Alternating Current Electric Field (ACEF) to Maintain Plant-Based Product Quality

Bara Yudhistira[1,2,*,a], Andi Syahrullah Sulaimana[3,4,b] and Fuangfah Punthi[1,c]

[1]Department of Food Science and Biotechnology, National Chung Hsing University, Taichung City 40227, Taiwan
[2]Department of Food Science and Technology, Sebelas Maret University, Surakarta City 57126, Indonesia
[3]Department of International Master Program of Agriculture, National Chung Hsing University, Taichung City 40227, Taiwan
[4]Department of Agro-industrial Technology, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

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Abstract: Alternating current electric field (ACEF) is a technique that can be applied to maintain the quality of plant-based products. This technique uses an electroporation process that has an impact on inactivating microorganisms and enzymes in food. The effect of ACEF application on food depends on the frequency, amplitude, time, type of food treated, etc. This review discusses the application of ACEF to several types of food, such as seafood, sweet potatoes, and oyster mushrooms. In general, the application of ACEF can maintain nutritional quality, physico-chemical properties, and extend the shelf life of products. Although ACEF can have a positive effect on the food being treated, process optimization is required to obtain an efficient process. The ACEF method can also be combined with hurdle technology to give food a better effect. This method can be used to assist the process of thawing, drying, etc. The results of the study show that ACEF has the potential to be applied to the food industry.

1 INTRODUCTION

Novel preservation using reduced temperature and/or short processing time has received widespread attention and has become an alternative to pasteurization and thermal sterilization and can be considered to be able to maintain better food quality. Preservation methods can be carried out using physical techniques such as cold plasma, high-pressure processes, and the use of electric fields (Yudhistira, et al., 2022a). Electric field (EFs) with high-intensity can be used for food preservation (Toepfl et al., 2007). EFs for preservation purpose has the advantages of efficient energy consumption, environmentally friendly, economical, can retain the nutritional compounds and sensory parameter of food (van Wyk et al., 2019). In addition, it has the potential to be applied to sterilization and food preservation. The characteristics of the electric field used are influenced by the type of plate electrode and the voltage mode (Mendes-Oliveira et al., 2020). EF treatment in many studies shows a strong antibacterial effect (Punthi et al., 2022).

Alternating current electric field (ACEF) is a non-thermal method for shelf life extend of perishable goods and reduce their microbiological, physiological, and activities of enzyme (Dalvi-Isfahan et al., 2016). ACEF treatment has been shown to maintain the quality and extend of shelf life of foods during their handling after harvest and storage (Sulaimana et al., 2022). Based on a previous study, ACEF (125 kV/m, 60 min) can produce longer shelf life of sea grapes by up to 12 days (Sulaimana et al., 2021). In addition, the best settings are 50 kV/m, 60 min, 9 mol photons m^{-2} s^{-1}, and 60% more efficient energy consumption (Sulaimana et al., 2022). ACEF applied also in oyster mushroom, browning reduce up to 40% after 12 days of storage by ACEF (600 kV/m, 50 Hz, 120 min). This treatment can inhibit

[a] https://orcid.org/0000-0001-8945-1454
[b] https://orcid.org/0000-0001-7822-2357
[c] https://orcid.org/0000-0001-6141-9858

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malondialdehyde, delay of electrolyte leakage, and inactivated of polyphenol oxidase (Hsieh et al., 2020). This treatment applied in sweet potato and show it can inhibit starch breakdown and maintain nutritional content (Pang et al., 2021).

The purpose of this paper is to provide recommendations for the critical information that should be presented in studies of ACEF for food preservation. These recommendations are meant to enable the comparability of data and to provide a solid foundation for a better understanding of the influence of various parameters on the efficacy of ACEFs and the mechanisms involved.

2 ALTERNATING CURRENT ELECTROSTATIC FIELD (ACEF) DEVICE

According to Muthukumaran et al. (2010), ACEF treatment can provide higher quality and lower operating costs, and it is applicable to all highly sensitive food products. Alternating current (AC) is a form of electrical current has the flow of electrons reverses direction at regular intervals (Committees, 2022). This is the electric current produced by a generator or outlet and the voltage periodically varies from positive to negative and vice versa (Anonymous, 2022). In addition, undesirable electrochemical reactions can be suppressed by an AC, which offers unique benefits such as the capacity to generate fast, programmable flows (Shin et al., 2019). Applications of AC electric fields can be modified, including waveform shape, frequency, and amplitude (Janićijević et al., 2016).

