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Scientific Research

Development of Helix Shape Glass Chamber for Pulsed Electric Fields Treatment Applications in Juice Industry

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ABSTRACT

The juice industry is seeking cost-effective Pulsed Electric Fields (PEF) reactor systems to treat bulk fluid. The paper discusses the development of a helix-shaped glass chamber (HSGC) for PEF treatment in the juice industry. PEF treatment is a non-thermal technology used for the preservation and processing of fruit juices. The HSGC design aims to improve the efficiency and effectiveness of PEF treatment by enhancing the distribution of electric fields within the chamber. The PEF treatment is believed to be biochemical and physical parameters. The traditional designs don't have good attributes for uniformity of PEF treatment and long fluid residence time. The developed HSGC was successfully applied on mango juice samples, and variation of chemical parameters including viscosity and conductivity, including microbial inactivation of microorganisms (Escherichia coli), was explored. The results are compared with the new values of the juice condition. The simulation results indicate that the juice fluid remains at a normal temperature range of 20-25°C. The results were encouraging and discussed, suggesting that HSGC is a viable option for processing sour mango juice with a significant amount of microbial inactivation without adversely affecting the physical and biochemical parameters. In addition, it is effective for long-term preservation of fruit juices and liquids. The residence time in the treatment chamber, the intensity, and uniformity of PEF treatment affect the variation in chemical. The results demonstrate the feasibility and advantages of using the helix-shaped chamber for PEF treatment, offering potential benefits for juice quality and shelf life. Overall, the paper provides valuable insights into the development of innovative technologies for the juice industry.

1- Introduction

Mango juice is one of the most consumed tropical fruit juices worldwide. Various consumers prefer it to other fruit juices—mango fruit juice is a source of vitamins A and C [1]. However, Mango juice has a limited shelf life due to microbial spoilage and enzymatic activities. Thus, thermal treatment is applied to inactivate microorganisms and enzymes during juice production [2]. Mango juice processing involves heat treatment up to 80 °C, which causes darkening of the color, denatured, the action of A and C vitamins, and degradation of anthocyanin [3]. Therefore, alternative technologies to process mango juice without adversely affecting its nutritional components and physical properties are in search.

PEF technology for the inactivation of microorganisms is one of the non-thermal processing methods and can replace traditional thermal pasteurization in certain applications [4-5]. PEF treatment is a cutting-edge technology that has gained significant attention in recent years for its potential applications in various industries, including food processing, biotechnology, and medicine. This non-thermal, non-chemical treatment involves the application of short bursts of high-voltage electrical pulses to cells or tissues, which can disrupt cellular membranes and lead to various beneficial effects, such as improved food preservation, enhanced extraction of bioactive compounds, and increased permeability for drug delivery. With its promising potential for improving product quality, safety, and efficiency, PEF treatment is becoming an increasingly important area of research and development in the field of electrical engineering and biotechnology. The PEF process involves the application of short pulses (microseconds) of high voltage (in the range of 20–80 kV/cm) to a liquid food flowing between two electrodes that confine a treatment zone in the PEF chamber. A high-intensity pulsed electric field can be applied using exponentially decaying, square wave, bipolar, or oscillatory pulses. Processing maybe conducted at ambient or slightly above-ambient temperature to avoid the deleterious effects of heat on flavour, colour and nutrient value of foods [6]. PEF treatment has emerged as a revolutionary technology in the juice industry, offering a non-thermal, non-chemical method for preserving and enhancing the quality of fruit juices. By subjecting the juice to short bursts of high-voltage electrical pulses, PEF treatment can effectively disrupt the cellular membranes of microorganisms, enzymes, and plant tissues, leading to improved preservation of flavor, color, and nutritional content. This innovative approach has the potential to extend the shelf life of juices, improve their sensory attributes, and enhance their safety without the use of heat or additives. As a result, PEF treatment is becoming an increasingly important area of research and development in the field of food processing and biotechnology, offering new opportunities for innovation and improvement in the juice industry. Application of PEF to fruit juices depending on electric field strength and processing time causes microbial reduction with minimal and/or no detrimental changes in the product quality. Orange juice [7], carrot-orange juice [8], cranberry juice [9], tomato juice [10], grape and pineapple juice [11], pineapple [12], and pineapple juice [13] were successfully processed by PEF for preservation and microbial inactivation, evaluation of important quality parameters and shelf life extension. However, there is a lack of literature on the PEF processing of mango juice.

