

Enhanced inactivation of pectin methylesterase in passion fruit juice by ohmic heating

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Abstract: This study investigated the effectiveness of ohmic heating (OH) for the inactivation of pectin methylesterase (PME) in passion fruit juice. PME is a heat-resistant enzyme responsible for juice cloud loss and quality deterioration during storage and is therefore commonly used as an indicator of pasteurisation efficiency. Juice samples were initially heated from 20 to 70 °C and subsequently held at 70 °C for 10 s while being subjected to different electric field strengths (20–40 V·cm⁻¹) and frequencies ranging from 50 to 10 000 Hz. The highest PME inactivation was observed at 60 Hz, and increasing electric field strength further enhanced the inactivation effect. Based on these results, a frequency of 60 Hz and an electric field strength of 30 V·cm⁻¹ were selected for subsequent experiments. The effects of temperature (60–90 °C) and holding time (0–90 s) on PME inactivation during OH treatment were then evaluated and compared with conventional heating (CH). OH treatment at 90 °C for 70 s resulted in approximately 90% PME inactivation, which was 10.2% higher than that achieved by CH. In addition, OH treatment caused no significant additional degradation of ascorbic acid, total polyphenols, or antioxidant activity, indicating that the applied electric field did not adversely affect these bioactive compounds. These findings demonstrate that ohmic heating is a promising and mild pasteurisation technology for fruit juice processing.

Keywords: enzyme inactivation; electrical processing; juice stability; pasteurisation efficiency; bioactive compounds

Purple passion fruit (*Passiflora edulis*) is widely cultivated in tropical and subtropical regions and is increasingly recognised for its economic and nutritional potential, in line with global agri-food strategies and the United Nations Sustainable Development Goals (SDG2: Zero Hunger; SDG3: Good Health and Well-being; SDG12: Responsible Consumption and Production) (Fonseca et al. 2022). Passion fruit juice is a popular beverage due to its high vita-

min C content, polyphenols, antioxidant capacity, and desirable sensory attributes (Prestes et al. 2023).

Passion fruit juice is considered to be deteriorated in sensory quality when it loses its turbidity, due to the demethylation of pectin by endogenous pectin methylesterase (PME), which produces acid-based pectin. This acid-based pectin can bind with multivalent cations like Ca²⁺ present in the juice, forming insoluble pectate precipitates (Croak and Corredig 2006). Con-

ventional heat treatments (CH) are commonly used to inactivate PME; however, they often lead to the degradation of thermolabile compounds, including vitamin C, aroma compounds, and polyphenols, thereby adversely affecting sensory and nutritional quality (Jiménez-Sánchez et al. 2017b; Prestes et al. 2023).

In response to growing consumer demand for minimally processed and nutrient-rich products, advanced thermal technologies – such as microwave, radio frequency, and ohmic heating (OH) – have been explored for their potential to balance microbial and enzymatic inactivation with the preservation of quality attributes (Jiménez-Sánchez et al. 2017a; Kubo et al. 2020). Among these technologies, OH has attracted considerable interest for liquid foods due to its direct, uniform, and rapid internal heating via the Joule effect (Patel and Singh 2018; Doan et al. 2023). Unlike CH, OH employs an alternating electric field that passes through a conductive food matrix, generating heat internally. Recent studies have suggested that OH may inactivate enzymes such as PME more effectively than CH, particularly when electric field strength and frequency are optimised (Jakób et al. 2010; Funcia et al. 2020; Kaur et al. 2024). In addition, OH may induce electroporation effects that further damage microbial and enzymatic structures.

Despite these advances, gaps remain in understanding the combined effects of electric field strength and frequency on PME inactivation and nutrient retention in passion fruit juice. Most previous studies on OH have focused on orange or apple juice, while limited information is available for passion fruit juice, which differs in matrix composition and rheological properties.

