Engineered Science

# Investigating the effect of pulsed electric field parameters on the quality of processed mango pickling

| | |
|---|---|
| Journal: | *Engineered Science* |
| Manuscript ID | ES-2023-0006.R2 |
| Manuscript Type: | Original Research |
| Date Submitted by the Author: | 17-Dec-2023 |
| Complete List of Authors: | Supasin, Supakiat; Payap University, Cannabis and Medicinal Plants for Local Development<br>Kantala, Chatchawan ; Rajamangala University of Technology Lanna, College of Integrated Science and Technology<br>Intra , Panich ; Rajamangala University of Technology Lanna, College of Integrated Science and Technology<br>Vongpradubchai , Somsak ; Thammasat University, Mechanical Engineering<br>Rattanadecho, Phadungsak; Thammasat University, |
| Keywords: | Pulsed electric field, Mango pickles, Quality change, Thai mango, Synergism |
| | |

# Table of Contents

December 13, 2023

Manuscript ID: ES-2023-0006.R1
Type of manuscript: Article
**Title:** Investigating the effect of pulsed electric field parameters on the quality of processed mango pickling
Journal: Engineered Science

Dear Editor,

Thank you very much for your kindness in the opportunity to resubmit our manuscript again. Please consider our revised manuscript entitled " **Investigating the effect of pulsed electric field parameters on the quality of processed mango pickling**" for publication in Engineered Science journal.

We have adjusted all point of your suggestion and addressed all comments of the reviewers. As recommended by the Reviewer#1, we do add more information according his/her suggestion. Therefore, we would like response to reviewer for the final version manuscript for publication as open access article in Engineered Science journal.



Thank you again for consideration of our manuscript.

Yours sincerely,

Phadungsak Rattanadecho, Ph.D.
Professor in Mechanical Engineering
Faculty of Engineering, Thammasat University
Rangsit Centre, Pathum Thani, 12120, THAILAND
Phone: +66-2-5643001-9; Fax: +66-2-5643010
E-mail address: ratphadu@engr.tu.ac.th

# Investigating the effect of pulsed electric field parameters on the quality of processed mango pickling

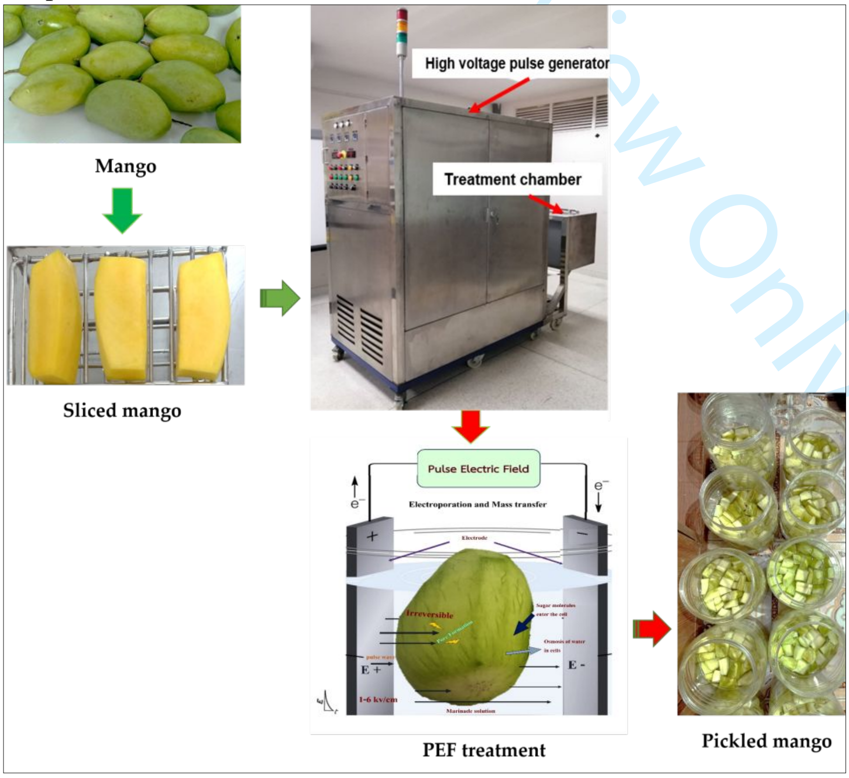
Supakiat Supasin [1], Chatchawan Kantala [2], Panich Intra [2,] Somsak Vongpradubchai [3] and Phadungsak Rattanadecho [3],*

*[1] Division of Cannabis and Medicinal Plants for Local Development, Graduate School, Payap University, Chiang Mai 50000, Thailand*
*[2] Research Unit of Applied Electric Field in Engineering (RUEE), College of Integrated Science and Technology, Rajamangala University of Technology Lanna, Chiang Mai 50220, Thailand*
*[3] Center of Excellence in Electromagnetic Energy Utilization in Engineering (CEEE), Department of Mechanical Engineering, Faculty of Engineering, Thammasat University, Pathum Thani 12121, Thailand*
* ***E-mail***: *ratphadu@engr.tu.ac.th*

Received: 21 April 2020
Accepted: 8 May 2020
Article type: Research Paper
DOI: https://dx.doi.org/10.30919/es8d1005



**Graphical abstract**



**Abstract**

Pulsed electric field (PEF) is a non-thermal process which is applied widely in various food processing methods. The aim of this study was to evaluate the synergistic effect of the developed PEF parameters, including pulse strength, pulse frequency, and pulse number, on the changes to sweet pickled Thai mango quality, including changes in moisture content, water activity, color, texture, and mass transfer. A 2 × 2 × 5 factorial experiment in a completely randomized design was used. Analysis of variance (ANOVA) showed that the main effects of the investigated parameters and their interaction were mostly significant. Application of PEF at 3 kV/cm, 1 Hz, and 500 pulses significantly improved water reduction, weight loss, and solid gains by 2 times, as well as the beta-carotene content (52.56 µg/100g) of sweet pickled mango, when compared to fresh and conventionally pickled mangoes. This finding suggests that combining PEF and osmotic dehydration could be an effective process for producing sweet pickled mango. The effect of combining PEF parameters and osmotic dehydration is advantageous for improving osmotic efficiency while retaining the phytochemical compounds of mango.

*Keywords:* Pulsed electric field; Mango pickles; Quality change; Thai mango; Synergism

# 1. Introduction

Mango (*Mangifera indica* L.), belonging to the family Anacardiaceae, is a commercially important tropical fruit grown in several parts of the world, especially in the Asian region such as in India, the Philippines, China, Thailand, Indonesia, Pakistan, and Bangladesh. [1,2] Mango has an attractive flavor, taste, aroma, and texture, and is high in nutrients such as reducing sugars, amino acids, and vitamins, as well as being rich in aromatic compounds, pectin, anthocyanins, and polyphenols.[1,3] In 2019, the global production of mango was 51 million tons.[1] There are three main parts to a mango: the pulp, the peel, and the kernel, of which the pulp is the most consumed part.[1,4] Although mango is mainly consumed fresh, it can be processed into many products in order to decrease postharvest losses during the main harvest season.[5] Currently, there are many processed mango products available in the global market; for example, canned slices in syrup, juice, nectar, jam, chutney, and dehydrated mango.[2]

During harvesting seasons, the price of mango decreases due to oversupply in the market.[5] Thus, in order to minimize this situation, sufficient preservation techniques need to be used to preserve the quality and shelf life.[6] Pickling is a traditional method of food preservation applied to fruits, vegetables, and meats.[7] This technique is widely used in households and many food industries. Mango pickles are made mostly from green mango and categorized as salty, oily, or sweet.[2] In Thailand, the sweet pickled mango is called ma-muang chae-im.[8] Generally, sweet pickled mango is firstly immersed in 30 °brix sugar solution and then 50 °brix of sugar solution.[9] However, the traditional pickling process is inefficient in terms of mass transfer, is time-consuming, and is difficult to control.[10] Currently, there are several innovative methods which can be used to increase the mass transfer of the solutions into the foods such as pulse pressure,[11,12] ultrasound[13] and pulsed electric field (PEF).[13-19] Among these, PEF has been well-explored to pretreat the fruit tissue in order to enhance the mass and heat transfer process.[14]

PEF is an emerging technology and can improve the functionality, extractability, and nutritional value of several food varieties,[20] for example in French fries manufactory.[21,22] This technology consists of electrical treatment with a pulse strength from 100 V/cm to 80 kV/cm.[23] Animal and plant cell electroporation require a lower electric field strength (0.5-2 kV/cm), whereas microbial cells require an electric field strength of 10-14 kV/cm.[24] For biomacromolecule modification, a larger electric field strength (>15 kV/cm) is applied. [25] It causes minimal loss to the color, aroma, flavor, and nutritional value of the fruit products. This process can increase cell permeabilization, resulting in increased heat and mass transfer.[14,20] Several research studies have successfully used PEF pretreatment for fruit tissues before the osmotic process on fruits such as kiwifruit,[14] strawberries,[26] mangoes,[27] apples,[15-18] and goji berries.[19] To the best of our knowledge, there have been no previous reports into the effects of PEF parameters on mass transfer in the mango pickling process.

