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Original Research Article

Unveiling Contamination Issues and Experimental Realities in Testing Industry-Proposed Electrolysed Water Treatment for Jackfruit Bulbs Preservation

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Abstract: This study investigates the efficacy and challenges of applying acidic electrolysed water (AEW) and slightly acidic electrolysed water (SAEW) for the microbial control and preservation of jackfruit bulbs. The experiment aimed to evaluate the industry-proposed electrolysed water treatment procedures for reducing microbial activity while maintaining the quality attributes of jackfruit bulbs, such as colour, texture, total soluble solids (TSS), pH, and weight. A batch electrolysis unit was used to generate AEW and SAEW, but inconsistencies in the physicochemical properties of SAEW, including lower oxidation-reduction potential (ORP), suggested an unsuccessful generation process. Microbial analysis revealed unexpectedly high microbial counts in treated samples, surpassing those of untreated samples, highlighting contamination issues during treatment. Observed challenges included insufficient drying time, short treatment duration, and cross-contamination during the large-scale process. Quality analysis revealed that the treated jackfruit bulbs experienced significant changes in colour and firmness, potentially linked to microbial growth. Water activity and TSS showed minimal variation, but a high initial water activity provided a conducive environment for microbial proliferation. While AEW demonstrated some promise in reducing microbial activity during preliminary trials, the results of this study underscore the need for refined treatment protocols and robust contamination control measures. Recommendations include optimising electrolysis conditions, extending treatment duration, and ensuring stringent hygienic practices during sample preparation and treatment. This research highlights critical gaps in the industry-proposed procedures and provides insights for improving the application of electrolysed water in postharvest treatment of fresh-cut fruits. Future studies should focus on replicating experiments under controlled environments to validate findings and overcome identified limitations.

Keywords: electrolysis; postharvest handling; food safety; minimal processing

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1. Introduction

Electrolysed water (EW) has emerged as a promising solution for cleaning and disinfection within the fruit and vegetable industry, offering significant benefits in enhancing postharvest quality and mitigating physiological diseases (Lu *et al*., 2022). EW's active chlorine components, including chlorine (Cl_2), hypochlorous acid (HOCl), and hypochlorite ion (OCl^-), play a key role in deactivating microbial cells present in fresh produce. OCl^- ions target the outer membrane of microorganisms, while HOCl penetrates cells to disrupt microbial cell walls and organelles, effectively neutralising their activity. The advantages of EW extend beyond its antimicrobial properties; it is environmentally safe, non-toxic, non-corrosive to organic materials, and cost-effective (Lyu *et al*., 2018). Notably, EW's environmentally safe nature lies in its ability to revert to its original form after use, posing no threat to humans or the environment (Rahman *et al*., 2016). Moreover, EW holds legal status as a food additive in nations such as the United States, Japan, and Korea, underscoring its safety and efficacy (Ding *et al*., 2019), making it a highly viable sanitation agent.

Recent studies have highlighted the significant applications of EW in microbial control for fresh fruits and vegetables, emphasising its effectiveness as a non-thermal disinfection method. Electrolysed water can be categorised into two main types: acidic electrolysed water (AEW) and slightly acidic electrolysed water (SAEW), both of which have demonstrated potent antimicrobial properties against a variety of pathogens commonly found on fresh produce. One of the key findings across multiple studies is the effectiveness of AEW in reducing microbial loads on fruits and vegetables. For instance, Zhao *et al*., (2021) highlighted that AEW exhibits superior antimicrobial activity due to its high oxidation-reduction potential (ORP) and low pH. The study demonstrated that AEW could effectively reduce *Escherichia coli* and *Listeria monocytogenes* populations on leafy greens and fruit surfaces, outperforming traditional chlorine-based disinfectants in microbial inactivation. Plesoianu *et al*., (2022) found that AEW significantly decreased the presence of *Staphylococcus* and *Bacillus* in fresh-cut apples, indicating its potential as a safe alternative to traditional chemical sanitisers. Meanwhile, Du *et al*. (2024) examined SAEW for its gentler action on fresh-cut fruits, including strawberries and lettuce. SAEW maintained a

balance between microbial reduction and minimal impact on sensory attributes, achieving reductions in microbial counts of 1–2 log CFU/g, comparable to chlorine treatments without harmful residue.

In addition to its antimicrobial properties, the application of EW has been associated with maintaining the quality of fresh produce. For example, Sun *et al*. (2022) found that AEW treatments could effectively retard softening and maintain the cell wall integrity of fresh longans during postharvest storage. AEW preserved texture while inhibiting microbial growth, showcasing its potential for tropical fruits with delicate structures. Li *et al*. (2023) found that AEW with a pH of 2.5 reduced the growth of *Phomopsis longanae* on longan fruits and improved energy metabolism to maintain cell integrity. Microbial reduction was achieved without compromising fruit quality. Jia *et al*. (2022) focused on jujube fruits, showing that SAEW treatments not only suppressed microbial activity but also regulated antioxidant enzyme activities, reducing oxidative stress and extending shelf life. Similarly, Issa-Zacharia (2024) highlighted the ability of SAEW not only to sanitise but also to enhance the nutritional value of harvested fruits, suggesting its dual role in food preservation. This aligns with findings from He *et al*. (2022) who reported that AEW combined with vacuum precooling effectively extended the shelf life of goji berries while maintaining their quality. The effectiveness of EW in preservation activities is influenced by several factors, including its pH, the presence of active chlorine, and external conditions such as temperature and treatment duration. The pH of electrolysed water plays a crucial role in its antimicrobial efficacy and preservation capabilities. AEW, typically characterised by a pH of 2.7 or lower, contains a high concentration of HOCl, which is responsible for its potent bactericidal properties. Studies have shown that AEW can effectively inactivate a wide range of pathogens, including bacteria and fungi, making it suitable for sanitising fresh produce (Rodríguez-Pereida *et al*., 2021; Takeda *et al*., 2020). Conversely, SAEW, with a pH ranging from 5.0 to 6.5, exhibits a milder antimicrobial effect but is often preferred for its lower corrosiveness and better compatibility with food products. Research by Rao *et al*., (2022) indicated that SAEW could achieve comparable antimicrobial effects to sodium hypochlorite while maintaining the sensory and nutritional quality of treated foods. In addition to pH, several external factors can influence the effectiveness of EW in preservation activities. Temperature is a significant factor; for example, He *et al*., (2022) found that combining AEW with vacuum precooling effectively maintained the quality of goji berries during storage at various temperatures, delaying the loss of vitamin C and other quality parameters. Treatment duration is another critical variable. Research by Santoyo *et al*., (2024) indicated that the

duration of exposure to EW significantly affects the reduction of microbial populations, with optimal treatment times varying depending on the type of microorganism and the specific conditions of the treatment. Figure 1 summarises the mechanism of action of EW on jackfruit bulbs, which involves several biochemical and physical processes that contribute to microbial inactivation and preservation of the fruit's quality.

Despite the promising findings, several gaps in the literature persist. One significant area is research on large-scale EW generation and its integration into automated food processing lines is limited, presenting a barrier to adoption by the food industry. Research by Khalid *et al*., (2020) indicates that while EW is a sustainable and cost-effective option for sanitation, the challenges in its application within food processing facilities need to be addressed. Investigating the barriers to adoption and developing strategies to overcome these challenges will be essential for the widespread implementation of EW in the food industry.

