2$	40.79 ± 0.04	59.17 ± 0.04	42.34 ± 0.05	57.66 ± 0.05	43.10 ± 0.14	56.89 ± 0.14
$T_3 \times TM_3$	40.69 ± 0.08	59.31 ± 0.08	42.19 ± 0.03	57.74 ± 0.03	43.0 ± 0.10	56.99 ± 0.10
$T_4 \times TM_1$	40.11 ± 0.13	59.88 ± 0.13	42.05 ± 0.07	57.95 ± 0.07	42.93 ± 0.11	57.06 ± 0.11
$T_4 \times TM_2$	40.09 ± 0.10	59.90 ± 0.10	41.91 ± 0.14	58.09 ± 0.14	42.90 ± 0.11	57.09 ± 0.11
$T_4 \times TM_3$	40.01 ± 0.05	59.99 ± 0.05	41.83 ± 0.04	58.17 ± 0.04	42.80 ± 0.10	57.19 ± 0.10
$T_5 \times TM_1$	38.97 ± 0.07	61.02 ± 0.07	40.22 ± 0.03	59.78 ± 0.03	41.71 ± 0.09	58.28 ± 0.09
$T_5 \times TM_2$	38.77 ± 0.13	61.22 ± 0.13	40.11 ± 0.03	59.88 ± 0.03	41.69 ± 0.10	58.31 ± 0.10
$T_5 \times TM_3$	38.70 ± 0.09	61.29 ± 0.09	40.10 ± 0.03	59.60 ± 0.03	41.55 ± 0.05	58.45 ± 0.05
Significant Level	NS		NS	NS	NS	NS

treated with EW had better sensory score than the untreated sample. Rahman et al. [1] reported that EW treated samples had better sensory scores than the untreated samples, as observed in this study as well. These results indicate that EW treatment can improve sensory qualities and extend shelf life of meat during storage at 5 °C. EWs contained OH and HOCl that have strong antimicrobial activity and antioxidant effect. Furthermore, residual NaCl content of EW provides meat samples with freshness color and keeps meat aroma as well.

Table 4. Sensory evaluation of beef treated with electrolyzed water

Treatment combination mode	Appearance	Aroma	Texture
$T_0 \times TM_1$	2.67 ± 0.006	2.65 ± 0.007	2.33 ± 0.01
$T_0 \times TM_2$	2.66 ± 0.009	2.67 ± 0.007	2.33 ± 0.02
$T_0 \times TM_3$	2.67 ± 0.007	2.64 ± 0.01	2.33 ± 0.02
$T_1 \times TM_1$	2.67 ± 0.02	3.31 ± 0.03	2.0 ± 0.04
$T_1 \times TM_2$	2.67 ± 0.009	3.33 ± 0.02	2.02 ± 0.02
$T_1 \times TM_3$	2.65 ± 0.03	3.33 ± 0.02	2.01 ± 0.02
$T_2 \times TM_1$	3.64 ± 0.03	4.66 ± 0.03	3.33 ± 0.01
$T_2 \times TM_2$	3.67 ± 0.03	4.67 ± 0.01	3.32 ± 0.02
$T_2 \times TM_3$	3.65 ± 0.03	4.64 ± 0.02	3.33 ± 0.03
$T_3 \times TM_1$	2.3 ± 0.007	4.33 ± 0.01	4.29 ± 0.04
$T_3 \times TM_2$	2.33 ± 0.007	4.33 ± 0.009	4.31 ± 0.01
$T_3 \times TM_3$	2.33 ± 0.03	4.30 ± 0.01	4.32 ± 0.007
$T_4 \times TM_1$	2.66 ± 0.007	4.33 ± 0.01	4.33 ± 0.01
$T_4 \times TM_2$	2.65 ± 0.007	4.32 ± 0.009	4.33 ± 0.02
$T_4 \times TM_3$	2.66 ± 0.007	4.32 ± 0.01	4.33 ± 0.01
$T_5 \times TM_1$	3.31 ± 0.009	4.66 ± 0.03	4.65 ± 0.009
$T_5 \times TM_2$	3.32 ± 0.007	4.64 ± 0.009	4.66 ± 0.03
$T_5 \times TM_3$	3.30 ± 0.09	4.64 ± 0.01	4.63 ± 0.009
Significant Level	NS	NS	NS

Color analysis

The Table 5 summarizes the findings of the evaluation of the color of beef based on numerous flame qualities, including brightness, redness, and yellowness of beef treated with varying quantities of electrolyzed water. Consumer tastes and the quality of beef products are significantly influenced by beef color. Customers' opinions of the quality of meat are significantly influenced by the redness of the beef [25]. Numerous factors, such as the type of animal,