Therefore, this study aimed to investigate the effect of the Thai developed-PEF machine combined with the pickling process in 30 °brix of sugar solution on Thai mango var. Chok-anan, which is the most frequently used in preserved mango production in Thailand due to its vibrant color, exotic flavor, distinctive taste, and nutritional properties.[28] Therefore, this study was to determine how varying levels of pulse strength, pulse frequency, and pulse number effect changes in moisture content, water activity ($a_w$), color, texture, and mass transfer.

## 2. Experimental section

### 2.1 Raw material

Mature green mangoes of the variety "Chok-anan" (100-150 g/fruit) were purchased from local farms in Chiang Mai, Thailand. Before processing, the mangoes were washed with water, peeled with a knife, and cut into 5 × 20 × 40 mm (height × width × length) rectangular-shaped pieces.[29] Each piece of mango weighed 10 ± 1 g. The materials used in this study complied with international, national and/or institutional guidelines.

## 2.2 PEF-assisted pickling process

The PEF system was built by the Research Unit of Applied Electric Field in Engineering (RUEE) Laboratory at Rajamangala University of Technology Lanna, Chiang Mai, Thailand (Figure 1). The system consisted of the control system, treatment chamber and spark gap. The maximum voltage applied was 40 kV and an electrical capacitor of 1 μF. The chamber dimension was 4 cm in width × 45 cm in height × 37.5 cm in length, with a maximum volume of 6,750 $cm^3$ (≈ 6.75 L). The chamber was filled to a volume of 2,500 $cm^3$ (30 °brix sucrose solution + mango pieces).

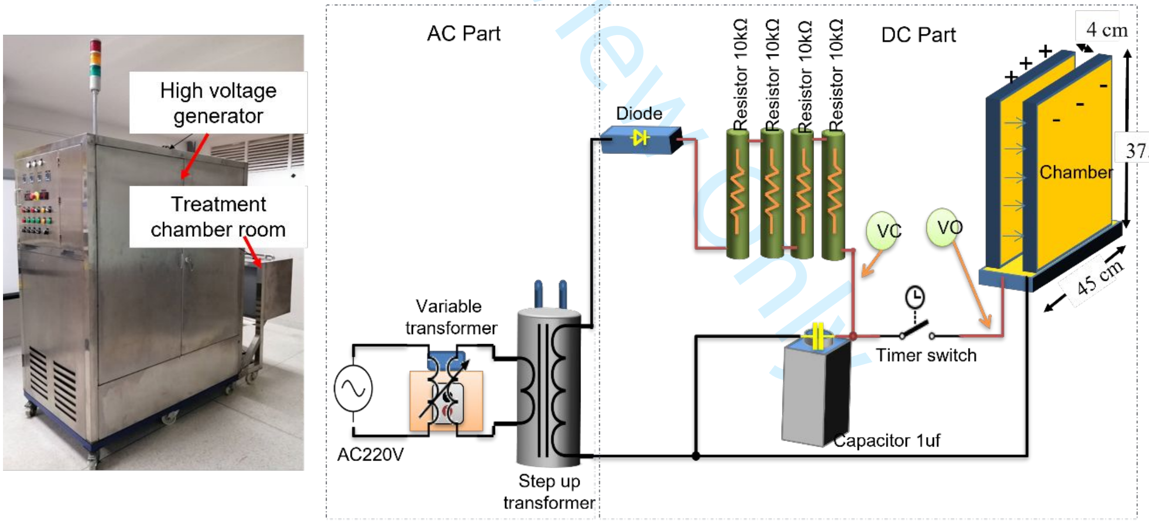



**Fig. 1**. PEF machine and diagram flow chart adapted from previous work.[29]

The ratio of mango to sucrose solution was 1:30 (w/v) and the mango was then randomly placed in the treatment chamber. The temperature of the treatment chamber was controlled at 30±1.0°C. The experiments were performed as detailed in Table 1. Each experiment was performed in triplicate. After PEF, the mango was transferred to a

3L glass jar and kept at 30±1.0°C for 24 hours before analysis. The specific energy ranged from 11.50 kJ/kg to 66.30 kJ/kg, which was effective for the decontamination process.[30] However, there was no impact on the temperature in the operating process because the process was controlled by cooling water. The pulse strength (E, kV/cm) and the specific energy input (kJ/kg) were calculated according to Eq. (1) and (2).[31]

$$E\ (kV\,|\,cm) = \frac{U}{d} \qquad (1)$$

$$Specific\ energy\ (kJ/kg) = \frac{U^2 \times C}{2 \times m} \times n \qquad (2)$$

where U is the charging voltage (kV); d is the distance between electrodes (cm); C is the PEF capacity unit (2 µF); m is the mass in the treatment chamber (kg); and n is the pulse number.

**Table 1** Overview of the applied PEF-settings in this study[1]. The conditions were conducted at 30°C.

| Treatment | PEF parameters | | | Specific energy (kJ/kg) |
|---|---|---|---|---|
| | E (kV/cm) | F (Hz) | N | |
| 1 | 2 | 1 | 500 | 11.50 |
| 2 | 2 | 1 | 700 | 16.10 |
| 3 | 2 | 1 | 900 | 20.70 |
| 4 | 2 | 1 | 1,100 | 25.30 |
| 5 | 2 | 1 | 1,300 | 29.90 |
| 6 | 3 | 1 | 500 | 25.50 |
| 7 | 3 | 1 | 700 | 35.70 |
| 8 | 3 | 1 | 900 | 45.90 |
| 9 | 3 | 1 | 1,100 | 56.10 |
| 10 | 3 | 1 | 1,300 | 66.30 |
| 11 | 2 | 3 | 500 | 11.50 |
| 12 | 2 | 3 | 700 | 16.10 |
| 13 | 2 | 3 | 900 | 20.70 |
| 14 | 2 | 3 | 1,100 | 25.30 |
| 15 | 2 | 3 | 1,300 | 29.90 |
| 16 | 3 | 3 | 500 | 25.50 |
| 17 | 3 | 3 | 700 | 35.70 |
| 18 | 3 | 3 | 900 | 45.90 |
| 19 | 3 | 3 | 1,100 | 56.10 |
| 20 | 3 | 3 | 1,300 | 66.30 |

[1] E is electric field strength (kV/cm); F is pulsed frequency (Hz); and N is number of pulses.

### 2.3 Conventional pickling process

The conventional mango pickling was performed according to Uthairungsri et al. [9] and Supasin et al.[29] Briefly, the mango cubes were immersed in 1L of 30 °brix sucrose solution in a ratio of 1:30 (w/v). The pickling process was performed in a 3L glass jar at 30±1.0°C for 24 hours before analysis.

### 2.4 Analysis

#### 2.4.1 Determination of mass transfer

Mass transfer of the sweet pickled mango was evaluated by calculating weight reduction (WR), water loss (WL), and solid gain (SG) using Eq. (3), (4), and (5) respectively.[14] The diffusion efficiency (DE) was evaluated by Eq. (6):

$$WR\ (g/g) = \frac{W_t - W_0}{W_0} \quad (3)$$

$$WL\ (g/g) = \frac{(W_0 - M_0) - (W_t - M_t)}{M_0} \quad (4)$$

$$SG\ (g/g) = \frac{M_t - M_0}{M_0} \quad (5)$$

$$DE = \frac{WL}{SG} \quad (6)$$

where:

$W_0$ = initial weight of fresh mango (g)

$W_t$ = weight of samples after a time t of preservation (g)

$M_0$ = dry mass of samples before preservation (g)

$M_t$ = dry mass of samples after a time t of preservation (g)

#### 2.4.2 Moisture content, water activity ($a_w$), and pH

The moisture content was measured using the method of the AOAC.[32] Moisture content was determined by drying samples in an oven (Memmert, Schwabach, Germany) at 105 °C until a constant weight was achieved. The $a_w$ was monitored using an Aqua LAB

4TEV (Decagon Devices, Inc., USA). The pH was measured by pH meter (Mettler Toledo, USA). The cube of mango (10g) was ground and mixed with 10mL of distilled water. The mixtures were vigorously shaken for 2 minutes and then centrifuged at 2,000 rpm for 5 minutes. The supernatant was corrected and used to measure pH. All experiments were performed in triplicate.

**2.4.3 Determination of color**

The color of fresh mango, untreated sweet pickled mango, and PEF-treated sweet pickled mango was directly read in terms of CIELab values (L*, a*, and b*) with a HunterLab chromameter (MiniScan EZ, Virginia, USA).[33] Each treatment was done in triplicate. The results were recorded, and the total color change (ΔE) calculated using Eq. (7).

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \qquad (7)$$

Where the letters with subscripts 0 are the value of the fresh mango.

**2.4.4 Texture analysis**

The hardness and toughness of the samples were measured with puncture mode of a texture analyzer (TA-XT plus, Stable Micro Systems, UK) equipped with a stainless-steel probe 5 mm in diameter. Pre-test, Test, and Post-test speeds were 1.5, 1.5, and 100 mm/s respectively. The samples were axial compressed by approximately 30%. Thirty replicates of the sample were tested.