So far, many studies have been conducted on PEF treatment, some of the most recent ones are mentioned here. In [14], the potential of PEF to modify the structure of caseins in micellar casein isolate (MCI) is investigated. MCI was PEF-treated at room (RT, 23°C) and cold (CT, 4°C) temperatures, using an electric field strength of 16 kV cm−1 for 6 or 31 μs. In addition, conditions simulating elderly digestion, such as the peptide profile released after gastric digestion and bioactivity, were studied. In [15], corn porous starch (CPS) was firstly prepared using enzymatic hydrolysis, followed by pore formation enhancement using the treatment of a PEF. Subsequently, the PEF treated porous starch (CPS-PEF) was cross-linked with sodium trimetaphosphate to investigate its structural and functional properties. In [16], the effects of PEF-assisted thawing at 1, 2, and 3 kV/cm on myofibrillar protein of Pekin duck meat is investigated and compared with a control (untreated) sample. The results showed that 2 kV/cm had the highest water-holding capacity at 82.22 ± 2.22%, followed by 3 kV/cm and 1 kV/cm. In [17], a PEF-assisted octenyl succinic anhydride modified waxy maize starch (WMS) was established, which could be used as an excellent Pickering emulsion stabilizer. The PEF treatment improved the esterification efficiency of WMS by disrupting its granule surface and crystalline structure to offer more sites for esterification. In [18], the effect of PEF pretreatment on the interaction between bovine serum albumin (BSA) and curcumin is investigated. Fluorescence quenching results showed that proper PEF pretreatment significantly increased the binding affinity of curcumin and BSA, the binding constant increased by 6.77 times under the conditions of 15 kV/cm for 0.51 ms. In [19], the impacts of PEF and low direct current (DCEF) electric field on the water- (WHC) and oil-holding capacity (OHC), microstructure, texture and physical structure of wheat gluten were investigated using wet gluten dough. The results showed that the PEF and DCEF affected the WHC and OHC significantly. In [20], the new technical feasibility of combining a large-scale screw pressing facility with an industrial-scale PEF system is reported for a great increase in the yields of plant juice and crude protein extracted from freshly harvested blends of perennial ryegrass (Lolium perenne) (70%) and white clover (30%). In [21], the effect of these PEF conditions (E=0.9 and 2.7 kV/cm, with pulse duration 1000 μs) at variable maximum temperatures was evaluated on quality attributes of freshly squeezed orange juice. Results were compared to orange juice that received no treatment or a mild or severe thermal pasteurization treatment. In [22], the effect of PEF treatment on cassava flour at mild intensities (1, 2, and 4 kV/cm) is investigated and combined with elevated levels of specific energy input (250–500 kJ/kg). Influences on starch digestibility, morphological characteristics, birefringence, short-range order and thermal properties were evaluated.

The juice industry is constantly seeking innovative technologies to improve the quality and shelf life of their products. One such revolutionary technology is the HSGC, which has emerged as a game-changing solution for juice processing. This unique chamber design offers a non-thermal, non-chemical method for

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preserving and enhancing the quality of fruit juices. By subjecting the juice to a helical path within the glass chamber, the helix shape design effectively disrupts the cellular membranes of microorganisms, enzymes, and plant tissues, leading to improved preservation of flavor, color, and nutritional content. This innovative approach has the potential to extend the shelf life of juices, improve their sensory attributes, and enhance their safety without the use of heat or additives. As a result, the HSGC is becoming an increasingly important area of research and development in the field of food processing and biotechnology, offering new opportunities for innovation and improvement in the juice industry. The design of the treatment chamber is one of the key factors in developing the pulsed electric field process for non-thermal pasteurization [23]. Chambers should impart uniform treatment to foods with a minimum increase in temperature, and the electrodes should be designed to minimize the effect of electrolysis [24-25]. Other factors that affect microbial inactivation in the PEF treatment are process factors (electric field intensity, treatment time, and temperature), microbial entity factors (type, concentration, and growth stage of microorganism), and media factors (pH, antimicrobials, and ionic compounds, conductivity and medium ionic strength) [26-28].

The study's main objective was the development of HSGC for PEF treatment of mango juices to inactivate microorganisms. The geometry of HSGC assures the exposer of uniform PEF as a function of electric field strength and long residence or treatment time for the fluid. The results are encouraging and discussed considering the parameters, the changes in pH, °Brix, and conductivity of PEF-treated mango juices, including the inactivation of Escherichia coli.