Table 5. Color analysis of beef treated with electrolyzed water

Treatment combination mode	Lightness (L*)	Redness (a*)	Yellowness (b*)
$T_0 \times TM_1$	42.89 ± 0.16^{n}	11.93 ± 0.18^{p}	9.70 ± 0.11^{a}
$T_0 \times TM_2$	43.11 ± 0.08^{m}	12.30 ± 0.06^{o}	9.67 ± 0.03^{a}
$T_0 \times TM_3$	43.23 ± 0.07^{m}	12.39 ± 0.07^{no}	9.51 ± 0.1^{b}
$T_1 \times TM_1$	43.98 ± 0.06^{l}	13.11 ± 0.06^{m}	8.52 ± 0.07^{c}
$T_1 \times TM_2$	43.83 ± 0.20^{l}	12.47 ± 0.12^{n}	8.57 ± 0.02^{c}
$T_1 \times TM_3$	44.06 ± 0.22^{k}	13.39 ± 0.18^{l}	8.44 ± 0.03^{d}
$T_2 \times TM_1$	45.01 ± 0.21^{j}	14.18 ± 0.06^{k}	7.71 ± 0.02^{f}
$T_2 \times TM_2$	45.09 ± 0.16^{j}	15.29 ± 0.18^{i}	7.79 ± 0.18^{e}
$T_2 \times TM_3$	45.35 ± 0.09^{i}	15.19 ± 0.15^{j}	7.63 ± 0.10^{g}
$T_3 \times TM_1$	46.69 ± 0.19^{g}	16.32 ± 0.08^{g}	6.28 ± 0.05^{j}
$T_3 \times TM_2$	46.52 ± 0.14^{h}	16.12 ± 0.17^{h}	6.62 ± 0.09^{h}
$T_3 \times TM_3$	46.97 ± 0.07^{f}	16.83 ± 0.13^{f}	6.51 ± 0.15^{i}
$T_4 \times TM_1$	47.32 ± 0.11^{e}	17.75 ± 0.11^{e}	5.45 ± 0.13^{l}
$T_4 \times TM_2$	47.75 ± 0.14^{d}	18.08 ± 0.08^{d}	5.71 ± 0.12^{k}
$T_4 \times TM_3$	47.96 ± 0.11^{c}	18.39 ± 0.12^{c}	5.44 ± 0.12^{l}
$T_5 \times TM_1$	49.02 ± 0.11^{b}	19.25 ± 0.06^{b}	4.35 ± 0.01^{n}
$T_5 \times TM_2$	49.16 ± 0.16^{b}	19.43 ± 0.15^{a}	4.52 ± 0.10^{m}
$T_5 \times TM_3$	49.42 ± 0.15^{a}	19.51 ± 0.09^{a}	4.59 ± 0.16^{m}
Significant Level	***	***	***

Means with different superscripts within same column differ significantly; * = Highly significant ($p < 0.001$).**

age at slaughter, muscle position anatomically, fat level, and cooking method, can affect the color of beef [26].

There was a highly significant difference in color attributes such as lightness ($p<0.001$), redness ($p<0.001$) and yellowness ($p<0.001$) among the treatments.

Correlation matrix of selected nutritional properties of beef

The results of Pearson's correlation coefficients in correlation analysis among selected physical and nutritional properties of beef are presented in the Table 6. There was nonsignificant (NS) correlation among the parameters. We found nonsignificant positive correlation between dry matter and crude protein (r = 0.8669); dry matter and ether extract (r = 0.6609); crude protein and ether extract (r = 0.3422); dry matter and ash (r = 0.5230); crude protein and ash (r = 0.1904); ether extract and ash (0.6763). We also found nonsignificant negative correlation between moisture and dry matter (r = –0.9448); moisture and crude protein (r = –0.8258); moisture and ether extract (r = –0.6845); moisture and ash (r = –0.4744)

Table 6. Pearson's correlation coefficients among selected nutritional properties of beef

Parameters	1	2	3	4
1. Moisture				
2. Dry matter	**–0.9448^{NS}**			
3. Crude protein	**–0.8258^{NS}**	**0.8669^{NS}**		
4. Ether extract	**–0.6845^{NS}**	**0.6609^{NS}**	**0.3422^{NS}**	
5. Ash	**–0.4744^{NS}**	**0.5230^{NS}**	**0.1904^{NS}**	**0.6763^{NS}**