3 ACEF EFFECT FOR FOOD PRESERVATION

High-intensity pulses are discharged into the food to inactivate microorganisms and enzymes. The food is passed between two electrodes, which results in electroporation and the membrane pores formation. It will make the cell membrane derangement, and intracellular material leakage. The food's physicochemical, nutritional, and sensory qualities should remain the same as those of fresh products after delivery (Guerrero-Beltrán & Welti-Chanes, 2015; Alam et al., 2018). Electric field (EF)S make pores on a sub-microsecond timescale, and the size and pores proliferation may be controlled by the electrical exposure time and the inherent material qualities being treated (Demir et al., 2018). The EF treatment involves the application of short-duration, high-voltage to a liquid or solid product placed between two electrodes. Polarization of the cell membrane causes cellular tissue permeabilization and disruption (Toepfl et al., 2014). Initial EF applications centered on its capacity to destroy microorganisms without the use of heat, enabling non-thermal pasteurization. EF is exposured to a cell, electroporation results in the opening of holes in the cell membrane (Kempkes & Munderville, 2018). Long and strong electrical pulses cause membrane components like water and lipids to rearrange, resulting in the formation of aqueous hydrophilic holes (Weaver, 2003). Pores examine cannot directly measure in nanometers using standard techniques such as electron microscopy. Nevertheless, modern computational approaches (molecular dynamics simulations) used to study the EF effect on cell membranes (Leach, 2001).

The electroporation mechanisms occur in two phases. First, water molecules grouped in a single wire penetrate the hydrophobic core of the bilayer. This material is predominantly water, but it also contains molecules made by plants (flavonoids, lipids, vitamins, etc.) that are now available within the tissue, as opposed to being imprisoned within the cell. Second, the water wires develop in length and expand into water-filled pores, which are subsequently stabilized by restructuring of lipid molecules. Due to the turgor pressure exerted by intact plant cells, the intact tissue is rigid. However, after electroporation, the release of intracellular material decreases this pressure, thereby softening the plant material (Tieleman, 2004; Nowosad et al., 2021). The effect of ACEF application on plant-based products can be seen in Table 1.

3.1 Enzyme Inhibition

Inactivation of an enzyme by EF is dependent on the enzyme type and EF circumstances. External EFs induce functional, conformational, and structural changes in enzymes, which generate free radicals that promote protein unfolding and aggregation due to energy absorption by polar groups in proteins (Punthi et al., 2022). Based on a previous study, ACFE can reduce PPO activity by 60%–80%, ACEF-treated has significant difference than untreated samples. In addition, ACFE 600 kV/m has the strongest the inhibitory effect. By blocking PPO and LOX activities, ACFE 400 kV/m and time 120-min has significantly inhibit the browning and oxidation of phenolics in oyster mashroom (Hsieh et al., 2020). Moreover, the first-order reaction depicts the chlorophyll breakdown caused by enzyme activity and lead to an increased pheophorbide yield as the duration of oxidative stress increases. The discoloration of winter sea grapes on the ocean floor may be a result of this response (Sulaimana et al., 2021). The treatment time and the type of electric wave configuration has a substantial effect on the enzyme activity. This investigation reveals that the effect of treatment time may depend on the sample's resistance to electric induction and the arrangement of the equipment (Sulaimana et al., 2022).

According to another study, in the control group, PPO activity grew for the first 30 days and then climbed dramatically for the remaining days, whereas its increased just marginally during the first 20 days. Except for the first 20 days treated roots PPO activity was much lower than that of untreated roots while they were being stored (Pang et al., 2021). EF treatment give vary enzymatic responses in plants depending on treatment conditions, molecular size, microstructure, and food source (Punthi et al., 2022).

3.2 Physical-Chemical Quality

Based on a previous study, ACEF may result in water loss from sea grape cells with high cell wall permeability. In this investigation, the water loss of sea grapes rose constantly during storage. This study revealed a considerable reduction in the MDA production of sea grapes after day 9 storage and demonstrated that the ACEF might preserve the water content of sea grapes by reducing the MDA product during postharvest storage (Sulaimana et al., 2021). Due to the intensification of ACEF, the chlorophyll content of sea grapes gradually diminished. Previous research demonstrated that a 60-minute ACEF treatment at 125 kV/m has a substantial effect on retaining chlorophyll content, resulting in a high total phenolic content (TPC) of sea grape during storage (Sulaimana et al., 2022).