2- Materials and methods

2-1- Preparation of Fresh Mango Juice

Preparing the fresh mango juice feedstock is a very important step before experimenting. In this study, fresh mango was purchased from the local food market, and a fruit juice extractor collected their juices in a controlled, clean environment. A paper filter then filtered the fruit juice to remove all pulp from the fibrous material. The cleaned pulp of the mango was allowed to flow through the helical shape chamber, and the HV pulsed electric field was switched on. If the fruit juice is not properly filtered, it is more frequent to have a dielectric breakdown at the liquid-solid interface than homogenous liquids [29] [30]. Also, the pulps can cause sparks in the juices that cause subsequently decrease the quality of the juices. Therefore, the fruit pulps and solid particles have to be separated by passing the fruit juices through paper filters (MN6151/4) to avoid unexpected difficulties of electric field discharge during the PEF treatment,

Every one of the Mango juices was tested through three different ranges of voltage and three various lengths of the sterilization chamber. The lengths of sterilization chambers were 10, 20, and 50 cm. Figure 1 shows the condition of the storage time.

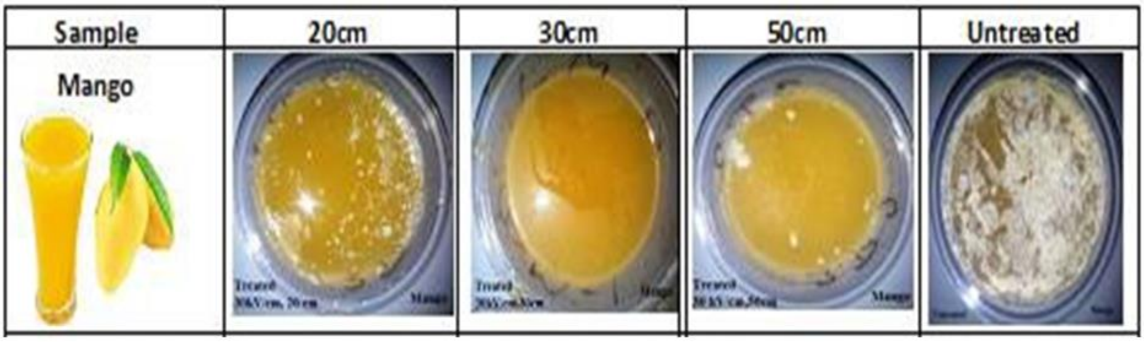

Figure 1: The held condition of tropical fruit juice treated samples after PEF for seven days

The temperature and humidity during the storage time were 25-26°C and 55-65%, respectively. Immediately after seven days, all treatment samples were measured for their chemical and bioscience parameters.

2-2- Setup For High Voltage PEF

A continuous PEF system was designed and constructed at the IVAT, Universiti Teknologi Malaysia. The system is composed of high voltage DC supply, a pulse-forming network system employing the double Blumlein concept to generate exponential decay pulses, a rotating spark gap as a switching medium, a high voltage probe for measuring the applied and output voltage, and the digital oscilloscope to record the generated pulses. Generally, exponential decay pulses are slightly more efficient and cheaper than the other types of pulses for microorganisms' degradation.

2-3- Design of the Helical Glass Chamber

The volume of the liquid in the sterilization chamber in this study was set to 75 mL for 20 cm, 120 mL for 30 cm, and 220 mL for the 50 cm helical sterilization chamber. The flow rate was 240 mL. Thickness was arranged in a helical shape. This helical shape provides the inner or centre of the helical chamber approximately 4 cm in diameter. While the outer side of the helical chamber of 5.4 cm in diameter. The hollow stainless steel cylinder electrode with an outer diameter of 4 cm is placed at the centre of the helical chamber. It is used as a medium for high-voltage pulses to generate a pulsed electric field in the treatment region. The thickness of the glass is 500 micrometres. In this simulation study, the helix treatment chamber was first designed by SOLIDWORKS software before being simulated using COMSOL software. Cross-sectional views of the new type of helix treatment chamber, which is drawn by SOLIDWORKS software, are shown in Figure 2 below.

