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Enhancing Nutritional Quality and Color Stability of Tomato Juice through Low-Intensity Pulsed Electric Field Treatment

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to evaluate the effect of low-intensity pulsed electric field (LIPEF) treatment on the lycopene content, ascorbic acid retention, and color enhancement of juice prepared by using Roma variety tomatoes.

Methodology: The tomato slices were kept in the PEF treatment chamber with varying electric field strength ranging from 2-8 kV/cm and pulse numbers between 10-70 with a monopolar pulse of 1 Hz frequency having a pulse on/off time respectively of 10 µs. After the PEF treatment, the slices were processed to extract the juice for further analysis.

Results: The study revealed significant findings regarding the effect of LIPEF treatment on Roma variety tomatoes. Treatment with 4 kV/cm and 50 pulses resulted in a remarkable 69.11% increase in lycopene content compared to untreated tomato juice. Additionally, there was a remarkable

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retention rate of 99.84% for ascorbic acid in the treated samples compared to the control. Furthermore, LIPEF treatment led to a substantial increase of 40.78% in the a* value, indicating enhanced red coloration of the extracted juice compared to the control. However, higher electric field strength affects the retention of ascorbic acid content.

Conclusion: The findings of this study demonstrate the effectiveness of low-intensity pulsed electric field (LIPEF) treatment in enhancing the lycopene content, retaining ascorbic acid, and improving the red coloration of Roma variety tomatoes. LIPEF treatment has the potential to be utilized in food processing industries to improve the quality and nutritional value of tomato-based products.

Keywords: Tomato; lycopene; LIPEF; electric field; pulse number.

1. INTRODUCTION

Tomato (*Solanum lycopersicum*) is a major vegetable consumed around the world, either fresh or processed in various forms including juices, pastes, purees, sauces, soups, and beverages [1]. They can either used in dried form using dehydration systems or can be used to extract color and lycopene which can be incorporated either for color replacement in products like soft serve ice cream. Lycopene is considered a protective food due to its extensive production and unique nutritional significance. It is known to be a valuable source of nutrients and bioactive substances, including vitamins, carotenoids, and phenolic compounds, that are helpful for human health [2]. Lycopene, the principal coloring substance in tomato, is a potent antioxidant and can quench singlet oxygen is twice that of β-carotene. It has been suggested that consuming lycopene-rich products may protect against cardiovascular diseases and cancer [3]. In several studies, bioactive compounds, including ascorbic acid and lycopene, were found to be degraded during processing, lowering their nutritional value [4-5]. Additionally, the perception and acceptance of consumers may be impacted by the color changes that take place during the manufacturing and storage process of tomato-based products. The researchers have been investigating the application of different emerging technologies in the food industry to enhance the nutritional value and quality of tomato-based products.

The growing demand for highly nutritious and fresh-like products has led the food industry to search for milder preservation technologies that can replace high-temperature processing methods. Non-thermal technologies are an emerging group of processing methods that can help preserve food either without the use of heat or at mild temperatures. Non-thermal food processing/preservation methods like ultrasound, pulsed electric field, high-pressure processing, cold plasma, etc. allow the processing of foods below temperatures used during thermal sterilization. These technologies have the potential to minimize changes in nutritional and organoleptic properties [6]. As a result, non-thermal technologies are becoming increasingly popular in the food industry as a means of producing high-quality, minimally processed foods that meet the demand of consumers for fresh, nutritious and safe products.

There are several extraction methods used to extract lycopene, including supercritical fluid extraction, microwave-assisted extraction, pressurized liquid extraction, and ultrasound-assisted extraction [7-9]. While these methods have their advantages and limitations, pulsed electric field (PEF) has several unique benefits that make it a promising option for enhancing the extraction of lycopene. The food sample is subjected to high or low-intensity electric field pulses throughout this process for a short period in a processing chamber [10]. It has been shown that PEF treatment with different electric conditions, such as the electric field strength and the pulse number, can provide different benefits and can be used for multiple applications [11]. Treating plant tissue with a PEF causes the cell membranes to rupture, resulting in increased permeability of the cell walls. Therefore, bioactive compounds are extracted more effectively [12].

PEF involves subjecting the food sample to a high or low-intensity PEF for a short period, typically microseconds. The application of high intensity pulsed electric field (HIPEF) to tomato-based products can improve their nutritional value, extend their shelf life, and also increase the juice yield, whereas low-intensity pulsed electric field (LIPEF) provides enhanced extraction of bioactive compounds, such as lycopene, from tomato-based products [13].