Another study shows from 1 to 6 days, phenolic content rose alongside alterations in cell membrane integrity. The disruption of cell membranes during pre-storage boosted phenolic biosynthesis during cold storage. On the last day of storage, the TPC of the ACEF samples was approximately 30% higher than control samples by significant difference between both samples, ACFE 600 kV/m can maintain with the highest TPC (Hsieh et al., 2020). Other study shows the HVAEF decreased water loss in sweet potatoes. HVAEF is one of ACEF treatment and this study to characterize the changes in water migration, NMR was used to examine the influence of HVAEF on water distribution. The HVAEF treatment decreased root water loss during storage. To further characterize the changes in water migration, NMR was used to examine the influence of HVAEF treatment on water distribution. It show water loss and firmness of sweet potatoes during postharvest storage gradually diminishes, resulting in the loss of hydrolysis of starch, freshness, and buildup of reducing sugar (Pang et al., 2021).

3.3 Hurdle Technology-Assisted ACEF

ACEF applications can be combined with other technologies (hurdle technology) to obtain optimal product properties and efficient handling processes. ACEF can be used as a pre-treatment for drying and thawing certain products. According to Punthi et al. (Punthi et al., 2022) Some studies on fruits and vegetables have revealed that PEF has the ability to reduce processing time by boosting the drying rate.

This is because ACEF can modify the product network structure and can change the water distribution, which will lead to changes in the drying process. Previous studies have also shown that EF can be used to speed up the thawing of frozen duck meat. The thawing process is about 20%–50% shorter by using PEF treatment at 1–4 kV/cm. In addition, PEF-assisted thawing at 1–3 kV/cm can reduce protein loss by 19% and thawing loss by 28%. It also provides a quality similar to fresh meat (Lung et al., 2022; Chang et al., 2023). Although the ACEF application provides many advantages, it still has limitations in its application. Punthi et al. (2022) stated that ACEF has some limitations, including a low processing capacity most of the time, as well as various models that are still at lab scale, the need to scale up, and in general, the process is still in the batch chamber, so it needs more time for food processing. In addition, it is necessary to adjust the tools or add other tools to the ACEF instrument. Because of this, some people who work with the machines need to improve their skills, and the machines' effectiveness also depends on how they are made. Furthermore, it needs some protocol to operate the ACEF machine to make the saving process possible, and in general, the operational costs of ACEF are high.

The procedure for using ACEF generally involves placing the patient in a chamber with electrodes installed. These electrodes are connected to a generator, which can be adjusted for power, pulse, etc. The size of the chamber can be adjusted according to the size of the material to be treated.

Table 1: Application ACEF on plant-based product.

Product	Treatment	Result	Ref
Oyster mushrooms	600 kV/m, 50 Hz, 120 min	This treatment effect to reduce decreased lipoxygenase activity and malondialdehyde levels, inhibit electrolyte leakage, inactivation of polyphenol oxidase. In general, this treatment, delay browning and improve the oyster mushroom quality during storage.	(Hsieh et al., 2020)
Seagrape	125 kV/m, 60 min	Reduce the quality by 10–30% and extend the shelf life by up to 12 days during storage.	(Sulaimana et al., 2021)
Seagrape	50 kV/m, 60 min, 9 mol photons m−2 s−1	A reduction of up to 60% more efficient for energy consumption and lower electric intensity with an adequate SLI and a moderate treatment time can produce the best quality of seagrape.	(Sulaimana et al., 2022)
Sweet potatoes	4 kV/m	This treatment can control the water loss and starch hydrolysis. It also can inhibit enzyme activity related to metabolism including inhibit starch breakdown, maintain nutritional content, and reduce enzymatic browning during cold storage.	(Pang et al., 2021)

The ACEF chamber undergoes an electroporation process and does not require other materials, such as water in the ozonation chamber to wash fruit/vegetable (Prabawa et al., 2022), and does not produce light or arcs in plasma technology in food preservation and packaging modification (Yudhistira, et al., 2022b). In addition, this technology does not produce high temperature changes when using the appropriate settings.

4 CONCLUSIONS

ACEF is a technique that can be used in food processing. This provides a preservation effect because it can inhibit the growth of microorganisms and enzyme activity. In addition, ACEF is a non-thermal method that can maintain the nutritional quality of food, and this advantage provides the prospects and potential for this technology to be applied to the food industry.

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