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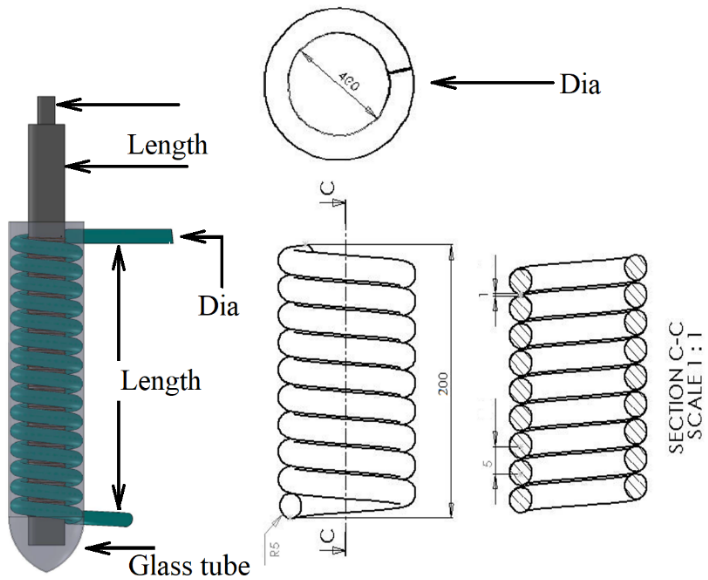

Figure 2: The 3D simulation of the helix sterilization chamber by SOLIDWORKS

The inner gap of the glass tube is 5mm, which allows the fruit juice to flow in the chamber easily. The main goal of the design is to develop a genuine pathway for keeping chemical and bioscience qualities and high nutrition values close to the original feedstock by the newly developed system. The simulation study, carried out using COMSOL software, is used to evaluate the performance of new designs of the helix treatment chamber in generating a uniform pulsed electric field to optimize treatment efficiency. Figure 3 shows the result of the simulation study showing the uniformity of the pulsed electric field within the treatment region that also provides a longer exposure time of treated tropical juices to the PEF.

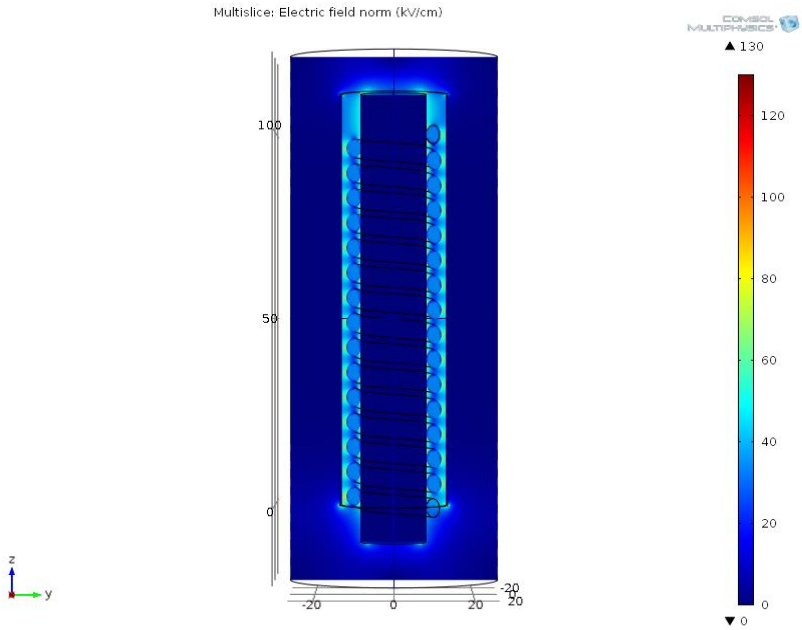

Figure 3: Simulation result of the helix treatment chamber simulated by COMSOL software

2-4- Development of Helix Shape Chamber for PEF Treatment

The design of the treatment chamber is amongst the important parameters which play a significant role in improving the PEF

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as a non-thermal pasteurization method. The PEF treatment is often practiced in two main pathways: bioscience and chemical analysis. In the bioscience route, it controls the process type, yield, and growth phase of microorganisms. While in the chemical route, its control media variables include pH, antimicrobial ionic compounds, conductivity, viscosity, °Brix, and channel ionic strength.