**2.4.5 Surface morphology**

The surface morphology of the fresh mango, conventionally pickled mango, and PEF-assisted pickled mango was examined using a scanning electron microscope (SEM; Prima E, Thermo Scientific, Waltham, MA, USA). The samples were placed on SEM stubs using double-faced tape and a photograph taken at an excitation voltage of 5 kV using an image detector (PentaFET precision, X-act, Oxford Instruments, Abingdon, UK).

**2.4.6 Electrical conductivity disintegration index (Z)**

Mango was mixed with distilled water in a ratio of 1:1 (w/v) and ground into pulp with a multipurpose blender. The mixture was then centrifuged at 2,000 rpm for 5 minutes. The supernatant was corrected and electrical conductivity was measured by conductometer (TDS&EC meter, China). The degree of tissue damage was evaluated from electrical conductivity disintegration index (Z) as following Eq. (8).[34]

$$Z = \frac{(\sigma - \sigma_i)}{(\sigma_d - \sigma_i)} \tag{8}$$

where σ is the measured electric conductivity value (S/m), and the subscripts i and d refer to the conductivities of the initial mango (fresh) and completely damaged tissue respectively.



### 2.4.7 Beta-carotene content

Beta-carotene content was measured using high-performance liquid chromatography (HPLC) according to the method of Supasin et al.[29] Briefly, the samples (0.1g) were ground by mortar and then 1.5 mL of 95% n-hexane, 0.75 mL of 95% ethanol, and 0.75 mL of acetone were added. Afterward, the extracted samples were transferred to a centrifuge tube and 5 mL of water was added. The centrifugation was performed at 3000 rpm and 25 °C for 10 minutes. The supernatant (5 mL) was then transferred into a new tube and the volume adjusted to 10 mL with 95% n-hexane. After being filtered through a 0.2 µm syringe filter (Labfil, China), the sample (20 µL) was injected into the HPLC (Agilent Technologies, Santa Clara, CA, USA) with a photodiode array detector and a $C_{18}$ reverse-phase column (Waters $C_{18}$, 250 × 4.6 mm, 5 µm particle size). The gradient elution used methanol and methyl-tert-butyl ether at a flow rate of 1.0 mL/min and detection wavelength of 470 nm.

### 2.4.8 Ascorbic acid content

The ascorbic content of mango was measured according to the method of Supasin et al.[29] The mangoes (2.5g) were ground and mixed with 3% m-phosphoric acid in a 100 mL volumetric flask. The mixtures were vigorously shaken for 2 minutes and then sonicated in an ultrasound bath for 5 minutes. An aliquot was then filtered through a 0.2 µm filter (Labfil, China). The sample (20 µL) was injected into the HPLC system, and the optical density measured at 248 nm using a UV detector at a flow rate of 0.5 mL/min. The mobile phase was a mixture of 3 mM potassium dihydrogen phosphate in 0.35% (v/v) o-phosphoric acid.

**2.5 Statistical analysis**

The experimental values were expressed as the average and standard deviation. SPSS software version 17.0 (IBM, NY, USA) was used to analyze the significance tests. The univariate general linear model was used to analyze the interaction and significant differences between treatments. The differences between PEF-pickled mangoes were analyzed using one-way analysis of variance (ANOVA) with Duncan's multiple range tests for post hoc testing. Correlations between the investigated parameters were examined using the Pearson correlation. A comparison of the non-PEF and PEF processes was determined by an independent-sample *t*-test. Results of $p < 0.05$ indicated a significant difference.



## 3. Results and discussion

**3.1 Effect of PEF parameters coupled with sweet pickling mango**

**3.1.1 Change in water loss (WL), solid gain (SG), water reduction (WR), and diffusion efficiency (DE)**

The characterization of fresh mango used in this study is shown in Table 2. The fresh mango contained high amounts of moisture (88.03±0.04%). The effect of the PEF-assisted pickling process on mango WL, SG, WR, and DE are presented in Table 3 and Table 4.

**Table 2** Fresh Thai mango var. Chok-anan characterization

| Characteristic | Average ± SD |
|---|---|

| | |
|---|---|
| Moisture (%) | 88.03±0.04 |
| Water activity | 0.976±0.002 |
| pH | 3.01±0.05 |
| color | |
| - L* | 56.27±0.64 |
| - a* | -3.24±0.30 |
| - b* | 28.64±0.86 |
| Hardness (N) | 53.35±6.21 |
| Toughness ($mJ/m^3$) | 183.12±54.90 |

**Table 3** Analysis of variance (ANOVA) for identified quality changes of sweet pickled mango by PEF-assisted pickling process[1].

| Source of variance | *p*-value | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WL | SG | WR | DE | MC | $a_w$ | *L** | *a** | *b** | Δ*E* | H | T |
| Main effect | | | | | | | | | | | | |
| E | 0.038 | 0.039 | 0.038 | 0.918 | 0.038 | 0.737 | 0.620 | 0.000 | 0.159 | 0.141 | 0.148 | 0.140 |
| F | 0.000 | 0.000 | 0.000 | 0.191 | 0.000 | 0.015 | 0.084 | 0.001 | 0.054 | 0.253 | 0.000 | 0.000 |
| N | 0.028 | 0.032 | 0.029 | 0.968 | 0.003 | 0.096 | 0.209 | 0.000 | 0.014 | 0.040 | 0.935 | 0.875 |
| Interactions | | | | | | | | | | | | |
| E × F | 0.347 | 0.354 | 0.350 | 0.808 | 0.348 | 0.027 | 0.397 | 0.009 | 0.598 | 0.814 | 0.129 | 0.139 |
| E × N | 0.012 | 0.013 | 0.012 | 0.848 | 0.012 | 0.425 | 0.067 | 0.000 | 0.621 | 0.141 | 0.185 | 0.553 |
| F × N | 0.004 | 0.005 | 0.004 | 0.751 | 0.004 | 0.001 | 0.098 | 0.000 | 0.525 | 0.336 | 0.052 | 0.297 |
| E × F × N | 0.077 | 0.083 | 0.077 | 0.695 | 0.076 | 0.045 | 0.316 | 0.000 | 0.071 | 0.003 | 0.372 | 0.313 |

[1] E is electric field strength (kV/cm); F is pulsed frequency (Hz); and N is number of pulses; WR = weight reduction (g/g); WL = water loss (g/g); SG = solid gain (g/g); DE = diffusion efficiency; MC = moisture content (%); H = hardness (N); T = toughness ($mJ/m^3$).



There was a non-significant ($p$>0.05) effect of the interaction of pulse strength, frequency, and number on WL, SG, WR, and DE (Table 3). However, WL, SG, and WR, were affected by the interactions of pulse strength × pulse number and frequency × pulse number ($p$<0.05). Pulse strength controls the efficiency of cellular tissue electroplasmolysis, while pulse frequency is a parameter affecting the electroporation process.[35] Meanwhile, an increase in pulse number significantly increased cell perforation, leading to a more efficient electroporation process.[36] Asavasanti et al.[37] suggested that pulse frequency plays an important role in the PEF-induced permeabilization of cell tissues. In this study, pulse frequency was the most effective parameter in changing the mass transfer of sweet pickled mango, with a $p$-value less than 0.000 (Table 3). A low pulse frequency (1 Hz) may cause more damage to cell membranes because there is more time for the cell to charge between pulses, thereby enhancing pore formation.[35] However, the increase of pulse frequency to 3 Hz decreased the degree of cell electroporation[38] and led to cell membranes resealing (supplementary Figure 1) and less moisture transport due to less tissue damage.[39]

**Table 4** Mean comparison of water loss (WL), solid gain (SG), water reduction (WR), and diffusion efficiency (DE) for the interaction of strength × frequency × pulse number in PEF-assisted sweet pickled mango[1].