As consumer awareness regarding the safety of fruit and vegetable consumption grows, so does the demand for high-quality, fresh-like products (Deng *et al*., 2020). Jackfruit has garnered attention as a vegetarian meat alternative globally due to its texture resembling animal-based meat (Smetana *et al*., 2023; Stukin, 2016). However, challenges persist in marketing jackfruit, particularly concerning microbial contamination during various stages of postharvest handling, production, and packaging (Deng *et al*., 2020; Ding *et al*., 2019). Jackfruits undergo minimal processing, including removal of inedible parts, grading, peeling, and cutting, which can inadvertently introduce cross-contamination among products and equipment surfaces (Shiroodi & Ovissipour, 2018). The consequences of contaminated produce are severe, often leading to foodborne outbreaks caused by pathogens such as *Escherichia coli*, *Salmonella* spp., *Shigella* spp., *Listeria monocytogenes*, *Bacillus cereus*, and *Staphylococcus aureus* (Bhilwadikar *et al*., 2019; Deng *et al*., 2020). Consequently, ensuring microbial safety during minimal processing is imperative for extending the shelf life and safeguarding the quality of fruits.

While chlorine-based sanitisers have traditionally dominated the food industry due to their ease of use and low cost, their efficacy in microbial removal is limited. Chlorine treatments typically reduce bacterial counts by only 1–2 logs on fresh vegetables, and their use raises concerns about human health and environmental pollution due to the release of chlorine vapours and potentially carcinogenic by-products such as trihalomethanes and haloacetic acids (Deng *et al*., 2020). Consequently, several nations have banned the use of chlorine for disinfecting fresh-cut vegetables due to safety and effectiveness concerns (Deng *et al*., 2020). In contrast, electrolysed water (Acidic, Slightly Acidic, Neutral, and Alkaline

Electrolysed Water) is generally considered safer than chlorine-based sanitisers as it does not produce harmful chlorine gas or harmful disinfection byproducts. This makes it safer for both workers handling the solution and consumers who may come into contact with the produce.

Given the attractive advantages of EW, Malaysian food industry is interested in implementing EW at their factory to wash jackfruit bulbs for their fresh fruit products. Hence, this study aims to evaluate the industry procedures for disinfecting jackfruit bulbs and assess the efficiency of electrolysed water, both AEW and SAEW, in mitigating microbial activity. In this study, natural microbes on fresh produce are targeted for disinfection. This approach provides a realistic assessment of the efficacy of AEW and SAEW in reducing microbial populations on minimally processed jackfruit bulbs. Additionally, the study will examine the efficacy of electrolysed water treatment on various quality parameters of jackfruit bulbs, including colour, texture, total soluble solids (TSS), pH, and weight.

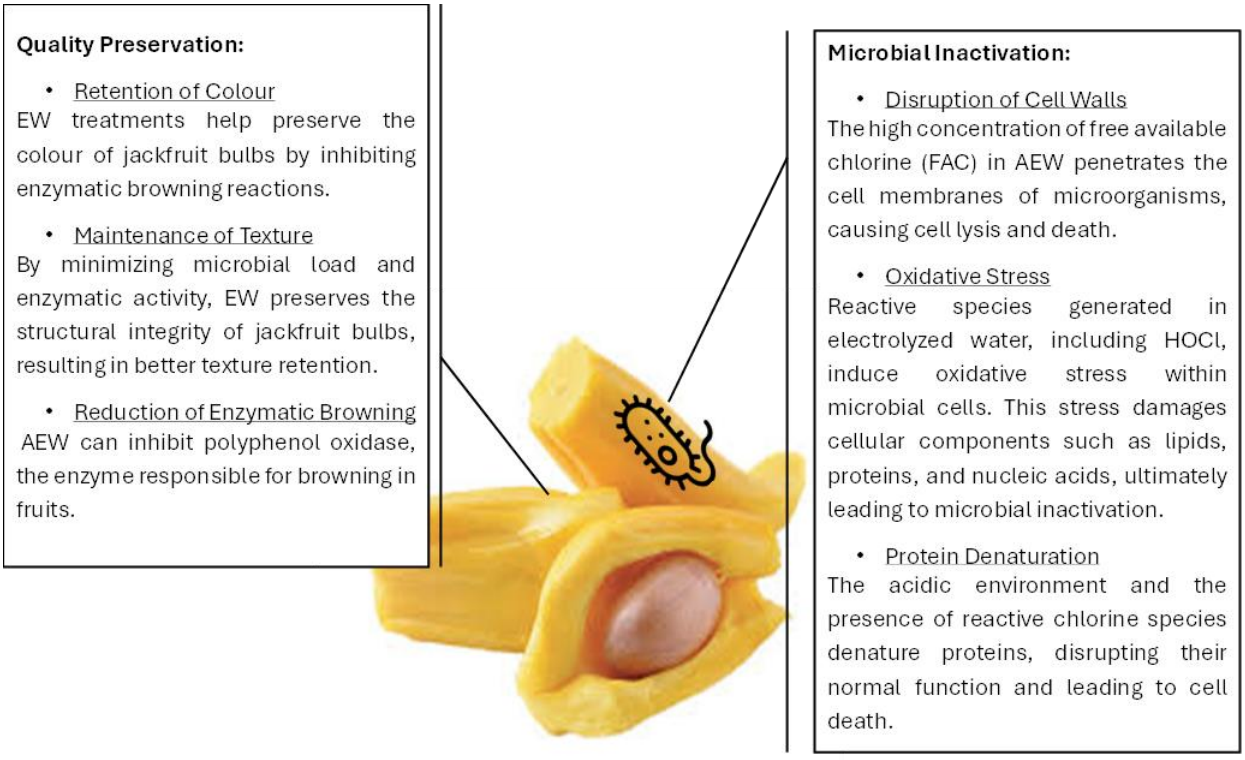

Figure 1. Mechanism of action of electrolysed water on jackfruit bulbs

2. Materials and Methods

2.1. Design of Treatment Procedure

Given the absence of prior research on the use of EW for disinfecting fresh jackfruit bulbs, a specific treatment procedure needed to be designed. Drawing upon previous studies

on fruit and vegetable disinfection, a suitable treatment procedure was identified and tailored to suit the characteristics of jackfruit bulbs and the available lab apparatus and facilities in the industry premises.

The industry representative proposed an alternative procedure to ensure completion within a single day. In this protocol, jackfruit bulbs were treated on a larger scale, with 3.4 kg of bulbs immersed at once in 10 L of different EW treatments (AEW and SAEW). This expedited process required four manpower resources to complete the sampling in one day. The workflow of the industrial procedure is illustrated in Figure 2.