Correlation matrix of selected physical properties of beef

The results of Pearson's correlation coefficients correlation analysis among selected physical and nutritional properties of beef are presented in the Table 7. There was nonsignificant (NS) correlation among the parameters. We found nonsignificant positive correlation between pH and drip loss after 24 hours (r = 0.7984); pH and drip loss after 48 hours (r = 0.8600); pH and drip loss after 72 hours (r = 0.9326); pH and cooking loss after 20 minutes (r = 0.8774); pH and cooking loss after 30 minutes (r = 0.9547); pH and cooking loss after 40 minutes (r = 0.9814) drip loss after 24 hours and drip loss after 48 hours (r = 0.9735); drip loss after 24 hours and drip loss after 72 hours (r = 0.9213); drip loss after 24 hours and cooking loss after 20 minutes (r = 0.9462); drip loss after 48 hours and cooking loss after 20 minutes (r = 0.9783); drip loss after 72 hours and cooking loss after 20 minutes (r = 0.9481); drip loss after 48 hours and cooking loss after 30 minutes (r = 0.9558); cooking loss after 20 minutes and cooking loss after 30 minutes (r = 0.9531); cooking loss after 30 minutes and cooking loss after 40 minutes (r = 0.9862).

Conclusion

The experiment was aimed to investigate the effect of electrolyzed water on the nutritional composition and sensory characteristics of beef. Electrolyzed water, specifically electrolytically generated hypochlorous acid, has been used as an effective sterilizing agent for raw meat for several decades. It was imperative to determine an acceptable level of electrolyzed water concentration and duration of exposure that would not compromise the nutritional quality of the meat. The study comprehensively analyzed physicochemical parameters such as proximate analysis, pH, drip loss, cooking yield, and cooking loss, as well as sensory attributes including appearance, aroma, texture, and color changes. The treatment with electrolyzed water did not induce significant changes in the proximate composition, pH, or cooking characteristics of the beef samples. However, a concentration of up to 50 ppm of electrolyzed water can be used for beef preservation to achieve desirable results, including enhanced nutritional and textural properties, as well as increased shelf life. The introduction of this practice offers the potential to reduce contamination and extend shelf life without compromising the sensory properties of the meat. These findings suggest that electrolyzed water can serve as a promising sanitizer for beef, thus contributing to improved food safety and consumers' confidence in meat products quality.

Table 7. Pearson correlation coefficients among selected physical properties of beef

Parameters	1	2	3	4	5	6
1. pH						
2. Drip loss after 24 h	**0.7984^{NS}**					
3. Drip loss after 48 h	**0.8600^{NS}**	**0.9735^{NS}**				
4. Drip loss after 72 h	**0.9326^{NS}**	**0.9213^{NS}**	**0.9545^{NS}**			
5. Cooking loss after 20 minutes	**0.8774^{NS}**	**0.9462^{NS}**	**0.9783^{NS}**	**0.9481^{NS}**		
6. Cooking loss after 30 minutes	**0.9547^{NS}**	**0.9240^{NS}**	**0.9558^{NS}**	**0.9695^{NS}**	**0.9531^{NS}**	
7. Cooking loss after 40 minutes	**0.9814^{NS}**	**0.8739^{NS}**	**0.9207^{NS}**	**0.9492^{NS}**	**0.9379^{NS}**	**0.9862^{NS}**

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AUTHOR INFORMATION

Gourpada Biswas, PhD Scholar, Agrotechnology Discipline, Khulna University. Khulna-9208, Bangladesh,
Tel.: +88–0171–096–60–86, E-mail: gourbiswas2010@gmail.com
ORCID: https://orcid.org/0009-0009-9446-5821
* corresponding author
Md. Shafiqul Islam, Professor, Agrotechnology Discipline, Khulna University. Khulna-9208, Bangladesh.
Tel.: +88–0171–119–07–98, E-mail: shafiqueatku@gmail.com
ORCID: https://orcid.org/0000-0003-2598-7254
S. M. Mahbubur Rahman, Professor, Biotechnology and Genetic Engineering Discipline, Khulna University. Khulna-9208, Bangladesh. Tel.: +88–0171–113–15–73, E-mail: manmr2018@gmail.com
ORCID: https://orcid.org/0000-0002-9505-6810
S. M. Abdullah Al Mamun, Professor, Agrotechnology Discipline, Khulna University. Khulna-9208, Bangladesh.
Tel.: +88–0171–746–99–35, E-mail: mamun@at.ku.ac.bd
ORCID: https://orcid.org/0000-0002-5420-088X

All authors bear responsibility for the work and presented data.

All authors made an equal contribution to the work.

The authors were equally involved in writing the manuscript and bear equal responsibility for plagiarism.

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