| Treatment | Mass transfer | | | DE |
|---|---|---|---|---|
| | WL (g/g) | SG (g/g) | WR (g/g) | (WL/SG) $^{ns**}$ |
| 1 | 0.98±0.01$^{abcd*}$ | 0.13±0.00$^{ab}$ | 0.85±0.01$^{ab}$ | 7.35±0.01 |
| 2 | 0.99±0.05$^{bcd}$ | 0.17±0.01$^{ab}$ | 0.86±0.05$^{ab}$ | 6.55±1.12 |
| 3 | 1.01±0.10$^{bcd}$ | 0.14±0.01$^{ab}$ | 0.88±0.09$^{ab}$ | 6.27±1.50 |
| 4 | 1.07±0.00$^{abcd}$ | 0.15±0.00$^{ab}$ | 0.93±0.00$^{ab}$ | 6.33±1.43 |
| 5 | 1.02±0.04$^{abcd}$ | 0.14±0.01$^{ab}$ | 0.88±0.03$^{ab}$ | 6.56±1.12 |
| 6 | 1.24±0.02$^{a}$ | 0.17±0.00$^{a}$ | 1.07±0.02$^{a}$ | 6.67±0.95 |
| 7 | 0.91±0.02$^{bcd}$ | 0.12±0.00$^{ab}$ | 0.79±0.02$^{ab}$ | 7.19±0.22 |
| 8 | 1.06±0.05$^{abc}$ | 0.14±0.01$^{ab}$ | 0.92±0.05$^{ab}$ | 7.24±0.15 |
| 9 | 1.14±0.07$^{ab}$ | 0.16±0.01$^{ab}$ | 0.99±0.06$^{ab}$ | 7.00±0.48 |
| 10 | 0.86±0.00$^{bcd}$ | 0.12±0.00$^{ab}$ | 0.75±0.00$^{ab}$ | 7.53±0.26 |
| 11 | 0.80±0.08$^{d}$ | 0.11±0.01$^{ab}$ | 0.69±0.07$^{ab}$ | 7.11±0.33 |
| 12 | 0.87±0.08$^{cd}$ | 0.12±0.01$^{ab}$ | 0.76±0.07$^{ab}$ | 7.09±0.35 |
| 13 | 0.81±0.10$^{cd}$ | 0.11±0.01$^{ab}$ | 0.70±0.09$^{ab}$ | 7.55±0.29 |
| 14 | 0.89±0.10$^{bcd}$ | 0.12±0.01$^{ab}$ | 0.77±0.09$^{ab}$ | 7.05±0.41 |
| 15 | 0.95±0.03$^{abcd}$ | 0.13±0.01$^{ab}$ | 0.82±0.03$^{ab}$ | 7.36±0.03 |
| 16 | 0.84±0.04$^{abcd}$ | 0.11±0.01$^{ab}$ | 0.73±0.03$^{ab}$ | 7.83±0.69 |
| 17 | 0.86±0.10$^{bcd}$ | 0.12±0.01$^{ab}$ | 0.75±0.09$^{ab}$ | 7.31±0.41 |
| 18 | 0.97±0.08$^{abcd}$ | 0.13±0.01$^{ab}$ | 0.84±0.07$^{ab}$ | 6.95±0.55 |
| 19 | 1.02±0.04$^{abcd}$ | 0.14±0.01$^{ab}$ | 0.89±0.04$^{ab}$ | 7.35±0.01 |
| 20 | 0.96±0.10$^{abcd}$ | 0.13±0.01$^{ab}$ | 0.83±0.09$^{ab}$ | 7.79±0.68 |

[1] WR = weight reduction (g/g); WL = water loss (g/g); SG = solid gain (g/g); DE = diffusion efficiency.
* a-d represented the significant difference in the columns at $p< 0.05$.
** ns = non significantly different.

The mean value showed that the sweet pickled mango treated with 3 kV/cm, 1 Hz, and 500 pulses (Treatment 6) had the highest values of WL, SG, and WR with an average of 1.24, 0.17, and 1.07 g/g, respectively (Table 4). Applying a high number of pulses (1300) resulted in decreased WR, WL, and SG. This might be because cell membrane damage is reversible (cells reseal) when increasing the pulse number.[40] A higher disintegration was obtained when longer pulses were used. The efficiency of the diffusion of this treatment was 6.67, which was not significantly different from other conditions.

### 3.1.2 Change in moisture and water activity ($a_w$)

The PEF processing, regardless of the interaction of pulse strength × frequency × pulse number, did not significantly affect the moisture content in the mango tissue (Table 3). However, moisture content was affected by the interactions of pulse strength × pulse number and frequency × pulse number, which was consistent with the change in mass transfer. The mean comparison for the interaction of pulse strength × frequency × pulse number indicated that the use of PEF significantly decreased the moisture content of sweet pickled mango ($p < 0.05$), as shown in Table 4. The lowest moisture content (71.16%) was obtained when applying 3 kV/cm of pulse strength, 1 Hz of frequency, and 500 pulses. The application of pulse strength, frequency, and pulse number creates pores in the cell membrane, which causes irreversible (cells rupture) or reversible (cells reseal) cell membrane damage and may induce cell opening in combination with subsequent moisture release, resulting in reduced moisture content of mango tissue and texture properties.[26,41] A pulse strength of around 1–10 kV/cm induces an electro-compressive force to break down the membrane and create pores which then work as a conductive channel that increases membrane permeability.[20,42] PEF treatment ruptures the membrane of the cell, which leads to disturbance of the water migration path and more rapid and extensive shrinkage of the material.[43] These phenomena result in decreased moisture content and increased mass transfer of plant tissue.

Unlike moisture content, water activity was significantly affected by pulse strength × frequency × pulse number (p=0.045). The change in water activity was due to osmotic dehydration, a water flow from the raw materials to the outer solution (water loss) and a flow of solute from the solution to the mango's tissues (solid gain). Despite the varied water absorption, PEF-treated mangoes lost soluble solids after water immersion in a comparable fashion[44]. The higher availability of free water after PEF induced cell opening. The Duncan analysis for the interaction between pulse strength × frequency × pulse number showed that the mango treated with three conditions: 2 kV/cm, 1 Hz, 1300 pulses (Treatment 5); 3 kV/cm, 1 Hz, 500 pulses (Treatment 6); and 2 kV/cm, 2 Hz, 1100 pulses (Treatment 14) had the lowest value of $a_w$, with an average of 0.958 (Table 4). The reduction in $a_w$ may be due to the higher sucrose gain during the pickling process.[45]



**Table 5** Mean comparison of moisture content, water activity, color, and texture properties for the interaction of strength × frequency × pulse number in PEF-assisted sweet pickled mango[1].