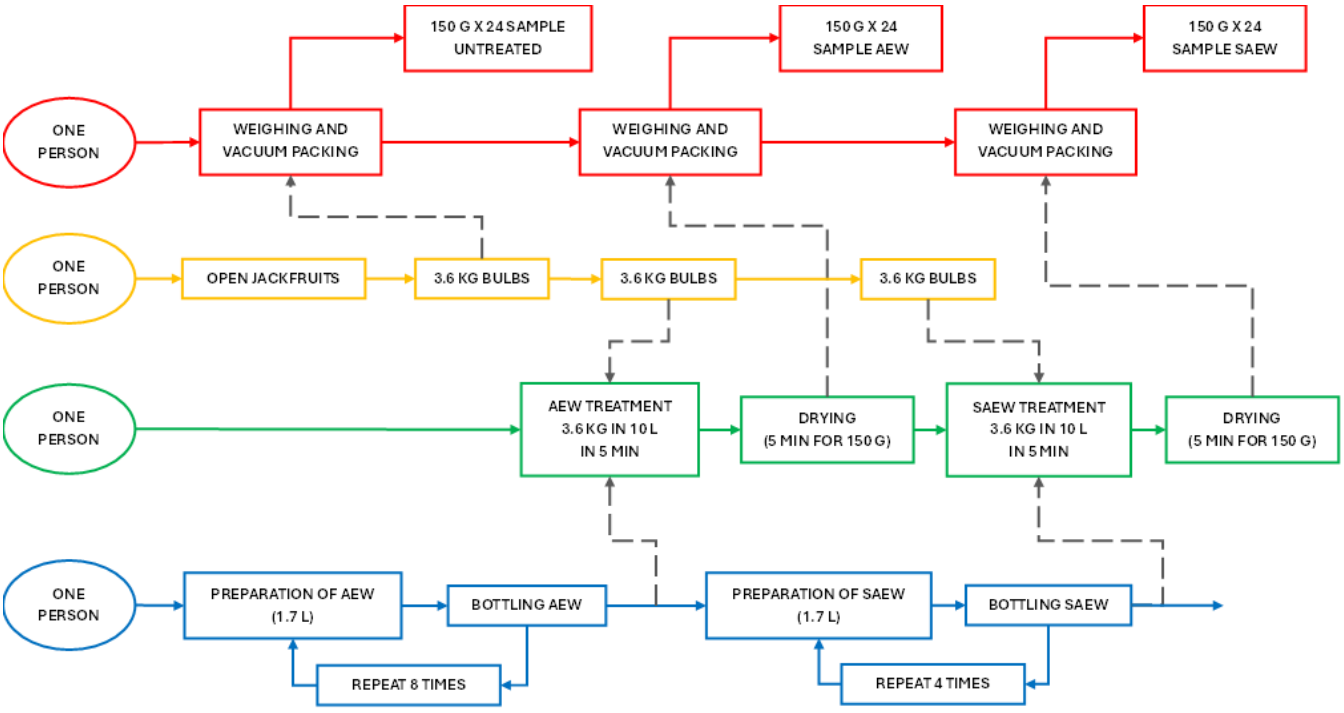

Figure 2. Workflow of industrial procedure

2.2. Preparation of Electrolysed Water

To disinfect 3.4 kg of jackfruit bulbs, 10 L of EW was utilised, testing the efficacy of two types: AEW and SAEW. The EW was produced batch-wise using a laboratory-scale electrolysis unit (Khalid *et al*., 2018), capable of generating 3.4 L of electrolysed water (1.7 L each of AEW and alkaline EW). Initially, a 0.65 w/v% NaCl solution was prepared by dissolving 22.1 g of sodium chloride (NaCl) (R&M Chemicals, London, United Kingdom) in 3.4 L of distilled water. This solution was then introduced into electrolysis chambers where two stainless steel 316 electrodes were positioned, one in each anode and cathode chamber, with a polyester membrane situated between them. The electrolysis process was conducted

for 8 minutes at 11.95 V and 11.95 A. AEW was collected from the anode chamber, and the electrolysis process was repeated several times until 10 L of AEW was obtained.

To produce SAEW, the electrolysis was conducted without the polyester membrane. Similarly, 22.1 g of NaCl was diluted with 3.4 L of distilled water to produce a 0.65 w/v% NaCl substrate. Two stainless steel 316 electrodes were mounted in the chamber, and the solution was poured into the electrolysis unit without a membrane. The voltage and current supplied by the DC power source were maintained at 11.95 V and 11.95 A, respectively, and the electrolysis process was carried out for 8 mins. SAEW was collected, and the process was repeated until 10 L of SAEW was obtained. The laboratory-scale electrolysis unit (Figure 3) used for these procedures was fabricated at Universiti Putra Malaysia (UPM) (Khalid *et al*., 2018), ensuring consistency and precision in the production of AEW and SAEW.

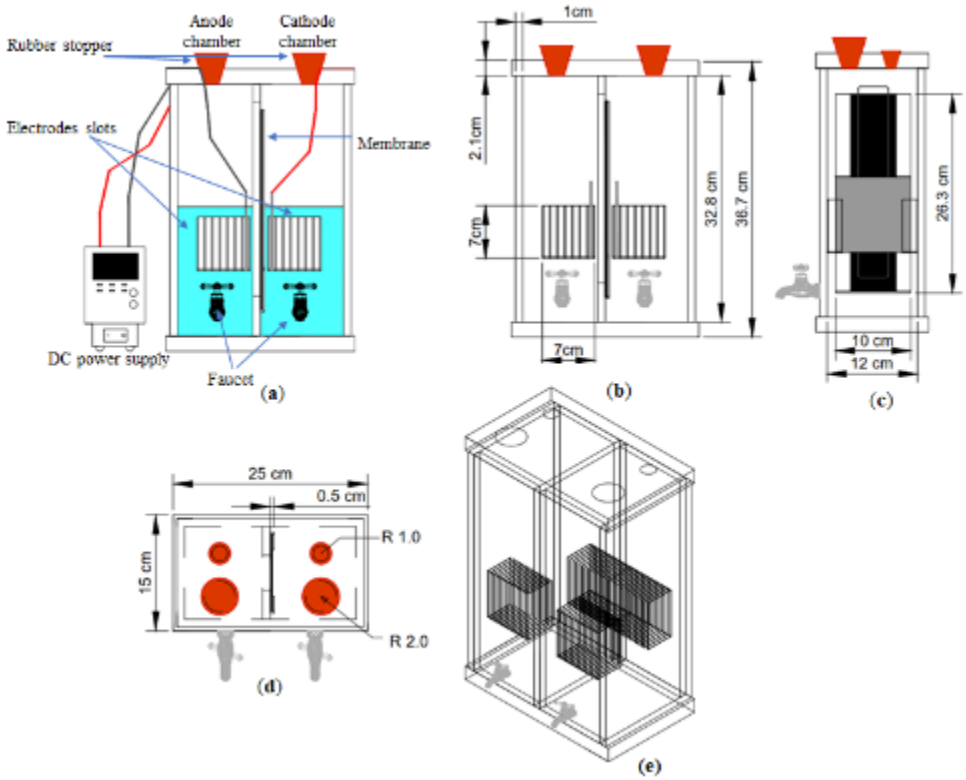

Figure 3. Schematic diagram of the laboratory-scale batch electrolysis unit: a) front-side view (complete set-up), b) front-side view, c) right view, d) top-side view, and e) perspective view.