To provide a high, relatively uniform electric field in the treatment zone, the PEF treatment chamber should be designed to minimize the capacity or conditions for an electrical breakdown. Local electric field enhancement causes electrical breakdown, hence minimizing electric field enhancement is another important factor that should be considered in designing the electrode surface. Several instrumental principles minimize the potential for electrical breakdown at the insulator. They are required for successful processing at high electric-field strengths, such as: (i) removing the insulator from the region of a high electric field, (ii) removing the "triple point" (i.e., the interface between the electrode, insulator, and liquid or pumpable food) from the high field region, (iii) increasing the length of the insulator, (iv) reducing the electric field enhancement by appropriate design of the shape of the electrodes.

In this paper, a new treatment chamber has been proposed for the unique design of helix shape as in Figure 4, which is expected to generate a uniform pulsed electric field and is capable of increasing residence time, thus increasing the efficiency of the PEF technique. Table 1 represents the residence time of each sterilization chamber. Before further developing the new treatment chamber, a simulation study on the proposed design has been conducted to verify the effectiveness of the new design in producing a uniform pulsed electric field in the treatment zone.

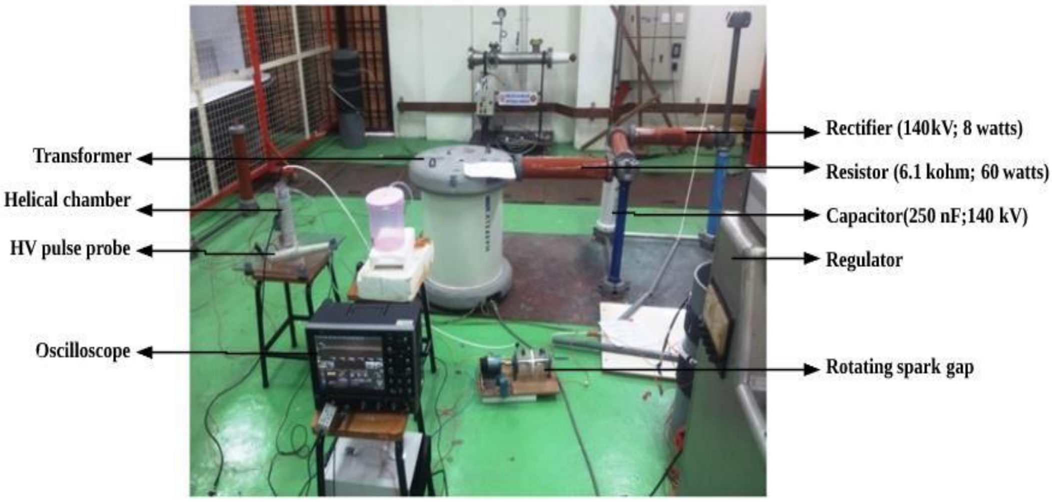

Figure 4: The pulse electric circuit experimental setup

Table 1: Residence times of each sterilization chamber

Sterilization chamber	Volume	Residence time
20 cm	75 mL	18.75s
30 cm	120 mL	30 s
50 cm	220 mL	55s

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2-5- Measurement of chemical and Bioscience properties

A comparison was made between fresh fruit and non-treatment samples under the same situation, applied with several ranges of PEF at 10, 20, and 30 kV/cm to protect sample juices under similar and standard conditions. They were to reach that goal, a popular chemical device assessment called YSI (ProDSS Digital, USA). Numerous applications are often required to achieve a significant reduction in microorganisms. A spectrophotometer (T60, UK) can ensure reliable bacterial culture growth in tropical fruit juice after the PEF test. Ideally, the absorbance of highly scattering UV rays shows the growth of bacteria in samples before and after the tests.

3- Results and discussions

3-1- Effect of the PEF as a function of electric field strength

Before and after PEF processing, the pH of the mango juice samples was measured, and the pH of the control samples was recorded as 5.13 with the application of 10, 20, and 30 kV/cm electric field strengths, the pH of the samples were 5.17, 5.17, and 5.16, respectively. In addition, analysis has been conducted to further determine the effective length of the helix chamber in sterilizing the Mango fruit juice samples. This was done by comparing the difference in pH value with the fresh samples, as seen in Table 2. Again, the result showed that the effective length of the chamber length was 30 cm, with the lowest difference in the pH value of Mango fruit juice.

The °Brix values of tropical fruit juices with helix sterilization chamber with different lengths, as well as with the application of the effective PEF of 30 kV/cm, are shown in Table 2. For mango juice samples, the °Brix values for 20 cm, 30 cm, and 50 cm chamber lengths were 10.16, 10.18, and 10.17, respectively.