Odriozola-Serrano [14] reported that PEF treated samples show higher lycopene content than the conventional extraction methods. The lycopene extraction and availability increase with electric field strength and pulse number. A maximum of 68% lycopene was recovered by Gachovska et al. [15]. Andreou [16] applied PEF to chopped tomatoes, they obtained the highest juice yield and lycopene content for PEF-treated samples than the untreated ones at 1 kV/cm with a constant pulse width (15 µs). It can also help to preserve the color of tomato-based products by reducing the degradation of carotenoids during processing. This technology serves as a pre-treatment method in several food processes, including food dehydration, extraction, enzyme inactivation, and reduction of pesticide residues [17-18]. Therefore, this study aimed to evaluate the effects of LIPEF strength and pulse number on the juice of the locally available tomato variety (Anand Roma).

2. MATERIALS AND METHODS

2.1 Raw Material

Fresh and ripe tomatoes of the Anand Roma variety (*Solanum lycopersicum)* were procured from the Vegetable Research Station at Anand Agricultural University, Anand, Gujarat, India. The tomatoes were washed with tap water to eliminate surface dirt from tomatoes, and the surface was wiped to remove water. The washed tomatoes were kept in a crate and stored at a temperature of 7 ± 2 ˚C in a temperature-controlled deep freezer. This study took place at the Department of Food Processing Technology and Department of Food Safety and Quality Assurance, College of Food Processing Technology and Bio-energy, Anand Agricultural University, Anand, Gujarat, India between September 2022 and March 2023. All chemicals used for chemical analysis of were analytical grade and borosilicate glasses were cleaned with neutral detergent, dried and used for analysis.

2.2 Equipment

The EPULSES®- LBM3A-20 pulse generator from Energy Pulse Systems, Portugal which utilizes a voltage of 400 V (three phases) to power a 9000 W has an efficiency of over 90% (Fig 1). The pulse generator is connected to a treatment chamber measuring 10 cm x 10 cm x 10 cm, and fitted with two electrodes. The treatment chamber consisted of two parallel plates of rectangular electrodes with electrode gaps varying from 2.5-10 cm in a batch treatment chamber.

2.3 PEF Treatment

The tomatoes were cut using a cutter (J23A model Fruit cutter, Khera Equipment) to obtain uniform slices of 1 cm thickness. The cut tomato slices were kept in the LIPEF treatment chamber of multipulse mode LIPEF treatment. They were subjected to electric field strength ranges of 2, 4, 6, and 8 kV/cm and pulse numbers 10, 30, 50, and 70 with a monopolar pulse of 1 Hz frequency having a pulse on/off time respectively of 10 µs. The tomato slices and water were placed together in the LIPEF chamber connected to the electrodes. A uniform sample of 300 g with the addition of 300 mL water was kept in a batch for treatment. After the LIPEF treatment, the slices are subjected to a single screw fruit juice extractor and homogenized in a food processor for uniform sampling. Fruit juice was collected in an amber-colored glass bottle to avoid loss of lycopene, and color degradation and juice was analyzed to determine different physico-chemical characteristics.

2.4 Determination of Lycopene Content

The lycopene content of the samples was estimated as per the method described by Ranganna [19]. Briefly, 5-10 g of sample was extracted using acetone several times in a pestle and mortar. Subsequently, the acetone extract was gently mixed with petroleum ether (10-15 mL) in a separating funnel. The addition of deionized water to the acetone layer facilitated the transfer of carotenoid pigment to the petroleum layer. The petroleum layer was then separated and transferred to a 50 mL volumetric flask and volume made up of petroleum ether. A 5 mL aliquot of this solution was diluted with petroleum ether to 50 mL, and its absorbance was analyzed at 503 nm using petroleum ether as a blank in a Systronics UV-Vis spectrophotometer 119 and the results were expressed in mg/100g

Lycopene (mg/100 g) = (3.1206 × OD of sample × Volume made up × Dilution × 100)/(1× Weight of sample × 1000)

2.5 Determination of Color

The visual color of the tomato juice samples was assessed using the Lovibond RT850i CREISS (Cyber Chrome, Inc. Stone Ridge, NY) in terms of L* (lightness), a* (redness), and b* (yellowness and blueness). With the help of a white and black standard, the device was calibrated. The color L*, a*, and b* values were recorded by placing the tomato juice samples in a glass cuvette against the light source [20].