2.3. Preparation of Jackfruit Samples and Disinfection Treatment

Six mature and unripe Honey Jackfruit J33, approximately 2–3 days away from full ripeness, were sourced from a local farm in Pahang. Previous studies by Swami and Kalse (2019) and Ranasinghe *et al*., (2019) have reported the composition of the edible portion of

jackfruit bulb, indicating a range of components including water content (72.0 to 94.0 g), protein (1.2 to 1.9 g), fat (0.1 to 0.4 g), carbohydrates (16.0 to 25.4 g), fibre (1.0 to 1.5 g), total sugars (20.6 g), and total minerals (0.87 to 0.9 g).

The fruits were carefully dissected using a butcher knife coated with cooking oil, and the bulbs were extracted from the whole fruit, ensuring the use of gloves to maintain hygiene. To prevent cross-contamination, the jackfruit bulbs were promptly weighed upon extraction from the fruit, followed by immediate treatment. Jackfruit bulbs were divided into three batches: two batches were subjected to different EW treatments (AEW and SAEW), while the third batch served as the control and remained untreated. Each batch was standardised to approximately 3.4 kg in weight. Jackfruit bulbs underwent treatment with electrolysed water at room temperature.

Initially, a volume of 10 L of AEW was generated and collected, then transferred to a treatment pail. The first two batches of jackfruit bulbs were fully immersed in the respective EW for 5 mins. Subsequently, approximately 150 g samples (3 to 5 bulbs) were prepared for the next analytical analyses. The 150 g samples were obtained by random sampling from the 3.4 kg batch to ensure representativeness. Thereafter, the 150g of treated samples were collected from the pail, dried using a manual rotary food drainer, and promptly vacuum-packed to prevent any potential cross-contamination. This process was repeated until there were no more treated jackfruit bulbs in the pail. Treated and untreated jackfruit bulb samples were vacuum-packed in nylon plastic bags to prevent cross-contamination and stored at 3–7°C in a refrigeration unit until further analysis. Figure 4 illustrates an example of a sample after vacuum packing.

For the untreated samples, packing occurred after the bulbs were extracted from the fruit and weighed. Each sample was labelled ‘untreated’ or ‘AEW’ or ‘SAEW’ according to their treatment. The experiment was then repeated using SAEW. Untreated samples were utilised as controls for comparison purposes. This procedure allowed for a comparative analysis of the effects of different treatment methods on the jackfruit bulbs. The experimental process, including treatments, was replicated twice to ensure consistency and validate the results

Figure 4. Sample of jackfruit bulbs in vacuum packaging

2.4. Microbial Analysis

Microbial analyses were conducted to assess the antimicrobial efficacy of EW on jackfruit bulbs. Several microbial tests were performed on the jackfruit bulb samples, including Total Aerobic Plate Count, Total Yeast, and Mold Count, Total Coliform Count, Total E. coli Count, Total *S. aureus* Count, and Salmonella. These pathogens were selected based on their common occurrence in foodborne outbreaks, as indicated by the Centres for Disease Control and Prevention (CDC) and the U.S. Food & Drug Administration (USFDA), and their detection is often required by importing countries.

The tests were planned to span 22 days, but due to logistical constraints, actual testing was conducted over 6 days on days 1, 2, 3, 4, 5, and 9 of the experiment. Microbial analyses were performed by Kelington Analytical Services Sdn. Bhd., Shah Alam, as access to the UPM laboratory was restricted during the movement control order (MCO). The methodologies for microbial analyses were adopted from the USFDA website.

For the aerobic plate count, the method outlined in the USFDA Bacteriological Analytical Manual (BAM) Chapter 3 (Maturin & Peeler, 2001) was followed. Decimal dilutions of food homogenate were prepared, and aliquots were plated onto Petri plates containing agar medium. The plates were then incubated at 35°C for 48 hours.

For total yeast and mould count, the procedure described in the USFDA BAM Chapter 18 (Tournas *et al*., 2001) was employed. Samples were prepared, diluted, and plated onto agar plates using the spread-plate method. After 5 days of incubation, the plates were counted.

The total coliform count was determined following the AOAC 991.14 and AOAC 998.08 methods (Latimer, 2023). Test suspensions were inoculated onto dry-film coliform count plates, incubated at 35°C for 24 h, and colonies were counted.

Similarly, the total *E. coli* count was determined using the same AOAC methods (Latimer, 2023). Samples were diluted, plated onto 3M Petrifilm, and incubated at 35°C for 48 hours. Colonies were counted, and blue colonies associated with gas production were identified as *E. coli*.

For the total *S. aureus* count, the method described in the USFDA BAM Chapter 12 (Tallent *et al*., 2016) was followed. Samples were plated onto Baird-Parker agar plates, incubated at 35–37°C for 45–48 h, and colonies were counted.

Lastly, for *Salmonella* spp., the procedure outlined in the USFDA BAM Chapter 5 (Andrews *et al*., 2023) was adopted. Samples were blended, incubated with sterile buffered peptone water, and then incubated at 35°C for 24 h.

2.5. Jackfruit Bulb Quality Analyses

2.5.1. Water activity

The water activity of the sample was determined using a water activity meter, which measures the dew point of the sample employing an optical sensor. Approximately 2 g of jackfruit bulbs were placed into the cup of the device and then positioned in the sample cabinet.

2.5.2. Colour

This method aimed to determine the anti-browning activity of EW on jackfruit bulbs. The colour test was performed using a colour spectrophotometer (HunterLab Ultrascan Pro, Reston, VA). The colour values of jackfruit bulbs were analysed and expressed in L*, a*, and b*, where L* represents black vs. white, a* represents red vs. green, and b* represents yellow vs. blue. The change in colour of jackfruit bulbs was calculated using Equation 1:

$$\Delta E_{ab} = \sqrt{({L_2}^* - {L_1}^*)^2 + ({a_2}^* - {a_1}^*)^2 + ({b_2}^* - {b_1}^*)^2} \quad (1)$$

Meanwhile, the browning index (BI) was calculated using Equation 2:

$$BI = \frac{100(x - 0.31)}{0.17} \quad (2)$$

Where $x = (a^* + 1.75L^*)/(5.645L^* + a^* - 3.012b^*)$

2.5.3. Texture

This method aimed to determine the effect of electrolysed water on the firmness and bio-yield point of jackfruit bulbs. The bio-yield point is expressed as the force required to cause permanent deformation, while firmness is expressed as the force required to push the probe into the food. The texture of the jackfruit bulb was measured using a texture analyser (Model TA. XT Plus, Stable Micro Systems™, England). Jackfruit bulb slices were punctured using a 5 mm cylinder probe at a test speed of 1.5 $mm \cdot s^{-1}$. The results were recorded in Newton (N).

2.5.4. pH

The juice was extracted from the jackfruit bulbs, and the pH was measured using a pH meter with a probe (AP85, Fisher brand™, Sweden). The probe was immersed in the juice at room temperature until the value was stable, and then the reading displayed on the screen was recorded.

2.5.5. Total soluble solids (TSS)

The juice was extracted from the jackfruit bulbs, and the total soluble solids (TSS) were measured using a pocket refractometer (PAL-α, ATAGO™, Japan). A few drops of the juice were placed on the sensor section using a dropper, and the reading displayed on the screen was recorded.