Table 2 presents the viscosity results of PEF tests for chambers with lengths of 20 cm, 30 cm, and 50 cm, respectively. These tables show that non-treated samples achieved lower viscosity values than treated ones. On the other hand, increasing the PEF intensity from 10 kV/cm to 30 kV/cm increases the viscosity of all sterilization chambers. The best viscosity value achieved at the highest PEF intensity in this study was 30 kV/cm. It was clear that the applied PEF prevented the growth of microorganisms in the liquid samples and preserved their chemical structure. Table 2 presents the conductivity results of PEF tests in chambers with 20 cm, 30 cm, and 50 cm, respectively. It was observed that the non-treated Mango juice samples resulted in a lower conductivity value for all three samples and three different chamber lengths. Similarly, increasing the pulsed electric field intensity from 10 kV/cm to 30 kV/cm also increased the conductivity value for all three different chamber lengths. The best conductivity result was achieved at higher PEF intensity, at 30 kV/cm.

The untreated samples' viable microorganisms (E. coli) counts were recorded as 18.9 log cfu/mL. Also, this untreated sample keeps for seven days in the same condition as the treated samples. After application of 10, 20, and 30 kV/cm, the amounts of inactivation were 14.1, 13.3, and 11.41 log cfu/mL, respectively. The changing of the Survival (log cfu/mL) with the untreated sample was 4.8, 5.6, and 7.5 log cfu/mL for 10, 20, and 30 kV/cm applied voltages, respectively.

3-2- Effect of PEF on mango juice processing by micro-science Results

PEF processing, as a function of resident time, was applied at 30 s with 30 kV/cm to determine the effect of the resident time on the pH, conductivity, viscosity, and °Brix value of mango juice. Control samples had a pH value of 5.13, and with increased applied PEF, the pH of the mango juice changed to 5.21, 5.24, and 5.21, yielding no significant difference. °Brix of the control samples was 10.31, and after increased PEF, the value increased and close to the control sample was obtained. Control samples had a conductivity of 3.11 **μ**S/cm, measured as 3.18, 3.20, and 3.23 **μ**S/cm after 10 to 30 kV/cm applied PEF, resulting in significant change. Before PEF processing, the viscosity content of the samples was measured as 9.14 cP. With the application of 30 s resident times, the viscosity content of mango juice samples was recorded as 19.44, 20.56, and 24.73 cP for applied PEF, as shown in Table 2. Results revealed that increasing the applied PEF intensity caused a change in the measured properties of mango juice. In addition, increasing the applied PEF intensity made the chemical parameters value less change from the control samples value. It means that the preservation of mango juice by the new design 30cm helix treatment chamber is effective by 30 kV/cm.

Table 2: Variation in chemical parameters of mango juices after seven days of PEF treatment under HSGC

Parameter	Fresh Mango Juices	Non- Treated Juices	Chamber Length (cm)	Strength of Pulsed Electric Field		
				10 kV/cm	20 kV/cm	30 kV/cm
Conductivity (μS/cm)	3.29	3.11	20	3.16	3.19	3.21
			30	3.18	3.20	3.23
			50	3.17	3.19	3.22
pH	5.27	5.13	20	5.19	5.19	5.21
			30	5.20	5.21	5.24
			50	5.18	5.17	5.21
Brix %	10.31	10.11	20	10.12	10.14	10.16
			30	10.15	10.16	10.18
			50	10.13	10.15	10.17
Viscosity (CP)	28.14	9.14	20	18.47	20.11	22.69
			30	19.44	20.56	24.73
			50	19.69	21.42	23.18

The initial untreated number of E. coli in mango juice was counted as 18.9 -log_{10} CFU/ml. After 30 s resident time and 10, 20, and 30 kV/cm applied voltages, the microbial count's reductions were recorded at 4.8, 5.6, and 7.5 -log_{10} CFU/mL, respectively. Figure 5 depicts the PEF's inactivation of mango juice microorganisms as a function of treatment time (n: 30s). Therefore, by increasing the PEF, the reduction of microorganisms in mango juice is increased by a 30 cm helix treatment chamber.