2.6 Determination of Ascorbic Acid

The titration technique, as described by Oliveira et al. [21], was used to determine the amount of ascorbic acid (vitamin C) in the sample. A sample of around 5 g was weighed, made up to 100 mL with 3% metaphosphoric acid, and filtered. To get a bright pink color, a 10 mL aliquot was added to a titration flask and titrated against 2, 6-dichlorophenol indophenol. Results of ascorbic acid content were calculated by using the below equation and the results were expressed as mg/100 g.

Ascorbic acid (mg/100g) = (Titre value × dye factor × volume made up × 100)/(mL of filtrate taken× volume of a sample taken for estimation)

2.7 Statistical Analysis

Experimental values were determined by conducting all experiments and analyses in triplicate and calculating their mean and standard deviation (SD). To assess statistically significant differences (P=0.05) among the means, two-way analysis of variance (ANOVA) and Tukey test (P=0.05) were employed. The statistical analysis was conducted using IBM SPSS Statistics 21 software (SPSS Inc., Chicago, USA).

3. RESULTS AND DISCUSSION

The effects of different electric fields (2, 4, 6, and 8 kV/cm) and pulse numbers (10, 30, 50, and 70) on lycopene, ascorbic acid, and color values were analyzed and the results were presented in Table 1.

3.1 Effects of LIPEF Treatment Condition on Lycopene Content in Tomato Juice

The lycopene content in untreated tomato juice was found to be 6.68 mg/100 mL. However, in LIPEF treated tomato juice, the lycopene content was found in the range of 7.41 to 11.30 mg/100 mL. The maximum and minimum values of 11.30 and 7.41 mg/100 mL respectively, lycopene was found in the treatment at 4 kV/cm for 50 pulse numbers and 8 kV/cm for 10 pulse numbers (Table 1).

The pulse number and electric field both had an impact on the lycopene content of the tomato juice, with the highest lycopene content observed in samples treated with 50 pulses, irrespective of different voltage levels. When subjected to an electric field of 4 kV/cm and 50 pulse number, tomatoes demonstrated a remarkable increase in lycopene content by 69.11% compared to untreated tomato juice. These findings are in line with previous research conducted by Gachovska et al. [15] and Shree et al. [22], where a 68.8% increase in lycopene content was achieved using 16 kV/cm and 50 pulse numbers. The increase in lycopene content observed may be due to the conversion of trans to cis lycopene, resulting from the LIPEF treatment conducted at temperatures lower than 40°C [23].

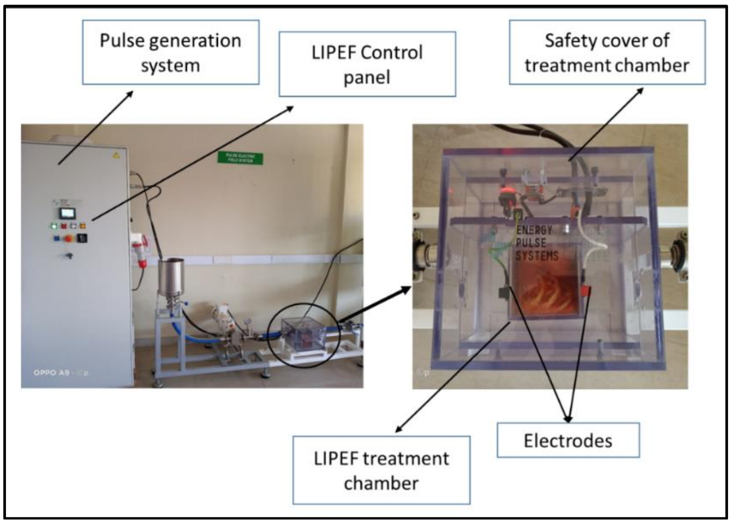

Fig. 1. Low intensity pulsed electric field system

Table 1. Physicochemical properties of tomato juice as affected by low-intensity pulsed electric field