2.5.6. Weight loss

This method aimed to determine the weight loss of jackfruit bulbs from the initial weight after the experiment. The weight was measured using an analytical balance. The weight loss (WL) values were determined and expressed as a percentage of losses from the initial weights of the samples, calculated using Equation 3:

$$\%WL = \frac{w_0 - w_d}{w_0} \times 100 \quad (3)$$

2.6. Statistical Analysis

Data analysis was performed using One-way analysis of variance (ANOVA) followed by Tukey's test for comparison of results, with significance set at $p \leqslant 0.05$. Microsoft Excel 2016 was utilised for data processing, and results were presented as mean ± standard deviation (n=2).

3. Results and Discussions

3.1. Electrolysed Water

For the generation of electrolysed water, the physicochemical properties of both AEW and SAEW were measured. The pH values of AEW and SAEW were 3.26 and 6.36, respectively. The ORP values of AEW and SAEW were 1128 mV and 423 mV, respectively. According to research by Ding *et al*. (2019), AEW typically exhibits a low pH of 2.5–3.5, a high ORP of 1000–1200 mV, and a free chlorine content of 30–90 ppm. Meanwhile, SAEW typically has a pH of 5.0–6.5 and an ORP of 800–900 mV. Free chlorine content was not assessed in this study. Table 1 presents a comparison of the properties of electrolysed water between the findings of this study and those from Ding *et al*. (2019).

Table 1. Comparison of electrolysed water properties between this work's findings and Ding *et al*.'s findings

Parameter	**Findings of this work**		**Findings from** Ding & Liao, (2019).	
	AEW	**SAEW**	**AEW**	**SAEW**
pH	3.26	6.36	2.5 – 3.5	5.0 – 6.5
ORP (mV)	1128	423	1000 – 1200	800 – 900
ACC (ppm)	N/A	N/A	30 – 90	N/A

N/A is not available

The physicochemical properties of the generated AEW were within the expected range. However, while the pH of the SAEW fell within the target range, the ORP was lower than expected, indicating that the SAEW was not successfully generated. This discrepancy may be attributed to the similarity of the physicochemical properties of the SAEW to those of distilled or tap water, which typically have a pH ranging from 6 to 7 and an ORP ranging from 300 to 400 mV. Additionally, these properties resemble those of the electrolyte solution before electrolysis. The unsuccessful generation of SAEW may be due to the unsuitability of the batch electrolysis unit for industrial-scale use. In conclusion, caution must be exercised (such as ensuring proper electrode assembly, membrane integrity, and optimised electrolysis conditions (voltage, current, and duration) to generate stable SAEW successfully) when generating electrolysed water using a batch electrolysis unit, as it may easily result in unsuccessful and unstable production of electrolysed water.

3.2. Microbial Analysis

The pH of electrolysed water is a crucial determinant of its antimicrobial efficacy and overall effectiveness in food preservation. AEW, with a pH of 3.26, is characterised by a high ORP of 1128 mV, which enhances its ability to inactivate a wide range of pathogens.

Research by Li *et al*. (2017) indicates that when the pH is maintained between 5.0 and 6.5, HOCl predominates, which is significantly more effective as a sanitiser than the OCl^- (Li *et al*., 2017). This suggests that while AEW is effective due to its low pH and high ORP, SAEW, with a pH of 6.36, may not achieve the same level of microbial reduction due to its lower ORP of 423 mV. However, the study's findings (Figures 5-7) indicate that both AEW and SAEW treatments were ineffective in controlling microbial growth on jackfruit bulbs, likely due to the generation of SAEW being suboptimal. The lower ORP observed in SAEW suggests that the treatment may not have been sufficiently potent to inhibit microbial growth, which aligns with previous studies that emphasise the importance of maintaining appropriate electrolysis conditions to achieve effective sanitisation (Ju *et al*., 2017). The microbial counts (aerobic plate count, total yeast and mould count, and total coliform count) were notably high from the beginning of Day 1 for both AEW and SAEW samples. Furthermore, the microbial counts for all samples increased rapidly throughout the experiment (from Day 1 until Day 3). These results suggest that both AEW and SAEW treatments were not successful, and cross-contamination may have occurred during the treatment process. Consequently, the planned microbial tests spanning 22 days had to be terminated after Day 9 of the experiment due to poor microbial results.

In addition to pH, several external factors influenced the effectiveness of electrolysed water treatments. Although the microbial count of the untreated sample was lower than that of the AEW and SAEW samples, it was still high at the beginning of the tests. This indicates that the preparation of the jackfruit bulb samples was not conducted under hygienic conditions during the handling process. This finding contrasts with a report by Ng *et al*. (2020), which stated that the untreated sample exhibited a lower microbial count at the initial plate count, suggesting controlled hygienic handling during the preparation of fresh jackfruit bulbs. During the industry testing, the preparation and handling of jackfruit bulbs were conducted under less-than-ideal hygienic conditions, leading to high initial microbial counts. The difficulty in achieving a hygienic handling environment was primarily due to inadequate time resulting from MCO, leading to rushed sample preparation and difficulty following proper methods, which in turn increased the likelihood of cross-contamination. Treating all jackfruit bulbs simultaneously on a large scale, approximately 3.4 kg, while using a batch electrolysis unit may have contributed to cross-contamination, as the water needed to be generated multiple times and accumulated in a bottle before the treatment process. This aligns with findings from Plesoianu *et al*., (2022), which emphasise the importance of hygienic practices in food handling to minimise microbial contamination.

Furthermore, the treatment duration of 5 mins may have been insufficient for effectively reducing microbial loads, particularly on a large scale. Studies have shown that longer exposure times can enhance the antimicrobial effects of electrolysed water (Cárdenas *et al*., 2022). Moreover, the drying time may have been inadequate, leaving water on the jackfruit, which could have contributed to incomplete microbial inhibition. In conclusion, the proposed procedure requires revision.