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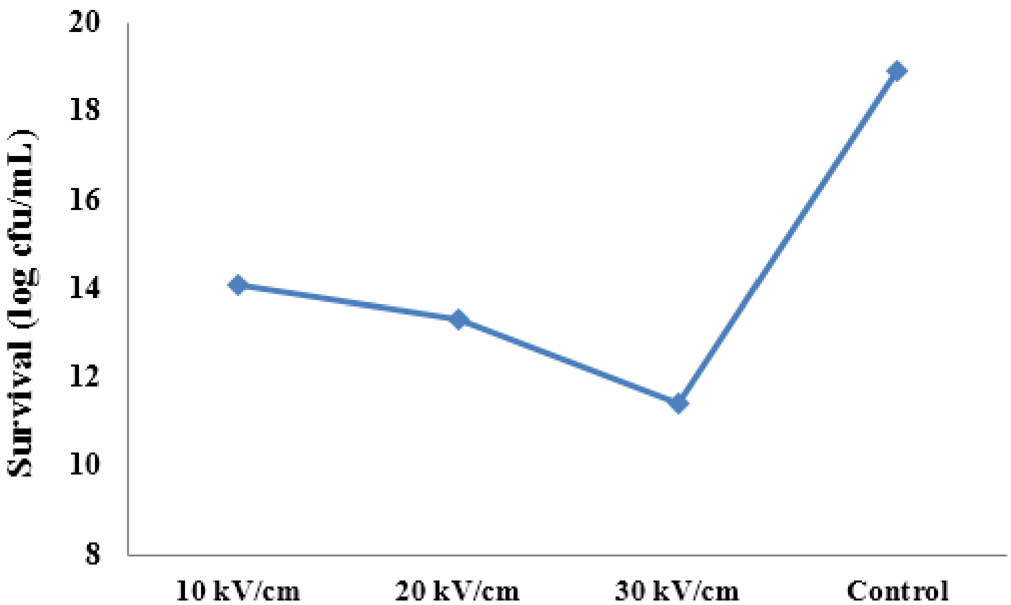

Figure 5: Inactivation of microorganisms of mango juice by PEF as a function of treatment time (n: 30 s). PEF processing parameters by 30 cm helix treatment chamber is 30-kV/cm electric field strength.

Although PEF processing of different food products has been studied extensively, information regarding PEF processing of mango juice is very limited. The results are like the studies conducted previously for measuring chemical properties. PEF treatment of apple juice and cider revealed no significant difference between control and PEF-treated samples for pH, °Brix, conductivity, and color [31], same as this research with the 30 cm helix treatment chamber by the 30 kV/cm for mango juice. Table 3 contains the information regarding microbial growth rate in treated mango juice at different chamber lengths and electric field strengths.

Table 3. Microbial growth rate (log_{10} CFU/ml) in treated juices with different chamber lengths and electric field strengths

Electric field	Microbial Growth Rate in Treated Mango Juice (log_{10} CFU/ml)			
	20 cm	30 cm	50 cm	Non-Treated
10 kV/cm	15.3	14.1	14.9	18.9
20 kV/cm	13.8	13.3	13.1	18.9
30 kV/cm	13.7	11.41	12.5	18.9

It was also revealed that compared to control samples, there was no significant difference between control and PEF-treated samples in pH and °Brix of the PEF-treated orange juice [32]. PEF treatment of citrus juices (grapefruit, lemon, orange, tangerine) was conducted by fifty pulses at 28 kV/cm, and it was presented that pH, °Brix, viscosity, and electric conductivity were affected [33]. As mentioned, Data related to microbial inactivation was also similar to those reported. Inactivation of E. coli with 35 kV/cm into model medium resulted in 7 -log_{10} cfu/mL inactivation [34]. As reported in several studies, microbial growth rate and LR value depend on the process variables such as PEF

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strength and treatment chamber length. For instance, G. A. [31] obtained a maximal inactivation of 5 CFU/mL Log cycles when 30 kV/cm was applied to apple juice using a co-field continuous treatment chamber in the research test. In another study by [35], reported that Log cycles of 2.6 -log_{10} cfu/mL when orange juice was processed by 31 kV/cm by a continuous coaxial treatment chamber [36].