| Treatment | Moisture content (%) | Water activity | Color | | | | Texture properties | |
|---|---|---|---|---|---|---|---|---|
| | | | L* | a* | b* | ΔE | Hardness (N) | Toughness (mJ/m³) |
| 1 | 74.66±0.11$^{c-g}$ | 0.961±0.003$^{a-f}$ | 57.77±6.74$^{abc}$ | 3.83±0.16$^{a}$ | 29.59±5.12$^{bcd}$ | 9.43±0.437$^{abc}$ | 24.58±22.95$^{fg}$ | 37.93±40.97$^{e}$ |
| 2 | 74.51±0.52$^{c-j}$ | 0.966±0.001$^{a}$ | 57.84±1.42$^{abc}$ | 2.88±0.00$^{bcd}$ | 31.73±1.04$^{a-d}$ | 7.12±0.77$^{bc}$ | 29.07±24.81$^{efg}$ | 38.75±35.93$^{e}$ |
| 3 | 74.24±0.95$^{d-g}$ | 0.959±0.004$^{b-f}$ | 53.45±0.04$^{bc}$ | 3.34±0.29$^{ab}$ | 31.62±2.34$^{a-d}$ | 7.92±0.64$^{abc}$ | 24.89±32.35$^{fg}$ | 39.28±60.72$^{e}$ |
| 4 | 73.44±0.01$^{fg}$ | 0.965±0.000$^{a}$ | 65.56±1.62$^{a}$ | 1.66±0.01$^{gh}$ | 32.77±1.80$^{a-d}$ | 11.32±1.99$^{a}$ | 28.22±40.34$^{efg}$ | 41.44±63.99$^{e}$ |
| 5 | 74.18±0.37$^{d-g}$ | 0.958±0.004$^{ef}$ | 53.87±1.85$^{bc}$ | 3.25±0.108$^{abc}$ | 32.31±0.62$^{a-d}$ | 7.94±0.75$^{abc}$ | 30.50±26.26$^{efg}$ | 40.48±43.20$^{e}$ |
| 6 | 71.16±0.21$^{h}$ | 0.958±0.000$^{def}$ | 58.29±4.23$^{bc}$ | 1.95±0.02$^{efg}$ | 28.43±0.93$^{cd}$ | 6.29±1.301$^{bc}$ | 22.30±20.61$^{g}$ | 34.61±39.64$^{e}$ |
| 7 | 75.65±0.25$^{b-e}$ | 0.963±0.000$^{a-e}$ | 60.74±1.92$^{ab}$ | 1.73±0.04$^{fgh}$ | 33.58±4.30$^{a-d}$ | 8.62±3.44$^{abc}$ | 36.59±42.39$^{d-g}$ | 54.83±75.02$^{e}$ |
| 8 | 73.59±0.53$^{efg}$ | 0.961±0.004$^{a-f}$ | 55.49±0.80$^{bc}$ | 2.93±0.77$^{bcd}$ | 34.96±2.22$^{ab}$ | 8.92±2.04$^{abc}$ | 47.32±38.47$^{c-f}$ | 73.22±70.09$^{c-e}$ |
| 9 | 72.50±0.71$^{gh}$ | 0.961±0.002$^{a-f}$ | 55.25±7.68$^{bc}$ | 1.70±0.60$^{gh}$ | 27.64±1.86$^{d}$ | 7.51±1.69$^{abc}$ | 44.96±34.71$^{c-g}$ | 64.62±64.06$^{de}$ |
| 10 | 76.29±0.01$^{bcd}$ | 0.956±0.003$^{f}$ | 51.29±0.82$^{c}$ | 2.58±0.20$^{cde}$ | 29.90±3.34$^{a-d}$ | 8.14±0.13$^{abc}$ | 44.49±34.27$^{c-g}$ | 64.05±61.73$^{de}$ |
| 11 | 77.09±0.77$^{b}$ | 0.965±0.001$^{ab}$ | 56.83±0.84$^{bc}$ | 1.24±0.32$^{gh}$ | 31.42±2.24$^{a-d}$ | 5.54±0.77$^{bc}$ | 76.02±30.94$^{a}$ | 127.83±69.02$^{ab}$ |
| 12 | 76.12±0.82$^{bcd}$ | 0.959±0.001$^{c-f}$ | 50.39±0.07$^{c}$ | 3.34±0.14$^{ab}$ | 35.93±1.98$^{a}$ | 11.49±1.30$^{a}$ | 67.20±27.79$^{abc}$ | 127.18±71.95$^{ab}$ |
| 13 | 77.03±0.99$^{b}$ | 0.964±0.001$^{abc}$ | 56.23±3.66$^{bc}$ | 3.36±0.27$^{ab}$ | 35.02±0.89$^{ab}$ | 9.55±0.39$^{ab}$ | 59.25±22.96$^{a-d}$ | 119.59±53.48$^{ab}$ |
| 14 | 75.87±0.97$^{bcd}$ | 0.958±0.000$^{def}$ | 55.28±1.46$^{bc}$ | 2.47±0.08$^{de}$ | 34.22±0.67$^{abc}$ | 8.12±0.22$^{abc}$ | 55.39±33.53$^{a-d}$ | 111.40±68.88$^{abc}$ |
| 15 | 75.12±0.32$^{b-f}$ | 0.964±0.001$^{abc}$ | 55.16±1.42$^{bc}$ | 1.03±0.49$^{h}$ | 31.20±3.38$^{a-d}$ | 5.61±1.63$^{bc}$ | 73.07±34.18$^{ab}$ | 138.03±80.46$^{ab}$ |
| 16 | 76.56±0.35$^{bc}$ | 0.965±0.003$^{ab}$ | 55.17±4.70$^{bc}$ | 1.21±0.01$^{h}$ | 28.06±0.36$^{cd}$ | 5.66±0.94$^{bc}$ | 67.79±30.53$^{abc}$ | 129.28±62.20$^{ab}$ |
| 17 | 76.23±1.01$^{bcd}$ | 0.966±0.003$^{a}$ | 57.86±1.79$^{abc}$ | 1.00±0.07$^{h}$ | 31.07±0.23$^{a-d}$ | 5.28±0.49$^{c}$ | 73.87±31.87$^{ab}$ | 151.00±82.46$^{a}$ |
| 18 | 74.81±0.81$^{cde}$ | 0.962±0.003$^{a-e}$ | 53.36±3.89$^{bc}$ | 2.40±0.07$^{def}$ | 33.62±0.13$^{a-d}$ | 8.47±1.37$^{abc}$ | 59.97±38.77$^{abc}$ | 108.01±69.35$^{abc}$ |
| 19 | 74.07±0.40$^{d-g}$ | 0.962±0.004$^{b-f}$ | 53.82±4.36$^{bc}$ | 2.86±0.68$^{bcd}$ | 34.76±1.30$^{ab}$ | 9.40±2.43$^{abc}$ | 66.87±38.49$^{abc}$ | 132.19±68.73$^{ab}$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 20 | $74.90 \pm 0.98^{b\text{-}f}$ | $0.962 \pm 0.001^{a\text{-}f}$ | $55.66 \pm 4.85^{bc}$ | $2.86 \pm 0.19^{bcd}$ | $32.72 \pm 3.91^{a\text{-}d}$ | $8.41 \pm 2.38^{abc}$ | $50.54 \pm 23.48^{b\text{-}e}$ | $103.38 \pm 52.13^{bcd}$ |

[1] Means ± standard deviation followed by different letters in the same column are significantly different based on Duncan's multiple range test ($p < 0.05$).

### 3.1.3 Change in color

In this study, a* and ΔE of the pickled mango was strongly affected by the interaction between pulse strength × frequency × pulse number, with a $p$-value of 0.000 and 0.003 respectively, while L* and b* values were not affected by the interaction between pulse strength × frequency × pulse number. According to Table 5, the application of PEF coupled with the pickling process of the mango at 2 kV/cm, 1 Hz, and 1100 pulses (Treatment 4) had the highest affect (65.56), whereas the highest a* value (3.83) was found at 2 kV/cm, 1 Hz, 500 pulse (Treatment 6). The increase or decrease in L* value was associated with the transparency gains due to air loss or air being present in the pore by diffusion solution.[45] A lower PEF strength (2 kV/cm) caused a greater increase in a* values, while a higher strength (3 kV/cm) resulted in a decrease in a* values, which aligns with the results reported for PEF-treated carrot.[43] Meanwhile, the highest values of b* (35.93) and ΔE (11.49) were seen at 2 kV/cm, 2 Hz, and 700 pulses (Treatment 12). The b* value indicates the yellow color of the products. The increase in b* value might be due to the application of a higher pulse strength.[43]



### 3.1.4 Change in texture properties

As shown in Table 3, there was a non-significant ($p>0.05$) effect of the interaction between pulse strength, frequency, and number on hardness and toughness of PEF-pickled mango. The mean results from Table 5 show that the interaction between pulse strength × frequency × pulse number at 2 kV/cm, 1 Hz, and 900 pulses (Treatment 3) could decrease the hardness and toughness of sweet pickled mango from 38.03 N and 98.67 mJ/m$^3$ for conventionally pickled mango to 21.32 N and 25.77 mJ/m$^3$ respectively. The hardness and toughness of the mango pickled by PEF were reduced by 1.78-2.40 and

3.83-7.34 times from conventionally pickled and fresh mango respectively. The change in texture properties after PEF treatment was due to perforation of the cell membranes, caused by the interaction between PEF parameters.[18] The increase in pore formation leads to an increase in the softening of the mango tissue due to the rupture of the internal structure.[13] Thus, the sugar molecules can diffuse to the mango surface through capillary forces.[44]

### 3.1.5 Pearson's correlation of PEF parameters coupled with sweet pickling mango

The results of Pearson's correlation analysis of investigated variables are presented in Table 6. A significant positive correlation has been found between WL and SG or WR, while a negative correlation exists between WL, SG, WR to DE and texture properties. This negative correlation indicates that there is a higher level of WL, SG, and WR; a lower hardness and toughness were obtained. The WL, SG, and WR were also strongly negatively correlated with moisture content. The increase in cell permeability results in increased WL, SG, and WR values, but decreased water molecules (moisture content) in mango tissue. Meanwhile, a positive correlation between DE and moisture content was observed. The color values, a* and b*, presented a positive correlation with ΔE.

**Table 6** Pearson's correlation analysis.

| | WL | SG | WR | DE | MC | $a_w$ | *L** | *a** | *b** | Δ*E* | H | T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WL | 1.000 | $0.894^{**}$ | $0.999^{**}$ | $-0.529^{*}$ | $-1.000^{**}$ | -0.280 | 0.243 | 0.081 | -0.278 | 0.090 | $-0.626^{**}$ | $-0.616^{**}$ |
| SG | | 1.000 | $0.896^{**}$ | $-0.632^{**}$ | $-0.896^{**}$ | -0.110 | 0.261 | 0.101 | -0.273 | 0.026 | $-0.640^{**}$ | $-0.643^{**}$ |
| WR | | | 1.000 | $-0.531^{*}$ | $-1.000^{**}$ | -0.281 | 0.238 | 0.086 | -0.274 | 0.103 | $-0.626^{**}$ | $-0.616^{**}$ |
| DE | | | | 1.000 | $0.529^{*}$ | 0.150 | -0.280 | -0.121 | -0.020 | -0.153 | $0.597^{**}$ | $0.615^{**}$ |
| MC | | | | | 1.000 | 0.278 | -0.242 | -0.081 | 0.277 | -0.091 | $0.622^{**}$ | $0.611^{**}$ |
| $a_w$ | | | | | | 1.000 | $0.535^{*}$ | $-0.485^{*}$ | 0.000 | -0.257 | 0.363 | 0.362 |
| *L** | | | | | | | 1.000 | -0.367 | -0.117 | 0.039 | -0.355 | -0.327 |
| *a** | | | | | | | | 1.000 | 0.411 | $0.627^{**}$ | -0.426 | -0.366 |
| *b** | | | | | | | | | 1.000 | $0.607^{**}$ | 0.238 | 0.279 |
| Δ*E* | | | | | | | | | | 1.000 | -0.274 | -0.237 |
| H | | | | | | | | | | | 1.000 | $0.977^{**}$ |
| T | | | | | | | | | | | | 1.000 |

$^{**}$ represented $p$<0.01 and $^{*}$ represented $p$<0.05.
WR = weight reduction (g/g); WL = water loss (g/g); SG = solid gain (g/g); DE = diffusion efficiency; MC = moisture content (%); H = hardness (N); T = toughness (mJ/$m^3$).