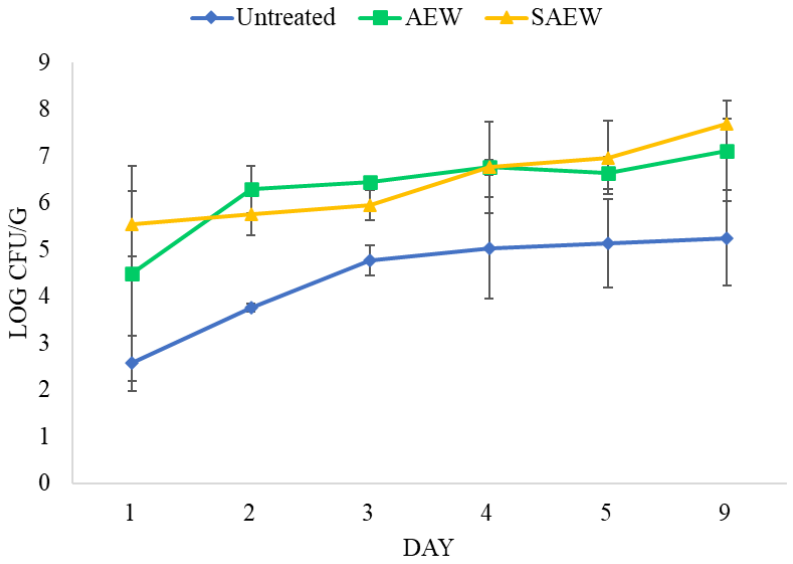

Figure 5. Total aerobic plate count on jackfruit bulbs with different treatments

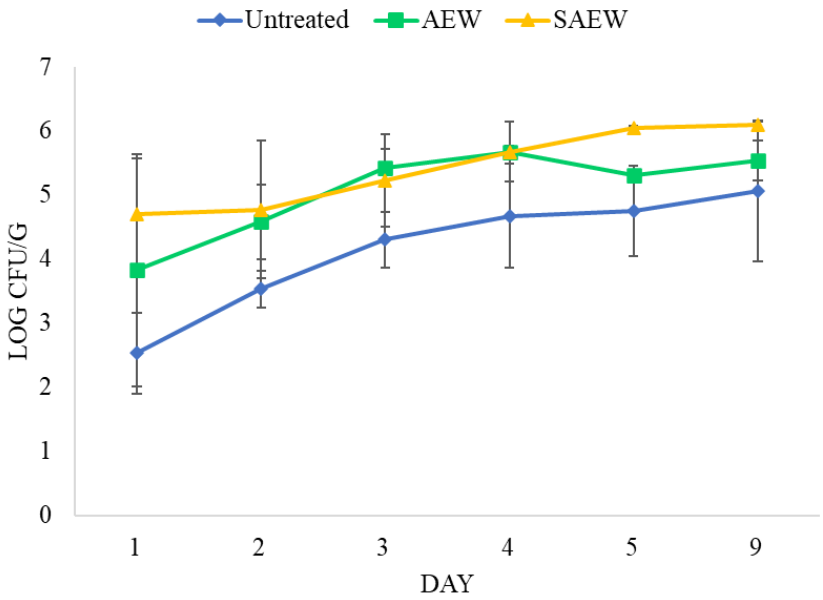

Figure 6. Total yeast and mould count on jackfruit bulbs with different treatments

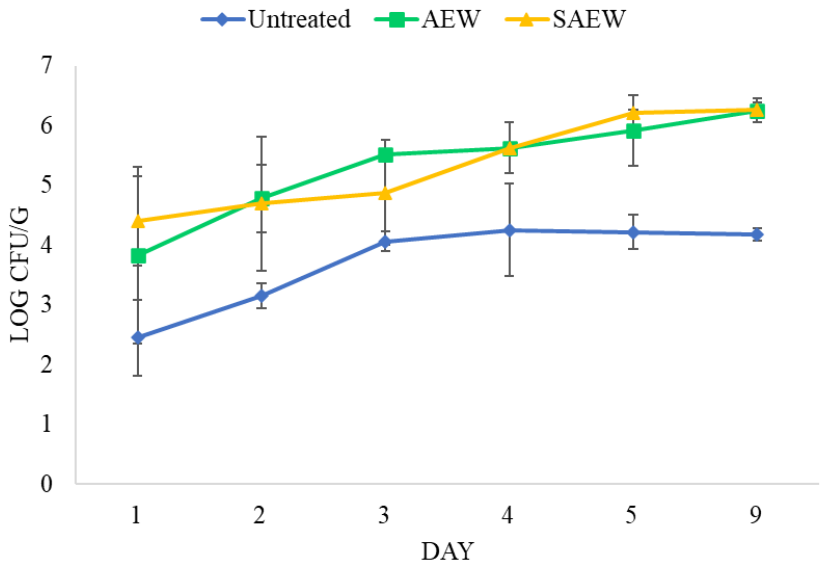

Figure 7. Total coliform count on jackfruit bulbs with different treatments

Despite reports by Mat Johari *et al*. (2020) and Navindra *et al*., (2009) indicating that minimally processed food products stored at low temperatures tend to inhibit microbial growth, the high microbial counts observed in this study suggest post-treatment contamination. Furthermore, the results indicate that both AEW and SAEW were not successfully generated, rendering the treatment process ineffective. The high sugar content in jackfruit bulbs, primarily consisting of natural sugars due to their high carbohydrate content, likely contributed to the rapid increase in microbial growth. Proper pre-treatment procedures for the bulbs are crucial for extending shelf life. Consequently, the antimicrobial activity of both electrolysed waters was insufficient to reduce microbial growth effectively. The microbial counts (aerobic plate count, total yeast and mould count, and total coliform count) were excessively high, classifying them as unsatisfactory according to guidelines by the Centre of Food Safety (The Expert Committee on Food Safety, 2014). While numerous studies have demonstrated the effectiveness of AEW and SAEW in reducing microbial counts, no research has yet demonstrated their efficacy in reducing microbial counts on jackfruit bulbs. However, during a preliminary experiment, AEW and SAEW samples exhibited slower microbial growth than the untreated sample (control), as observed by the degree of bloating in the sample packaging after 30 days. Figure 8 presents the results of the preliminary experiment on jackfruit bulbs. Based on observations, the AEW sample showed minimal bloating, while the untreated sample exhibited significant bloating. The bloating of samples is attributed to microbial respiration, suggesting that the AEW sample may have

lower microbial growth potential and that microbial analysis results have the potential to yield success.

The findings of this study highlight the need for improved treatment protocols when using electrolysed water for preserving jackfruit bulbs. While previous research has demonstrated the effectiveness of AEW and SAEW in reducing microbial counts in various food products, including fresh-cut fruits and vegetables, the unique characteristics of jackfruit may require tailored approaches. For instance, combining electrolysed water treatments with other preservation methods, such as low-temperature storage or modified atmosphere packaging, could enhance microbial control and extend shelf life (Cabañas *et al*., 2023; He *et al*., 2022; Nour *et al*., 2021).

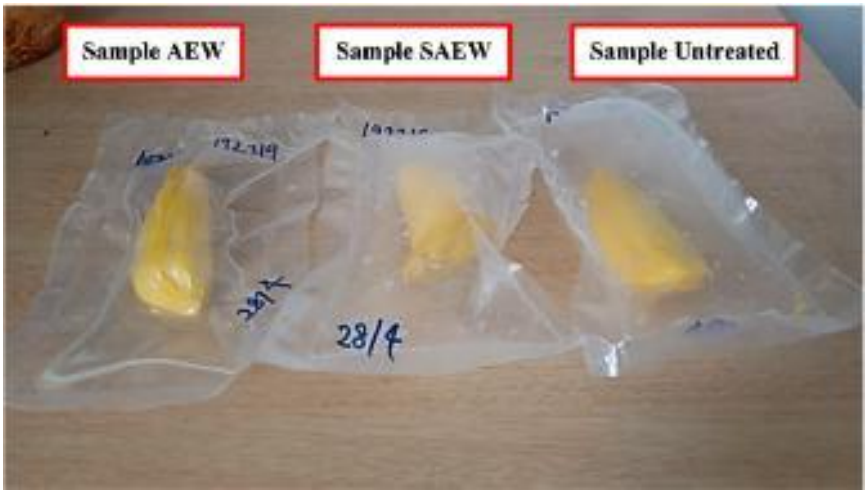

Figure 8. Result of mocking experiment on jackfruit bulbs

3.3. Water Activity

Table 2 presents the water activity (AW) of jackfruit, which ranged from 0.8 to 0.855. The results did not exhibit an obvious trend, but the high water activity in jackfruit initially suggests sufficient moisture to support bacterial, yeast, and mould growth. A water activity of 0.80 corresponds to 80% of the vapour pressure of pure water (Dept of Health Education and Welfare Public Health Service Food and Drug Administration, 2016). Studies by Hayta and Aday (2015) and Jemni *et al*. (2014) have reported a reduction in water activity over increased storage time, although this decline was gradual after 30 days. Therefore, the results did not demonstrate significant differences, likely due to the short experimental duration.