The aim of this study was to evaluate the effectiveness of ohmic heating in PME inactivation and quality retention in passion fruit juice in comparison with conventional heating. The specific objectives were: (i) to investigate the effects of electric field strength and frequency on PME inactivation during OH; (ii) to compare the thermal and non-thermal effects of OH on PME activity; (iii) to assess the impact of OH and CH on ascorbic acid content, total polyphenols, and antioxidant capacity; and (iv) to identify suitable OH conditions that balance PME inactivation with nutritional retention.

MATERIAL AND METHODS

Sample preparation

Fresh purple passion fruits (*Passiflora edulis*) were procured from a local market in Ho Chi Minh City, Vietnam. Fruits were selected based on freshness,

uniform reddish-purple skin, and a smooth surface. Juice was manually extracted and filtered through a 1-mm stainless-steel mesh. The fresh juice exhibited the following characteristics: total soluble solids (TSS) = 14.5 ± 0.50 °Brix, pH = 2.2 ± 0.06 , and electrical conductivity = 8.7 ± 0.16 mS·cm⁻¹.

A 1 : 4 dilution ratio of passion fruit juice was adopted based on previous beverage formulation studies (Zhu et al. 2017), which demonstrated that this ratio preserves the characteristic aroma while maintaining soluble solids and acidity within acceptable ranges. Sensory evaluation indicated that juice diluted at a ratio of 1 : 4 exhibited a balanced sweet–sour taste and was easy to consume. Therefore, in this study, the extracted juice was diluted at a ratio of 1 : 4 with distilled water for subsequent analyses. The diluted juice exhibited the following characteristics: TSS = 2.9 ± 0.18 °Brix, pH = 2.8 ± 0.08 , and electrical conductivity = 1.75 ± 0.03 mS·cm⁻¹. The juice samples were aliquoted and stored at -20 °C until use.

Chemicals

Analytical-grade sodium chloride (NaCl), sodium hydroxide (NaOH), and citrus-derived pectin were obtained from HiMedia Laboratories (India).

Heating apparatus

Ohmic heating (OH). The ohmic heating system consisted of a Teflon chamber ($2.5 \times 14.5 \times 7.5$ cm), selected for its thermal insulation and chemical inertness (Figure 1). Two titanium electrodes ($0.1 \times 14.3 \times 7.5$ cm) were installed at opposite ends of the chamber with a spacing of 2 cm. A type-K thermocouple was positioned at the centre of the chamber to monitor temperature. The system allowed precise control of electric field strength (20 – 40 V·cm⁻¹) and frequency (50 – $10\,000$ Hz). Fifty millilitres of juice were heated from 20 °C to the target temperatures under various electrical conditions.



Figure 1. Photograph of the experimental ohmic heating (OH) system

Conventional heating (CH). For comparison, conventional heating was conducted in glass test tubes (15 cm height × 1.7 cm diameter) containing 4 mL of juice. Samples were heated in a thermostatically controlled water bath at 95 °C to match the heating rate applied during ohmic heating. Each treatment was performed in triplicate, with each replicate placed in an individual glass test tube.

Heating treatments

Effect of frequency and electric field strength on PME activity in passion fruit juice during ohmic heating. Fifty millilitres of passion fruit juice were placed in the sample chamber and heated under different combinations of electric field strengths (20, 30, and 40 V·cm⁻¹) and frequencies (50, 60, 500, 1 000, and 10 000 Hz). For each electrical condition, the juice was heated from 20 to 70 °C and held at this temperature for 10 s. After treatment, 4 mL of juice were transferred to sterile tubes, rapidly cooled in ice water (0 °C), and analysed for PME activity. The effects of frequency and electric field strength on PME inactivation were subsequently evaluated, and suitable levels of both parameters were identified.

Previous studies have demonstrated that a frequency of 60 Hz effectively minimises the degradation of key juice constituents (Doan et al. 2021b). Therefore, a fixed frequency of 60 Hz was applied when assessing the effects of electric field strength (20, 30, and 40 V·cm⁻¹) on ascorbic acid content, total polyphenols, and antioxidant activity.