### 3.2 Comparison of mango pickles from conventional pickling processes and PEF-assisted pickling processes

According to the results above, the highest mass transfer (WR, WL, and SG) was presented at 3 kV/cm, 1 Hz, and 500 pulses (Treatment 6). Therefore, this condition was chosen for comparison with non-PEF pickling processes mango (Table 6).

**Table 7**. Comparison of physicochemical properties, texture properties, and mass transfer of raw, conventional pickling processes and PEF-assisted pickling processes in 30 °brix syrup[1].

| Investigated parameters | Type of mango processes | |
|---|---|---|
| | Conventional pickling processes | PEF-assisted pickling processes |
| MC (%) | 80.95±0.49[a] | 71.16±0.22[b] |
| $a_w$ | 0.964±0.002[a] | 0.958±0.000[b] |
| pH | 3.00±0.01[b] | 3.16±0.03[a] |
| $L^*$ [ns2] | 52.27±1.37 | 58.29±4.23 |
| $a^*$ | -0.77±0.07[b] | 1.96±0.03[a] |
| $b^*$ [ns] | 33.66±4.52 | 28.43±0.93 |
| $\Delta E$ [ns, 3] | 7.12±3.93 | 6.30±1.30 |
| Hardness (N) | 37.78±21.37[a] | 23.05±15.07[b] |
| Toughness ($mJ/m^3$) | 75.67±46.78[a] | 34.87±26.79[b] |
| WR (g/g) | 0.45±0.04[b] | 1.07±0.02[a] |
| WL (g/g) | 0.52±0.05[b] | 1.24±0.02[a] |
| SG (g/g) | 0.07±0.01[b] | 0.17±0.00[a] |
| cell disintegration (Z) | 0.05±0.01[b] | 0.64±0.05[a] |
| Beta-carotene (µg/100g) | 43.87±0.21[b] | 52.56±0.15[a] |
| Ascorbic acid (mg/100g) | 61.31±0.35[a] | 32.54±0.11[b] |

[1] Means followed by different letters in the same row are significantly differences ($p < 0.05$) between non-PEF and PEF pickled mango (independent-sample *t*-test).

[2] ns = non significantly different.

[3] The $\Delta E$ was calculated based on the raw mango color.

#### 3.2.1 Physicochemical properties

PEF caused both desirable and undesirable changes in the quality properties of mango due to the mechanism of the process.[36] The results demonstrated that PEF could decrease the moisture content, $a_w$, hardness, and toughness ($p < 0.05$), while the color parameters showed no difference in L* and b* values ($p > 0.05$), resulting in a non-significant difference in the color change (ΔE) of conventional pickling processes (7.12 ± 3.93) and PEF-assisted pickling processes (6.30 ± 1.30), as presented in Table 7. The decreased moisture content and $a_w$ were due to the prevention of moisture uptake during the PEF process, in which sugar molecules form a film layer on the mango surface.[44] There were no significant differences between the L* and b* values; meanwhile, a higher a* value (1.96 ± 0.03) was obtained in PEF-treated pickled mango. The PEF caused the interaction of different compounds responsible for coloration in foods.[46] The pH value of the mango pulp of PEF-assisted pickling processes increased from 3.01 to 3.16. This might be due to enzyme activity during the pickling process and the attribution of the native acids lixiviation during the application of PEF.[47] The reduction in hardness and toughness coupled with the PEF pickling process was likely due to pore creation and the rupture of the internal structure, resulting in increased softening of the plant tissues.[13]

According to Table 7, the pickled mango treated with PEF had significantly increased WR, WL, and SG values of 1.07 ± 0.02, 1.24 ± 0.02, and 0.17 ± 0.00 g/g ($p < 0.05$), while the WR, WL, and SG values of conventional pickling processes were 0.45 ± 0.04, 0.52 ± 0.05, and 0.07 ± 0.01 g/g respectively. Therefore, the PEF might reduce the fermentation time by at least 3-5 times compared to the conventional pickling process, which required 5–15 days for fermentation.[9] Applying pulse strength, pulse frequency, and pulse number not only enhances the degree of membrane rupture but also increases the density of pores in the membrane and cell wall.[48] A high degree of cell disintegration (Z) was found in PEF-pickled mango, at 0.64± 0.05, while the z value of non-PEF pickled mango was 0.05± 0.01.

### 3.2.2 Mango surface structure

Changes in the structure the mango surface after the PEF pickling processes were examined using SEM (Figure 2). Fresh mango (Figure 2a) had larger pores than sweet pickled mango in both untreated (Figure 2b) and PEF-treated forms (Figure 2b). The net-like pattern of mango tissue had collapsed after PEF treatment, as presented in Figure 2c. The cell disintegration (*Z*) was found in the mango after the PEF pickling process at 30 °brix ($Z = 0.64$), which caused changes in the microstructure of the mango in both surface sides. Meanwhile, the Z value of non-PEF pickled mango was 0.05±0.01.

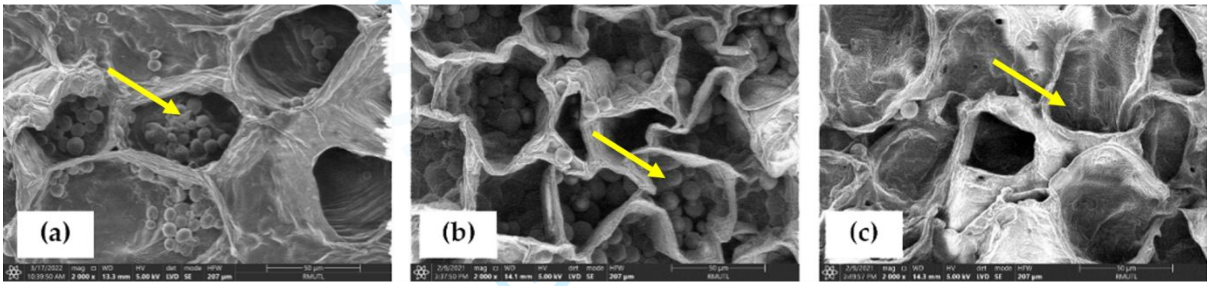



**Fig. 2.** SEM photomicrographs of surface of mango tissue: (a) fresh mango, (b) Conventional pickled mango, and (c) PEF-assisted pickling process at 2,000×. Yellow arrows indicate a change in the of structure surface the mango.

**3.2.3 Beta-carotene and ascorbic acid content**

The PEF processing significantly affected the content of beta-carotene and ascorbic acid in PEF pickled mango (Table 6). The content of beta-carotene was 52.56 µg/100g, which increased by 20% when compared with conventional mango pickles. Also, the concentration of ascorbic acid (32.54 mg/100g) was decreased by 47% from conventional mango pickles. The increase of beta-carotene was due to the acceleration of carotenoids during the PEF process.[49] Bot et al.[49] suggested that PEF can induce modification of not only cell membranes but also carotenoids-protein conformation. PEF might convert geranyl-geranyl diphosphate into phytoene by phytoene synthase and convert phytoene into phytofluene, beta-carotene, and lycopene by phytoene desaturase.[50] Meanwhile, the loss of ascorbic acid during PEF of sweet pickled mango was due to faster leaching into the osmotic solution.[14] In addition, PEF also attacked the hydroxyl group of the second carbon atom of ascorbic acid to complete the conversion of the configuration.[51]

From the results, it was found that PEF could improve the mass transfer of the osmotic agent into mango tissue. Therefore, the quality and functionality of sweet pickled mango passed through the PEF process can be improved. The function of PEF on mango tissue is evaluated and presented in Figure 3. The electroporation of PEF strengthened the electric field (cat-ions and an-ions) on the surface of the mango and caused changes to the tissue structure. The destruction of the tissue led to the formation of pores around the cell membranes.