Parameters	Electric field (kV/cm)	Pulse number			
		10	**30**	**50**	**70**
Lycopene (mg/100 g)	2	8.34±0.02^{cB}	9.01±0.05^{bC}	10.43±0.10^{aB}	7.75±0.09^{dC}
	4	9.07±.04^{cA}	10.30±0.06^{bA}	11.30±0.10^{aA}	9.23±0.02^{cA}
	6	7.79±0.08^{cC}	9.58±0.04^{bB}	10.11±0.04^{aBC}	7.95±0.24^{cC}
	8	7.41±0.10^{cD}	8.21±0.62^{bD}	9.94±0.21^{aC}	8.55±0.25^{bB}
Ascorbic acid (mg/100 g)	2	24.10±0.75^{aA}	24.19±0.68^{aA}	24.23±1.78^{aA}	23.82±1.14^{aA}
	4	24.19±0.68^{aA}	24.58±0.68^{aA}	24.96±2.27^{aA}	23.43±2.46^{aA}
	6	23.43±0.64^{aA}	23.82±1.14^{aA}	24.19±2.47^{aA}	23.07±0.64^{aA}
	8	23.40±1.81^{aA}	23.37±0.64^{aA}	23.43±2.46^{aA}	23.03±1.80^{aA}
L*	2	19.69±0.58^{aA}	19.76±0.57^{aA}	19.94±0.54^{aA}	19.58±0.57^{aA}
	4	19.59±0.57^{aA}	19.38±0.52^{aA}	19.80±0.38^{aA}	20.06±0.62^{aA}
	6	21.61±0.64^{aA}	21.35±0.62^{aA}	19.90±0.56^{aA}	21.31±0.63^{aA}
	8	21.16±0.65^{Aa}	20.40±0.60^{aA}	19.96±0.56^{aA}	21.25±0.62^{aA}
a*	2	14.84±0.03^{bB}	16.17±0.56^{bA}	18.03±1.17^{aB}	13.65±0.02^{Cb}
	4	15.50±0.07^{bA}	16.39±0.57^{bA}	19.39±0.19^{aA}	16.61±1.19^{bA}
	6	15.36±0.10^{bA}	15.95±0.48^{bA}	18.19±0.59^{aB}	15.50±0.09^{bA}
	8	14.69±0.41^{bB}	15.41±0.03^{bA}	18.11±0.59^{aB}	13.71±0.09^{cB}
b*	2	8.96±0.24^{aA}	9.08±0.22^{aA}	8.62±0.20^{aA}	8.57±0.21^{aA}
	4	9.02±0.21^{aA}	9.86±0.23^{aA}	8.87±0.21^{aA}	8.80±0.20^{aA}
	6	8.90±0.27^{aA}	9.06±0.21^{aA}	8.90±0.20^{aA}	8.96±0.19^{aA}
	8	8.93±0.20^{aA}	9.57±0.23^{aA}	9.50±0.20^{aA}	8.85±0.19^{aA}

(The values are presented as mean ± SD (n=3). Different lowercase letters in the same column indicate significant statistical differences in the effect of pulse number, while different uppercase letters in the same column indicate significant statistical differences in the electric field factor)

The lycopene content was found to increase with the increase in the electric field from 2 kV/cm to 4 kV/cm and then decreased with a further increase in the electric field with respect to all pulses. The lycopene content increased by increasing the pulse number from 10 to 50, and decreased with further increase in pulse number regardless of the electric field used as shown in Fig. 2. Statistical analysis was carried out to observe the effect of treatment on lycopene and presented in Table 1. It was observed that the lycopene content in tomato juice significantly increased (P=0.05) through the application of LIPEF treatments and an electric field, pulse number and their interaction had a significant effect on the increase in lycopene content.

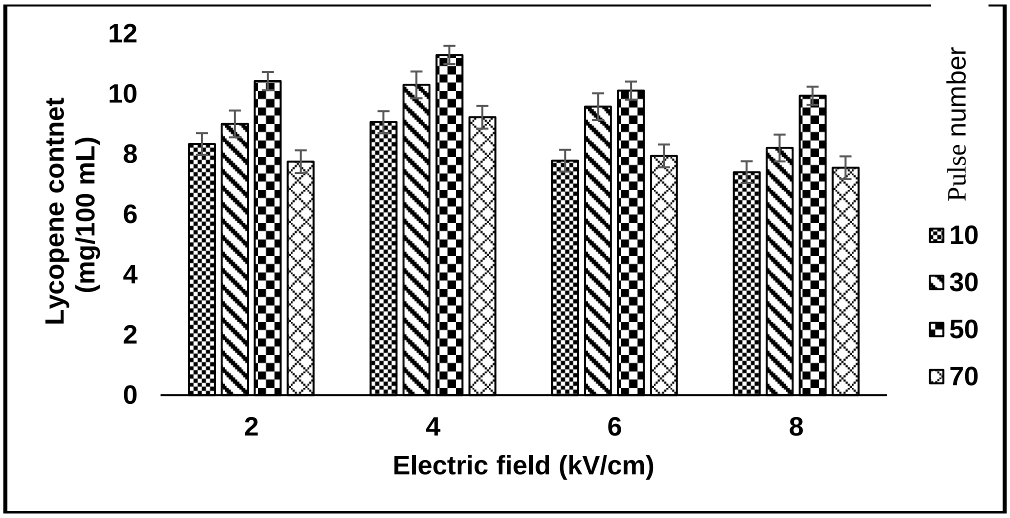

Fig 2. Effect of pulse number and electric field on lycopene content (mg/100 mL)