Table 2. Water activity for jackfruit bulbs with different treatment

Day	Water activity (AW)		
	Untreated	**AEW**	**SAEW**
1	0.8 ± 0.04	0.82 ± 0.00	0.835 ± 0.01
2	0.83 ± 0.00	0.83 ± 0.00	0.83 ± 0.00
3	0.825 ± 0.01	0.84 ± 0.00	0.82 ± 0.00

3.4. Colour

The observed changes in colour parameters of jackfruit bulbs during storage can be significantly influenced by microbial growth and associated enzymatic activities. The interplay between microbial contamination and enzymatic browning processes is critical in determining the visual quality of fresh-cut fruits, including jackfruit. This discussion explores how microbial activity may accelerate enzymatic browning and contribute to colour changes in jackfruit bulbs. The colour parameter changes of untreated, AEW-treated, and SAEW-treated jackfruit bulbs over 22 days are presented in Table 3. The total colour change of jackfruit bulbs was analysed in terms of L* (lightness), a* (red-green), and b* (yellow-blue) values. The lightness of the jackfruit bulbs increased in both untreated and treated samples over the storage period. The untreated samples showed a notable increase in L* from 68.46 to 80.99, while AEW-treated samples exhibited a slight decrease from 76.94 to 78.89. SAEW-treated samples also showed an increase from 71.84 to 80.54. The increase in L* values suggests a lightening effect, which may be attributed to the degradation of pigments or the formation of new light-reflecting compounds due to microbial activity and enzymatic reactions. The a* values, which represent the red-green spectrum, decreased significantly in AEW-treated samples from 9.74 to 4.17, indicating a loss of red colour. In contrast, untreated samples maintained relatively stable a* values, while SAEW-treated samples decreased from 7.76 to 3.17. This decline in a* values suggests that microbial activity may have led to the degradation of anthocyanins or other red pigments, contributing to a shift towards a greener hue (Treviño-Garza *et al*., 2015). The b* values, representing the yellow-blue spectrum, showed an increase in both AEW and untreated samples, suggesting a darkening of the yellow colour. The untreated samples increased from 37.84 to 43.50, while AEW-treated samples increased from 47.26 to 48.83. SAEW-treated samples also increased from 38.55 to 45.75. This change may indicate the formation of brown pigments due to enzymatic browning, which is often accelerated by microbial activity.

Table 3. L*, a*, and b* values for jackfruit bulbs with different treatment

Day	Colour		
	L*	a*	b*
Untreated			
0th day	68.46 ± 21.64	6.33 ± 0.58	37.84 ± 6.80
22nd day	80.99 ± 1.45	6.26 ± 4.31	43.50 ± 3.92
AEW			
0th day	76.94 ± 5.92	9.74 ± 3.96	47.26 ± 5.88
22nd day	78.89 ± 2.44	4.17 ± 1.36	48.83 ± 2.55
SAEW			
0th day	71.84 ± 13.27	7.76 ± 0.52	38.55 ± 2.90
22nd day	80.54 ± 0.30	3.17 ± 1.13	45.75 ± 0.42

The results presented in Table 4 provide valuable insights into the effects of different treatments (untreated, AEW, and SAEW) on the total colour difference (ΔEab) and browning index of jackfruit bulbs over a 22-day storage period. The ΔEab value for untreated jackfruit bulbs was 17.19 ± 18.27. This relatively low value indicates that the untreated samples maintained a degree of colour stability during the storage period. The high standard deviation suggests variability in the initial colour quality of the fruit, which may be attributed to differences in ripeness or handling conditions prior to the experiment. The minimal colour change observed in untreated samples could imply that the initial microbial load was not sufficient to cause significant degradation of colour, or that the fruit was of relatively high quality at the outset. The AEW-treated samples exhibited an ΔEab value of 7.05 ± 2.27, indicating a slight colour change. This low value suggests that the AEW treatment was effective in preserving colour initially. The SAEW-treated samples showed an ΔEab value of 13.74 ± 9.72, which indicates moderate colour change. This value is higher than that of AEW, suggesting that SAEW treatment was less effective in preserving colour compared to AEW. The higher standard deviation in SAEW-treated samples indicates variability in the effectiveness of the treatment, which could be due to differences in the production or application of SAEW. The browning index for untreated jackfruit bulbs was 87.22 ± 19.10 on Day 0 and slightly decreased to 85.22 ± 0.65 by Day 22. This could indicate that the untreated samples retained some of their initial quality, possibly due to lower enzymatic activity or microbial load at the beginning of the storage period. The relatively stable browning index also suggests that the untreated samples may have had a lower initial susceptibility to browning compared to the treated samples. The AEW-treated samples exhibited a browning index of 101.63 ± 31.91 on Day 0, which decreased significantly to

78.05 ± 4.61 by Day 22. The initial browning index for AEW-treated samples (101.63 ± 31.91) suggests that these samples may have had a higher baseline of browning compared to untreated (87.22 ± 19.10) and SAEW-treated (83.27 ± 12.63) samples. The slightly brownish colour of the AEW samples could be due to several factors, including natural pigmentation, ripeness and quality variability. However, the substantial decrease in browning index over the storage period suggests that the AEW treatment may have initially stimulated enzymatic activity but ultimately resulted in a reduction in browning as microbial activity increased. This finding highlights the complexity of the interactions between treatment, microbial growth, and enzymatic browning. The SAEW-treated samples had a browning index of 83.27 ± 12.63 on Day 0, which increased to 93.76 ± 14.09 by Day 22. This increase indicates that SAEW treatment was less effective in controlling browning compared to AEW. The rise in the browning index suggests that microbial activity and enzymatic reactions were not adequately inhibited, leading to enhanced browning over time. Li *et al*., (2017) reported that SAEW and AEW treatments inhibited colour changes in fresh-cut lotus roots during storage. According to Aday (2016), the browning index increased for untreated and treated samples over time, with an increasing trend observed only in SAEW samples. The decreasing trend observed in untreated and AEW samples may be due to contamination of the electrolysed water, failing to affect the enzymes responsible for browning. The inconsistencies in the results may be attributed to the susceptibility of fruits to damage, leading to the destruction of plant cell tissues on the fruit surface.

Table 4. Total colour difference (ΔEab) and browning index for jackfruit bulbs with different treatments

Treatment	ΔE_{ab}	Browning index	
		0^{th} day	**22nd day**
Untreated	17.19 ± 18.27	87.22 ± 19.10	85.22 ± 0.65
AEW	7.05 ± 2.27	101.63 ± 31.91	78.05 ± 4.61
SAEW	13.74 ± 9.72	83.27 ± 12.63	93.76 ± 14.09

Microbial growth can significantly influence the enzymatic browning process in fruits. The presence of microorganisms can lead to the production of enzymes such as polyphenol oxidase (PPO), which catalyses the oxidation of phenolic compounds, resulting in the formation of brown pigments. The high microbial counts observed in the AEW and SAEW-treated samples suggest that microbial activity may have contributed to the observed colour changes. The enzymatic browning process is initiated when the fruit tissue is damaged, exposing phenolic compounds to oxygen. Microbial activity can exacerbate this process by increasing the levels of phenolic compounds through the breakdown of plant cell walls and

the release of intracellular contents (Gabr *et al*., 2012). This interaction between microbial growth and enzymatic activity likely played a significant role in the rapid colour changes observed in the jackfruit bulbs during storage.