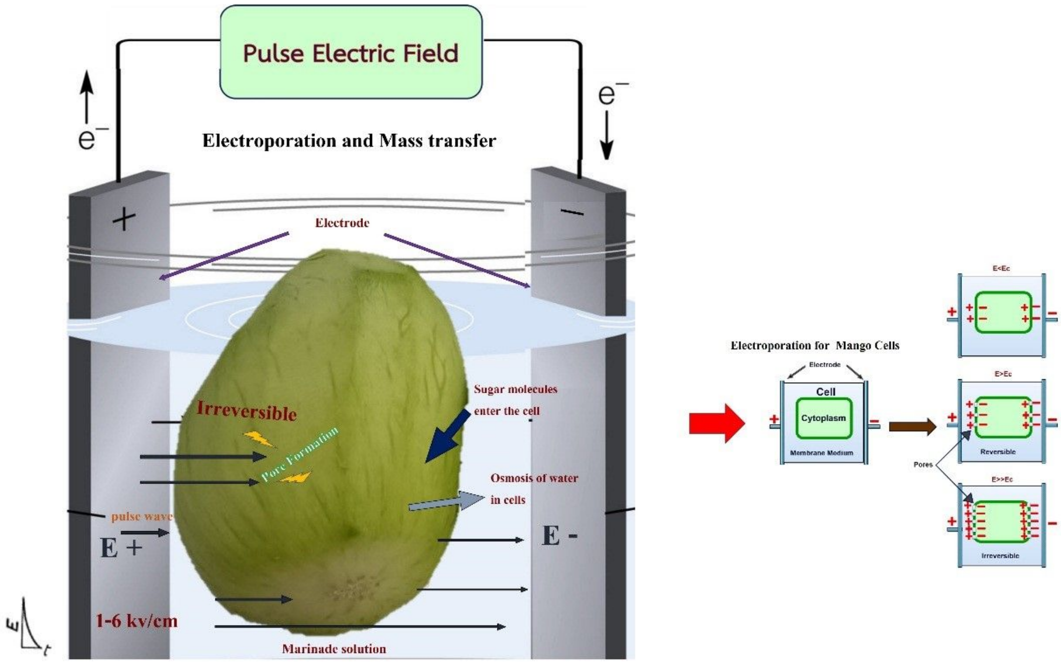



**Fig. 3.** The mechanism of the PEF-assisted pickling process on the mango tissue.

# 4. Conclusions

The application of pulse strength, pulse frequency, and pulse number of pulsed electric field was conducted to investigate the effect of PEF on the pickling process of sweet pickled mango. Using pulse strength, frequency, and pulse number of 3 kV/cm, 1 Hz, and 500 pulses respectively increased the release of moisture, WR, WL, and SG. PEF is effective in increasing mass transfer by reducing moisture and water activity, thus reducing the time for the process of pickling mango by 3-5 times. The application of the PEF pulse strength, pulse frequency, and pulse number also significantly affected the color and texture properties of sweet pickled mango. The reduction in hardness and toughness of PEF-pickled mango confirmed their improved permeability properties. PEF-pickled mango loses less ascorbic acid but has increased beta-carotene content. SEM images suggested that PEF effectively reduced the pore shape of mango tissue. Thus, in the food pickling process, the combination of PEF with traditional food pickling processes can be a real alternative to the traditional pickling process alone.



# Acknowledgements

This research was funded by the National Research Council of Thailand (NRCT) under the Royal Golden Jubilee Ph.D. Program (RGJ), contract no. PHD/0092/2561. This study was supported by the National Research Council of Thailand (Grant Number N42A650197), Thailand Science Research and Innovation Fundamental Fund (TUFF45/2566).

# Supporting information

-

## Conflict of interest

There are no conflicts to declare.

## Reference

1 V. R. Lebaka, Y.-J. Wee, W. Ye, M. Korivi. Nutritional composition and bioactive compounds in three different parts of mango fruit. *Int. J. Environ. Res. Public Health,* (2021), **18**, 741. doi:10.3390/ijerph18020741.

2 W. O. Owino, J. L. Ambuko. Mango fruit processing: Options for small-scale processors in developing countries. *Agriculture,* (2021), **11**, 1105. doi:10.3390/agriculture11111105.

3 M. E. Maldonado-Celis, E. M. Yahia, R. Bedoya, P. Landázuri, N. Loango, J. Aguillón, B. Restrepo, J. C. Guerrero Ospina. Chemical composition of mango (Mangifera indica L.) fruit: Nutritional and phytochemical compounds. *Front. Plant Sci.,* (2019), **10**, 1073. doi:10.3389/fpls.2019.01073.

4 S. Maloba, J. Ambuko, M. Hutchinson, W. Owino. Off-season flower induction in mango fruits using ethephon and potassium nitrate. *J. Agric. Sci.,* (2017), **9**, 158-167.

5 M. Wongkaew, J. Sangta, S. Chansakaow, K. Jantanasakulwong, P. Rachtanapun, S. R. Sommano. Volatile profiles from over-ripe purée of Thai mango varieties and their physiochemical properties during heat processing. *Plos One,* (2021), **16**, e0248657. doi:10.1371/journal.pone.0248657.

6 K. Ashwani, S. Amarjeet, S. Monika. Standardization of recipe and method for mango chutney. *Haryana J. Hort. Sci.,* (2010), **39**, 247-249.

7 O. Acosta, X. Gao, E. K. Sullivan, O. I. Padilla-Zakour. Pickled egg production: Effect of brine acetic acid concentration and packing conditions on acidification rate. *J. Food*

*Prot.,* (2014), **77**, 788-795. doi:10.4315/0362-028X.JFP-13-362.

8 N. Indrati, P. Sumpavapol, R. S. Samakradhamrongthai, N. Phonsatta, P. Poungsombat, S. Khoomrung, A. Panya. Volatile and non - volatile compound profiles of commercial sweet pickled mango and its correlation with consumer preference. *Int. J. Food Sci. Tech.,* (2022), **57**, 3760-3770. doi:10.1111/ijfs.15703.

9 N. Uthairungsri, K. Kijroongrojana, P. Sumpavapol. Development of sorbet from sweet pickled mango syrup. *Veridian E-J Sci. Tech. Silpakorn Uni.,* (2019), **6**, : 85-Field: Food Technology.

10 Y. Zhang, M. Zielinska, S. K. Vidyarthi, J.-H. Zhao, Y.-P. Pei, G. Li, Z.-A. Zheng, M. Wu, Z.-J. Gao, H.-W. Xiao. Pulsed pressure pickling enhances acetic acid transfer, thiosulfinates degradation, color and ultrastructure changes of "Laba" garlic. *Innov. Food Sci. Emerg. Technol.,* (2020), **65**, 102438. doi:10.1016/j.ifset.2020.102438.

11 Y. Zhang, M. Zielinska, G.-F. Li, L.-Z. Deng, B.-H. Sun, Z.-A. Zheng, Z.-J. Gao, H.-W. Xiao. Pulsed vacuum pickling (PVP) of garlic cloves: Mass transfer kinetics and quality attributes. *Dry. Technol.,* (2020), **38**, 712-723. doi:10.1080/07373937.2019.1700380.

12 F. Vallespir, J. A. Cárcel, F. Marra, V. S. Eim, S. Simal. Improvement of mass transfer by freezing pre-treatment and ultrasound application on the convective drying of beetroot (Beta vulgaris L.). *Food Bioprocess Technol.,* (2018), **11**, 72-83. doi:10.1007/s11947-017-1999-8.

13 J. Li, J. Shi, T. Wang, X. Huang, X. Zou, Z. Li, D. Zhang, W. Zhang, Y. Xu. Effects of pulsed electric field pretreatment on mass transfer kinetics of pickled lotus root (*Nelumbo nucifera* Gaertn.). *LWT-Food Sci. Tech.,* (2021), **151**, 112205. doi:10.1016/j.lwt.2021.112205.

14 E. Dermesonlouoglou, I. Zachariou, V. Andreou, P. Taoukis. Effect of pulsed electric fields on mass transfer and quality of osmotically dehydrated kiwifruit. *Food Bioprod. Process.,* (2016), **100**, 535-544. doi:10.1016/j.fbp.2016.08.009.

15 E. Amami, E. Vorobiev, N. Kechaou. Modelling of mass transfer during osmotic dehydration of apple tissue pre-treated by pulsed electric field. *LWT-Food Sci. Tech.,* (2006), **39**, 1014-1021. doi:10.1016/j.lwt.2006.02.017.

16 A. Nazari, M. A. Salehi, B. Abbasi Souraki. Experimental investigation of effective factors of pulsed electric field in osmotic dehydration of apple. *Heat Mass Transf.,* (2019), **55**, 2049-2059. doi:10.1007/s00231-019-02571-8.

17 K. A. Taiwo, A. Angersbach, D. Knorr. Effects of pulsed electric field on quality factors and mass transfer during osmotic dehydration of apples. *J. Food Process Eng.,* (2003), **26**, 31-48. doi:10.1111/j.1745-4530.2003.tb00588.x.

18 M. Bazhal, M. Ngadi, G. Raghavan, D. Nguyen. Textural changes in apple tissue during pulsed electric field treatment. *J. Food Sci.,* (2003), **68**, 249-253. doi:10.1111/j.1365-2621.2003.tb14147.x.

19 E. Dermesonlouoglou, A. Chalkia, G. Dimopoulos, P. Taoukis. Combined effect of pulsed electric field and osmotic dehydration pre-treatments on mass transfer and quality of air dried goji berry. *Innov. Food Sci. Emerg. Technol.,* (2018), **49**, 106-115. doi:10.1016/j.ifset.2018.08.003.

20 F. J. Barba, O. Parniakov, S. A. Pereira, A. Wiktor, N. Grimi, N. Boussetta, J. A. Saraiva, J. Raso, O. Martin-Belloso, D. Witrowa-Rajchert. Current applications and new opportunities for the use of pulsed electric fields in food science and industry. *Food Res. Int.,* (2015), **77**, 773-798. doi:10.1016/j.foodres.2015.09.015.

21 S.-H. Lee, H. M. Shahbaz, S.-H. Jeong, S.-Y. Hong, D.-U. Lee. Effect of pulsed electric field treatment on cell-membrane permeabilization of potato tissue and the quality of French fries. *Ital. J. Food Sci.* , (2022), **34**, 13-24. doi:https://doi.org/10.15586/ijfs.v34i3.2180.