3.2 Effects of LIPEF Treatment Condition on Color Value Retention in Tomato Juice

The L*, a*, and b* values of untreated or fresh tomato juice samples were found to be 19.53, 13.65, and 8.95, respectively, which were similar to the values reported by Andreou et al. [24]. The L*, a* and b* values in the LIPEF treated tomato juice was found in the range of 19.38 to 21.35, 13.65 to 19.39 and 8.57 to 9.86 respectively (Table 1). The LIPEF treatment at 6 kV/cm for 30 pulse numbers gives the maximum L* value of 21.35, while the minimum L* value of 19.38 was observed at 4 kV/cm for a pulse number of 30. The L* values indicate a non-significant effect (P>0.05), with no significant differences observed among the different treatments. The a* value reached its maximum of 19.39 at 4 kV/cm for a pulse number of 50, whereas the minimum value of 13.65 was obtained at 8 kV/cm for a pulse number of 70. Regarding the b* value, the highest value of 9.86 was observed at 4 kV/cm for a pulse number of 30, while the lowest value of 8.57 was obtained at 2 kV/cm for a pulse number of 70 and it shows significant (P=0.05) effect. The b* values showed that non-significant (P>0.05) effect and the different treatments did not have significant differences. Treatment of tomato juice at 4 kV/cm for 50 pulse numbers led to an increase in carotenoid content, which was associated with a 40.78% rise in a* value. However, higher electric fields (6 and 8 kV/cm) typically caused a reduction in a* values. The a* value increased with an increase in pulse number from 10 to 50 pulse, with a further increase in pulse number (Fig. 3). That might be due to the result of LIPEF treatments, cell vacuoles may be disrupted, releasing enzymes, substrates, and other substances, causing color degradation, such as lipoxygenase activity, which degrades carotenoid content [24].

3.3 Effects of LIPEF Treatment Condition on Ascorbic Acid Retention in Tomato Juice

The ascorbic acid content of fresh or untreated tomato juice was 24.98 mg/ 100 mL, which is within the range of 7.65 to 59.4 mg/100 mL as reported by Sánchez-Moreno et al. [25]. During the LIPEF treatment, the ascorbic acid content varied from 23.03 to 24.96 mg/100 mL. LIPEF treatment affected the retention of ascorbic acid in tomato juice, with the highest retention of 99.95% observed in juice treated at 4 kV/cm for 50 pulse numbers at 1 Hz, while the highest ascorbic acid loss of about 7.65% was observed at 6 and 8 kV/cm for 70 pulse number at 1 Hz (Table 1). There have been studies showing that orange, orange-carrot and strawberry juices retain more than 80% of ascorbic acid in the juice [26-27]. A slight increase in ascorbic acid retention was observed with an increase in pulsed up to 50 pulse numbers, which decreased