Effect of temperature on PME activity (OH vs. CH). Based on previous studies, a frequency of 60 Hz was selected due to its effectiveness in PME inactivation while minimising the degradation of bioactive compounds. The results from the previous experiment indicated that PME inactivation increased with electric field strength (40 > 30 > 20 V·cm⁻¹), whereas other studies have suggested that 30 V·cm⁻¹ provides optimal preservation of bioactive compounds (Doan et al. 2021b). Consequently, an electric field strength of 30 V·cm⁻¹ combined with a frequency of 60 Hz was selected to investigate the effect of temperature.

Juice samples were heated using ohmic heating from 20 to 60, 70, 80, and 90 °C, with holding times ranging from 0 to 90 s. After each treatment, 4 mL of juice were cooled and analysed for PME activity.

In parallel, conventional heating treatments were conducted under equivalent time–temperature profiles to assess potential non-thermal effects. The juice volume was adjusted to 4 mL to ensure that heating

rates and holding times during conventional heating matched those applied during ohmic heating. Any differences in PME inactivation efficiency were attributed to non-thermal effects associated with the electric field.

Effect of ohmic and conventional heating on juice quality attributes. To evaluate the impact of electrical treatment on juice quality, the following parameters were analysed in OH and CH treatments: ascorbic acid content, total polyphenol content (TPC), and antioxidant activity. Ohmic heating involves both thermal and electrical effects, whereas conventional heating provides thermal input only. Comparisons between OH and CH allowed the assessment of potential degradation or enhancement of bioactive compounds attributable to the additional electrical (non-thermal) effects associated with OH processing.

The experimental scheme is illustrated in Figure S1 (Electronic Supplementary Material – ESM).

Analytical methods

Determination of PME activity. Pectin methyl-esterase (PME) catalyses the cleavage of methyl groups from the pectin side chain, exposing carboxyl (–COO⁻) groups. These acidic groups were quantified using an acid–base titration method as described by Doan et al. (2021a). Briefly, 1 mL of heat-treated passion fruit juice was mixed with 50 mL of 1% (w/v) pectin solution prepared in 0.2 N NaCl. The mixture was adjusted to pH 7.5 using 0.1 N NaOH. After a reaction period of 1 h, the solution was titrated with 0.05 N NaOH until the pH again reached 7.5. The volume of 0.05 N NaOH consumed was recorded. All titrations were performed using an automatic potentiometric titrator (G20 Compact Titrator, Mettler Toledo, Switzerland).

PME activity units (PEU) and relative PME activity were calculated using the following equations (Doan et al. 2021a):

$$PME \text{ activity units (PEU)} = \frac{(ml \text{ NaOH}) \times (0.05 \text{ N NaOH})}{(1 \text{ ml sample} \times 60 \text{ min})} \times 10^3 \quad (1)$$

$$Relative \text{ PME activity (\%)} = \frac{PEU \text{ of treated sample}}{PEU \text{ of control sample}} \times 100 \quad (2)$$

$$PME \text{ inactivation (\%)} = 100 - Relative \text{ PME activity} \quad (3)$$

The control sample is untreated passion fruit juice.

Determination of ascorbic acid content. The ascorbic acid content of passion fruit juice was determined

by high-performance liquid chromatography (HPLC), adapted from the method reported by Doan et al. (2021b). A 1 mL aliquot of centrifuged juice was mixed with 9 mL of 0.1% (w/v) oxalic acid solution and homogenised for 3 min. The mixture was filtered through a 0.45 µm membrane prior to analysis. A 20 µL aliquot was injected into an HPLC system (Shimadzu LC-2050, Japan). Separation was achieved using a C18 reverse-phase column (5 µm, 150 mm × 4.6 mm; Agilent Technologies, USA), with 0.1% oxalic acid as the mobile phase. Detection was performed at 243 nm, with a column temperature of 25 °C and a flow rate of 1 mL·min⁻¹. Ascorbic acid content was quantified using an external calibration curve prepared with L-ascorbic acid standards (Sigma, USA) in the concentration range of 0–80 mg·L⁻¹ and expressed as mg·L⁻¹.