4. Conclusion

Development of HSGC for PEF treatment application in the juice industry represents a significant contribution to the advancement of food processing technology. It opens up new possibilities for enhancing the quality and safety of juice products, ultimately benefiting both producers and consumers. Further research and implementation of this innovative technology are warranted to fully realize its potential in the juice industry. The unique HSGC offers several advantages, including improved fluid dynamics, enhanced electric field distribution, and increased treatment uniformity. These features have the potential to optimize the PEF treatment process, leading to better preservation of nutritional quality, extended shelf life, and improved microbial safety of juice products. This paper has outlined the design and construction process of the innovative HSGC, highlighting its potential to enhance the efficiency and effectiveness of PEF treatment for Mango juice. At last, the experimental implementation shows that the helix treatment chamber improves the applied PEF on mango juice and the helix chamber's electric field uniformity effectively preserves the mango juices. The summary of the results of this paper is as follows:

- The effective length of the chamber length was 30 cm, with the lowest difference in the pH value of Mango fruit juice.
- Non-treated samples achieved lower viscosity values than treated ones.
- Increasing the PEF intensity from 10 kV/cm to 30 kV/cm increases the viscosity of all sterilization chambers.
- The applied PEF prevented the growth of microorganisms in the liquid samples and preserved their chemical structure.
- Increasing the PEF intensity from 10 kV/cm to 30 kV/cm also increased the conductivity value for all chamber lengths.
- The best conductivity result was achieved at higher PEF intensity, at 30 kV/cm.
- Increasing the applied PEF intensity caused a change in the measured properties of mango juice.
- Increasing the applied PEF intensity made the chemical parameters value less change from the control samples value.
- The preservation of mango juice by the new design 30cm helix treatment chamber is effective by 30 kV/cm.

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Data Availability Statement: Data will be available on request, and interested individuals can contact hafrouzi@swinburne.edu.my for further information.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

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توسعه محفظه شیشه ای شکل هلیکس برای کاربردهای تصفیه میدان های الکتریکی پالسی در صنعت آبمیوه سازی

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چکیده

صنعت آبمیوه به دنبال سیستم‌های راکتور میدان‌های الکتریکی پالسی مقرون‌به‌صرفه (PEF) برای تصفیه سیال در مقیاس حجیم است. این مقاله توسعه یک محفظه شیشه‌ای مارپیچ شکل (HSGC) را برای بهبود و بررسی PEF در صنعت آبمیوه مورد بحث قرار می‌دهد. تصفیه PEF یک فناوری غیر حرارتی است که برای نگهداری و فرآوری آب میوه استفاده می شود. هدف طراحی HSGC بهبود کارایی و اثربخشی درمان PEF با افزایش توزیع میدان های الکتریکی در داخل محفظه است. اعتقاد بر این است که درمان PEF سبب بهبود پارامترهای بیوشیمیایی و فیزیکی می‌شود. طرح‌های سنتی ویژگی‌های خوبی برای یکنواختی درمان PEF و زمان ماندگاری طولانی سیال ندارند. HSGC توسعه‌یافته با موفقیت بر روی نمونه‌های آب انبه اعمال شد و تنوع پارامترهای شیمیایی از جمله ویسکوزیته و هدایت، از جمله غیرفعال‌سازی میکروبی میکروارگانیسم‌ها (اشرشیاکُلی) مورد بررسی قرار گرفت. نتایج با مقادیر جدید شرایط آبمیوه مقایسه شده است. نتایج شبیه سازی نشان می دهد که سیال آب میوه در محدوده دمای معمولی ۲۵-۲۰ درجه سانتی گراد باقی می ماند. نتایج دلگرم‌کننده و مورد بحث قرار گرفت و نشان داد که HSGC یک گزینه مناسب برای پردازش آب انبه ترش با مقدار قابل‌توجهی غیرفعال‌سازی میکروبی بدون تأثیر نامطلوب بر پارامترهای فیزیکی و بیوشیمیایی است. علاوه بر این، برای نگهداری طولانی مدت آب میوه و مایعات موثر است. زمان ماندگاری در محفظه تصفیه، شدت و یکنواختی تیمار PEF بر تنوع مواد شیمیایی تأثیر می گذارد. نتایج، امکان و مزایای استفاده از محفظه مارپیچ شکل را برای درمان PEF نشان می‌دهد، که مزایای بالقوه‌ای برای کیفیت آبمیوه و ماندگاری دارد. به طور کلی، این مقاله بینش های ارزشمندی را در مورد توسعه فناوری های نوآورانه برای صنعت آبمیوه ارائه می دهد.

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