3.5. Texture

Table 5 presents the bio-yield point and firmness results for untreated, AEW-treated, and SAEW-treated jackfruit bulbs. Both the bio-yield point and firmness decreased over the 22 days for all samples. This decline may be attributed to the conversion of organic acids into starch and sugar during fruit ripening, a process known as gluconeogenesis (Mat Johari *et al*., 2020). The bio-yield point of untreated jackfruit bulbs did not exhibit a significant decreasing trend, while AEW-treated bulbs showed a decrease from 9.24 to 6.93 N, and SAEW-treated bulbs exhibited a significant decrease from 14.76 to 11.01 N. This decreasing trend in the bio-yield point of jackfruit bulbs may be due to diminishing turgor pressure and cell wall integrity (Mat Johari *et al*., 2020). Referring to the microbial analysis results, both SAEW and AEW samples had high microbial counts.

The firmness of untreated jackfruit bulbs decreased from 26.12 to 22.00 N over 22 days, while AEW-treated bulbs decreased from 51.85 to 44.99 N, and SAEW-treated bulbs decreased from 72.48 to 67.97 N. Hayta and Aday (2015) reported that firmness decline during storage mainly results from the degradation of cell walls and cell structures. Additionally, this may be due to water loss from the jackfruit bulbs, leading to cell rupture and tissue damage (Mat Johari *et al*., 2020). Aday (2016) also suggested that protein denaturation, membrane solubilisation, loss of turgor pressure in cells, and weight and volume losses in tissues contribute to firmness decline. However, according to Ding *et al*., (2015), there was no significant difference in firmness between untreated and SAEW-treated samples. Moreover, Jemni *et al*. (2014) reported that dates treated with UV-C light combined with electrolysed water showed the highest firmness. Additionally, Aday (2016) reported that electrolysed water retarded the loss of mushroom firmness compared to untreated samples.

Table 5. Bio-yield point and firmness for jackfruit bulbs with different treatments

Treatment	Texture			
	Bio-yield point (N)		Firmness (N)	
	0^{th} day	22^{nd} day	0^{th} day	22^{nd} day
Untreated	3.79 ± 1.24	3.03 ± 0.75	26.12 ± 0.74	22.00 ± 1.47
AEW	9.24 ± 0.57	6.93 ± 0.40	51.85 ± 4.50	44.99 ± 6.36
SAEW	14.76 ± 1.88	11.01 ± 2.04	72.48 ± 4.14	67.97 ± 4.62

3.6. pH

Table 6 presents the pH values of jackfruit samples. There was a decrease in pH values after 22 days, with AEW exhibiting the lowest pH of 5.33 and SAEW decreasing from 6.40 to 5.35. The most significant changes were observed in samples treated with AEW and SAEW, while slight changes were noted in untreated samples. However, untreated samples should have exhibited the lowest pH based on research by Aday (2016). This decrease in pH values likely resulted from the production of organic acids by microorganisms. Referring to the microbial analysis, the electrolysed water was contaminated by microorganisms during the experiment, leading to increased organic acid production and pH changes.

Table 6. pH value for jackfruit bulbs with different treatment

Treatment	pH	
	0^{th} day	**22^{nd} day**
Untreated	6.14 ± 0.05	5.74 ± 0.01
AEW	6.15 ± 0.00	5.33 ± 0.01
SAEW	6.40 ± 0.01	5.35 ± 0.01

3.7. Total Soluble Solids (TSS)

Table 7 presents the TSS values of jackfruit samples. A decreasing trend in TSS was observed in all samples, consistent with research by Navindra *et al*. (2009), Chen *et al*. (2020), and Khayankarn *et al*. (2013). The differences in TSS among untreated, AEW-treated, and SAEW-treated samples were 7.45, 4.6, and 4.85, respectively. AEW and SAEW samples exhibited lower differences in TSS compared to untreated samples. This decreasing trend may be attributed to increased respiration resulting from wounds during processing, as sugars and organic acids are primary substrates for plant respiration. Additionally, changes in soluble solids may be attributed to ripening processes.

Table 7. TSS value for jackfruit bulbs with different treatments

Treatment	TSS (%)	
	0^{th} day	**22^{nd} day**
Untreated	17.85 ± 0.49	10.4 ± 0.28
AEW	17.9 ± 0.85	13.3 ± 0.14
SAEW	17.65 ± 1.20	12.8 ± 0.99

3.8. Weight Loss

Table 8 presents the weight loss of untreated, AEW-treated, and SAEW-treated samples. Weight loss is a significant factor in assessing the quality of fresh-cut produce, as

they are particularly susceptible to water loss-induced weight loss. Gradual increases in weight loss were observed in all samples after 22 days. Minimal weight losses of 1.25% were recorded in SAEW samples, while the highest weight loss of 2.74% was observed in untreated samples. No significant difference was observed between AEW and SAEW samples after 22 days. Consequently, electrolysed water may not damage cell walls, leading to increased water loss. These findings support previous research by Aday (2016), which reported slight differences in weight loss between untreated and electrolysed water-treated mushroom samples.

Table 8. Percentage of weight loss for jackfruit bulbs with different treatment

Treatment	Weight loss (%)
Untreated	2.74 ± 1.48
AEW	1.90 ± 0.67
SAEW	1.25 ± 0.19

4. Conclusions

The outcomes of this experiment deviated from expectations, primarily due to significant contamination issues encountered during the treatment process. High microbial counts were observed on Day 1 for both AEW and SAEW samples, which likely contributed to the inconsistent quality parameters of jackfruit bulbs, including colour, texture, TSS, pH, and weight. Several factors contributed to these contamination issues. Firstly, the rushed handling of jackfruit bulbs, necessitated by MCO, resulted in inadequate attention to hygienic practices during preparation. This lack of careful handling likely increased the risk of microbial contamination, undermining the effectiveness of the treatments. Secondly, the insufficient drying time after washing the jackfruit bulbs may have left residual moisture on the surface, creating an environment conducive to microbial growth. The presence of moisture can facilitate the proliferation of bacteria and fungi, further complicating the preservation efforts. Additionally, the potential for cross-contamination during the treatment process was a significant concern. Treating a large batch of approximately 3.4 kg of jackfruit bulbs simultaneously using a batch electrolysis unit may have contributed to cross-contamination, as the water needed to be generated multiple times and accumulated in a bottle before treatment. This accumulation could have led to the dilution of the antimicrobial properties of the electrolysed water, reducing its effectiveness against microbial loads. In conclusion, the proposed method requires significant refinement. Measures to address contamination issues, such as improving handling protocols, ensuring adequate drying times, and preventing cross-contamination during treatment, are essential for future applications to

yield reliable results. The findings underscore the importance of maintaining stringent hygiene practices and optimising treatment parameters to enhance the effectiveness of electrolysed water in preserving the quality of fresh produce.

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