Determination of total polyphenol content (TPC). Total polyphenol content was determined using the Folin–Ciocalteu method, following the procedure described by Jesus et al. (2020) with minor modifications. Juice samples were centrifuged at 6 000 rpm for 10 min, and 1 mL of the supernatant was mixed with 5 mL of 10% (v/v) Folin–Ciocalteu reagent. Subsequently, 4 mL of sodium carbonate solution (75 g·L⁻¹) was added. The reaction mixture was incubated in the dark at 30 °C for 1 h, after which absorbance was measured at 765 nm using a UV–Vis spectrophotometer (Thermo Spectronic Genesys 20, Thermo Electron Corporation, USA). TPC was calculated from a calibration curve prepared with gallic acid standards (0–50 mg·L⁻¹) and expressed as mg gallic acid equivalents per litre (mg GAE·L⁻¹).

Determination of antioxidant activity. Antioxidant capacity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging method, based on the procedure outlined by Igual et al. (2010) with slight modifications. Juice samples were centrifuged at 6 000 rpm for 10 min, and the supernatant was collected. A 0.1 mL aliquot of diluted juice was mixed with 3.9 mL of DPPH solution (0.030 g·L⁻¹ in methanol). The mixture was incubated in the dark at 30 °C for 30 min, and absorbance was measured at 515 nm using a spectrophotometer (Thermo Spectronic Genesys 20, Thermo Electron Corporation, USA) at 25 °C (Equation 4). A blank was prepared using deionised water in place of the sample.

$$\% \text{ DPPH} = \frac{(A_o - A_m)}{A_o} \times 100 \quad (4)$$

where: A_m – absorbance of juice sample; A_o – absorbance of blank.

Statistical analyses

All experiments were performed in triplicate, and results were expressed as mean ± SD. One-way and two-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) test, were used to evaluate statistical differences at a significance level of $P < 0.05$, using Statgraphics Centurion XV (Statgraphics Technologies, Inc., USA) and R software (version 4.3.1, R Core Team, Austria).

RESULTS AND DISCUSSION

Effects of frequency and electric field strength on PME activity in passion fruit juice during ohmic heating

This study investigated the effects of frequency and electric field strength on PME activity in passion fruit juice during ohmic heating under fixed thermal conditions (70 °C for 10 s) (Figure 2). The investigated parameters included frequencies of 50, 60, 500, 1 000, and 10 000 Hz and electric field strengths of 20, 30, and 40 V·cm⁻¹.

The results demonstrated that both frequency and electric field strength significantly affected PME activity ($P < 0.05$). A frequency of 60 Hz resulted in the highest level of PME inactivation, while increasing electric field strength further enhanced the inactivation effect. At 60 Hz, PME inactivation values of 35.94, 59.36, and 72.58% were observed at electric field strengths of 20, 30, and 40 V·cm⁻¹, respectively. At other frequencies, PME inactivation ranged from 26.14–33.73% at 20 V·cm⁻¹, 38.93–52.60% at 30 V·cm⁻¹, and 45.13–64.58% at 40 V·cm⁻¹.

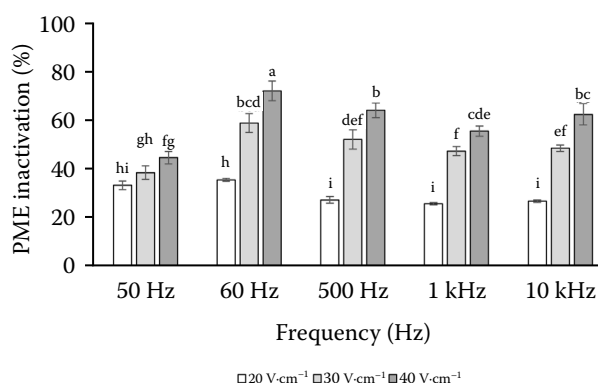


Figure 2. Effect of frequency and electric field strength on pectin methylesterase (PME) activity in passion fruit juice under Ohmic heating (70 °C, 10 s)