22 T. Fauster, D. Schlossnikl, F. Rath, R. Ostermeier, F. Teufel, S. Toepfl, H. Jaeger. Impact of pulsed electric field (PEF) pretreatment on process performance of industrial French fries production. *J. Food Eng.,* (2018), **235**, 16-22. doi:https://doi.org/10.1016/j.jfoodeng.2018.04.023.

23 E. Vorobiev, N. Lebovka. *Electrotechnologies for extraction from food plants and biomaterials*. Vol. 5996 (Springer, 2008).

24 Z. Bhat, J. D. Morton, S. L. Mason, A. E.-D. A. Bekhit. Pulsed electric field operates enzymatically by causing early activation of calpains in beef during ageing. *Meat Sci.,* (2019), **153**, 144-151. doi:https://doi.org/10.1016/j.meatsci.2019.03.018.

25 D. Niu, X.-A. Zeng, E.-F. Ren, F.-Y. Xu, J. Li, M.-S. Wang, R. Wang. Review of the application of pulsed electric fields (PEF) technology for food processing in China. *Food Res. Int.,* (2020), **137**, 109715. doi:https://doi.org/10.1016/j.foodres.2020.109715.

26 U. Tylewicz, S. Tappi, C. Mannozzi, S. Romani, N. Dellarosa, L. Laghi, L. Ragni, P. Rocculi, M. Dalla Rosa. Effect of pulsed electric field (PEF) pre-treatment coupled with osmotic dehydration on physico-chemical characteristics of organic strawberries. *J. Food Eng.,* (2017), **213**, 2-9. doi:10.1016/j.jfoodeng.2017.04.028.

27 W. Tedjo, K. A. Taiwo, M. N. Eshtiaghi, D. Knorr. Comparison of pretreatment methods on water and solid diffusion kinetics of osmotically dehydrated mangos. *J. Food Eng.,* (2002), **53**, 133-142. doi:10.1016/S0260-8774(01)00149-2.

28 V. Santhirasegaram, Z. Razali, C. Somasundram. Effects of thermal treatment and sonication on quality attributes of Chokanan mango (*Mangifera indic*a L.) juice. *Ultrason. Sonochem.,* (2013), **20**, 1276-1282. doi:10.1016/j.ultsonch.2013.02.005.

29 S. Supasin, C. Kantala, P. Intra, P. Rattanadecho. Postharvest preservation of Thai mango var. Chok-Anan by the combination of pulsed electric field and chemical pickling. *Hortic.,* (2022), **8**, 584. doi:https://doi.org/10.3390/horticulturae8070584.

30 S. Toepfl, V. Heinz, D. Knorr. High intensity pulsed electric fields applied for food preservation. *Chem. Eng. Process.: Process Intensif.,* (2007), **46**, 537-546. doi:https://doi.org/10.1016/j.cep.2006.07.011.

31 Y. Koch, J. Witt, A. Lammerskitten, C. Siemer, S. Toepfl. The influence of Pulsed Electric Fields (PEF) on the peeling ability of different fruits and vegetables. *J. Food Eng.,* (2022), **322**, 110938. doi:10.1016/j.jfoodeng.2021.110938.

32 W. Horwitz. Official methods of analysis of the AOAC International. *J. Food Nutr. Dis.,* (2000),

33 N. Utama‐ang, I. Kuatrakul, W. Klangpetch, P. Walter, A. Kawee‐ai. Comparative evaluation of physicochemical, functional and texture properties and sensory acceptance of different instant rice varieties coated with Spirulina and edible polymers. *Int. J. Food Sci. Tech.,* (2022), **57**, 4183-4193. doi:10.1111/ijfs.15738.

34 N. I. Lebovka, N. V. Shynkaryk, E. Vorobiev. Pulsed electric field enhanced drying of potato tissue. *J. Food Eng.,* (2007), **78**, 606-613. doi:10.1016/j.jfoodeng.2005.10.032.

35 S. Roohinejad, D. W. Everett, I. Oey. Effect of pulsed electric field processing on carotenoid extractability of carrot purée. *Int. J. Food Sci. Tech.,* (2014), **49**, 2120-2127. doi:10.1111/ijfs.12510.



36 A. Wiktor, M. Iwaniuk, M. Śledź, M. Nowacka, T. Chudoba, D. Witrowa-Rajchert. Drying kinetics of apple tissue treated by pulsed electric field. *Dry. Technol.,* (2013), **31**, 112-119. doi:10.1080/07373937.2012.724128.

37 S. Asavasanti, W. Ristenpart, P. Stroeve, D. M. Barrett. Permeabilization of plant tissues by monopolar pulsed electric fields: effect of frequency. *J. Food Sci.,* (2011), **76**, E98-E111. doi:10.1111/j.1750-3841.2010.01940.x.

38 A. O. Bilska, K. A. DeBruin, W. Krassowska. Theoretical modeling of the effects of shock duration, frequency, and strength on the degree of electroporation. *Bioelectrochemistry,* (2000), **51**, 133-143. doi:10.1016/S0302-4598(00)00066-0.

39 N. Lebovka, M. Bazhal, E. Vorobiev. Simulation and experimental investigation of food material breakage using pulsed electric field treatment. *J. Food Eng.,* (2000), **44**, 213-223. doi:10.1016/S0260-8774(00)00029-7.

40 G. Saulis. Electroporation of cell membranes: the fundamental effects of pulsed electric fields in food processing. *Food Eng. Rev.,* (2010), **2**, 52-73. doi:10.1007/s12393-010-9023-3.

41 S. Ersus, M. H. Oztop, M. J. McCarthy, D. M. Barrett. Disintegration efficiency of pulsed electric field induced effects on onion (Allium cepa L.) tissues as a function of pulse protocol and determination of cell integrity by 1H‐NMR relaxometry. *J. Food Sci.,* (2010), **75**, E444-E452. doi:10.1111/j.1750-3841.2010.01769.x.

42 O. Chauhan, L. Unni. Pulsed electric field (PEF) processing of foods and its combination with electron beam processing. *Electron beam pasteurization and complementary food processing technologies,* (2015), 157-184. doi:10.1533/9781782421085.2.157.

43 A. Wiktor, M. Nowacka, M. Dadan, K. Rybak, W. Lojkowski, T. Chudoba, D. Witrowa-



Rajchert. The effect of pulsed electric field on drying kinetics, color, and microstructure of carrot. *Dry. Technol.,* (2016), **34**, 1286-1296. doi:10.1080/07373937.2015.1105813.

44 A. Lammerskitten, V. Mykhailyk, A. Wiktor, S. Toepfl, M. Nowacka, M. Bialik, J. Czyżewski, D. Witrowa-Rajchert, O. Parniakov. Impact of pulsed electric fields on physical properties of freeze-dried apple tissue. *Innov. Food Sci. Emerg. Technol.,* (2019), **57**, 102211. doi:10.1016/j.ifset.2019.102211.

45 J. Moreno, G. Bugueño, V. Velasco, G. Petzold, G. Tabilo‐Munizaga. Osmotic dehydration and vacuum impregnation on physicochemical properties of Chilean papaya (*Carica candamarcensis*). *J. Food Sci.,* (2004), **69**, FEP102-FEP106. doi:10.1111/j.1365-2621.2004.tb13361.x.

46 D. Gabrić, F. Barba, S. Roohinejad, S. M. T. Gharibzahedi, M. Radojčin, P. Putnik, D. Bursać Kovačević. Pulsed electric fields as an alternative to thermal processing for preservation of nutritive and physicochemical properties of beverages: A review. *J. Food Process Eng.,* (2018), **41**, e12638. doi:10.1111/jfpe.12638.

47 I. Escriche, A. Chiralt, J. Moreno, J. Serra. Influence of blanching‐osmotic dehydration treatments on volatile fraction of strawberries. *J. Food Sci.,* (2000), **65**, 1107-1111. doi:10.1111/j.1365-2621.2000.tb10247.x.

48 S. Ersus, D. M. Barrett. Determination of membrane integrity in onion tissues treated by pulsed electric fields: use of microscopic images and ion leakage measurements. *Innov. Food Sci. Emerg. Technol.,* (2010), **11**, 598-603. doi:10.1016/j.ifset.2010.08.001.

49 F. Bot, R. Verkerk, H. Mastwijk, M. Anese, V. Fogliano, E. Capuano. The effect of pulsed electric fields on carotenoids bioaccessibility: The role of tomato matrix. *Food Chem.,* (2018), **240**, 415-421. doi:10.1016/j.foodchem.2017.07.102.

50 P. D. Fraser, P. M. Bramley. The biosynthesis and nutritional uses of carotenoids. *Prog. Lipid Res.,* (2004), **43**, 228-265. doi:10.1016/j.plipres.2003.10.002.

51 Z.-H. Zhang, X.-A. Zeng, C. S. Brennan, M. Brennan, Z. Han, X.-Y. Xiong. Effects of pulsed electric fields (PEF) on vitamin C and its antioxidant properties. *Int. J. Mol. Sci.,* (2015), **16**, 24159-24173. doi:10.3390/ijms161024159.

## 20-word Innovative Description

The combination of PEF and pickling process for food pickling processing can be a real alternative to traditional processing.