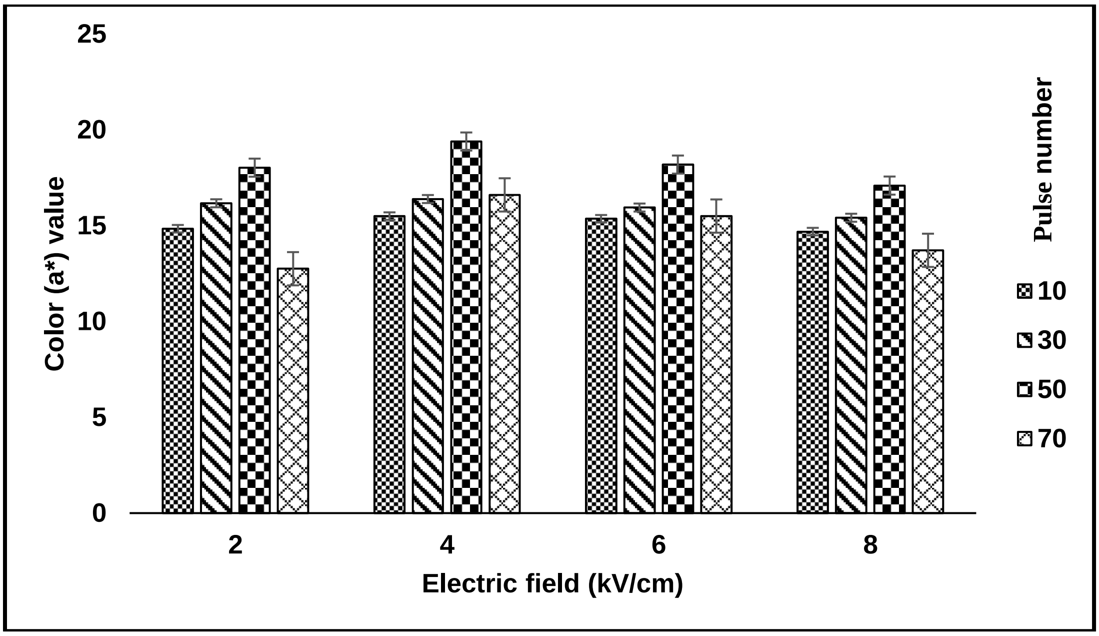

Fig. 3. Effect of pulse number and electric field on color a* value

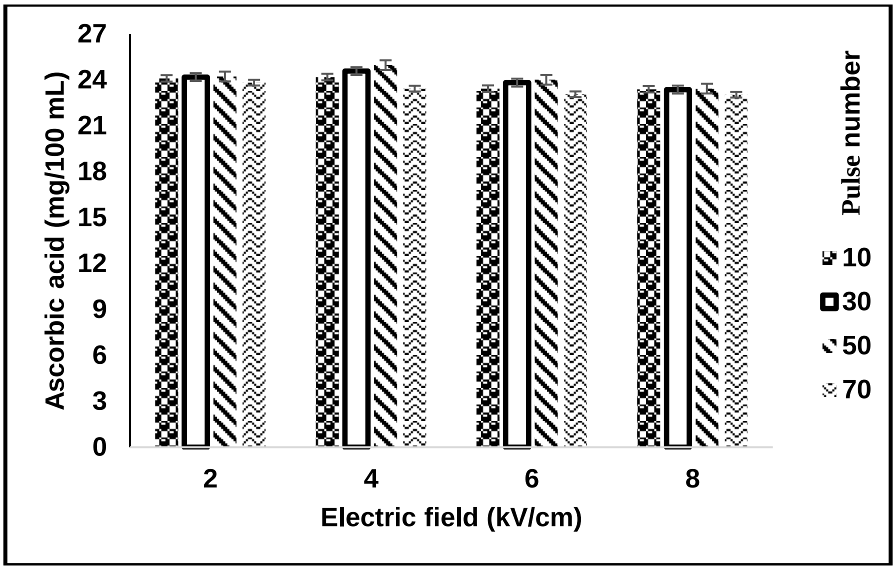

Fig. 4. Effect of pulse number and electric field on ascorbic acid content (mg/100 mL)

with a further increase in electric field above 4 kV/cm and 50 pulse numbers (Fig. 4). The negligible difference in ascorbic acid content between the control and LIPEF-treated tomato juice may be due to the low processing temperature [17]. LIPEF processing can also stabilize ascorbic acid by inactivating ascorbate oxidase, an enzyme that catalyzes ascorbic acid oxidation in fruit juices [28]. It was observed that the electric field, pulse number and their interaction were non-significant effects on ascorbic acid content (Table 1).

4. CONCLUSION

The study presents the effect of LIPEF on the physicochemical properties of tomato juice of the Roma variety. LIPEF significantly affected the lycopene content of juice, irrespective of voltage, maximum lycopene obtained at 50 pulses. A remarkable 69.2 % higher lycopene content was observed at 4 kV/cm and a pulse number of 50 than the control sample. With the increase in pulse number and electric field strength, a trend of increase in the lycopene content was obtained from this experiment. PEF does not affect L* values, the highest a* was observed at 4 kV/cm for a pulse number of 50, which shows a qualitative increase in the redness of juice. Higher Voltage degrades the ascorbic acid content, a maximum ascorbic content was obtained from 4 kV/cm at 50 pulse number among the PEF-treated samples. The higher content of lycopene in comparison to the control demonstrates the potential of PEF as a method to increase the lycopene in the product. However, the effect of bipolar pulses, as well as the shape of the pulse also needs to be investigated in future research work to validate it further. Also, pilot-scale trials of the present research need to be conducted from an economical point of view.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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