^{a–i} different letters indicate significant differences (Tukey HSD two-way test)

These findings are consistent with previous studies, including those by Sain et al. (2024), Demirdöven and Baysal (2014), Funcia et al. (2020), and Abdelmaksoud et al. (2018), which also reported enhanced PME inactivation with increasing electric field strength. Demirdöven and Baysal (2014) investigated the effect of electric field strength on PME inactivation in orange juice treated at 50 Hz for 60 s and reported a 96% reduction in PME activity at an electric field strength of 44 V·cm⁻¹ and a temperature of 70 °C. They also observed a direct correlation between increasing electric field strength (from 26 to 54 V·cm⁻¹) and enhanced PME inactivation. Funcia et al. (2020) examined the influence of electric field strength on PME inactivation during ohmic heating of orange juice at 60 Hz. At a constant temperature of 60 °C and a holding time of 200 s, they reported a pronounced effect of electric field strength (32–36 V·cm⁻¹) on PME inactivation. Similarly, Abdelmaksoud et al. (2018) investigated the effects of electric field strength (30–40 V·cm⁻¹) and temperature (60–80 °C) on PME inactivation in mango juice and found that treatment at 40 V·cm⁻¹, 80 °C, and a holding time of 60 s resulted in the highest PME inactivation rate (95.7%). A comparable trend was reported in a recent study, in which increasing electric field strength accelerated the heating rate and thereby enhanced the inactivation of quality-degrading enzymes in citrus beverages (Jain et al. 2025).

Samaranayake and Sastry (2016) investigated the effect of frequencies from 1 Hz to 1 MHz on PME inactivation during Ohmic heating of tomato juice at 65 °C and a low electric field strength of 0.4 V·cm⁻¹. Their results indicated that a frequency of 60 Hz was most effective for PME inactivation evaluated the effect of frequencies ranging from 1 Hz to 1 MHz on PME inactivation during ohmic heating of tomato juice at 65 °C and a low electric field strength of 0.4 V·cm⁻¹. Their results indicated that a frequency of 60 Hz was the most effective for PME inactivation. Accordingly,

a frequency of 60 Hz was selected for subsequent experiments.

Effective pasteurisation conditions should achieve sufficient enzyme inactivation while minimising the loss of freshness and nutritional quality. Although ohmic heating at 60 Hz and an electric field strength of 40 V·cm⁻¹ resulted in higher PME inactivation, it also caused a significant reduction in ascorbic acid content, likely due to accelerated oxidative degradation. Therefore, an electric field strength of 30 V·cm⁻¹ was considered optimal, as it provided an appropriate heating rate while minimising nutrient losses (Table 1).

Effect of temperature and holding time on PME inactivation in passion fruit juice (OH vs. CH)

At a fixed frequency of 60 Hz and an electric field strength of 30 V·cm⁻¹, passion fruit juice was heated to temperatures ranging from 60 to 90 °C, with holding times of 0–90 s (Figure 3). Statistical analysis confirmed that both temperature and holding time significantly affected PME inactivation. At a holding time of 50 s, PME inactivation increased with temperature, reaching 48.7, 56.2, 58.5, and 77.4% at 60, 70, 80, and 90 °C, respectively.

These results are in agreement with previous studies. Doan et al. (2021a) investigated the effect of temperature on PME inactivation in pomelo juice using ohmic heating at temperatures of 60, 70, 80, and 90 °C, with a holding time of 50 s at 60 Hz and 30 V·cm⁻¹. They reported PME inactivation levels of approximately 59, 86, 90, and 98% at 90 °C, respectively.

Similarly, Leizeron and Shimoni (2005) demonstrated that ohmic heating at elevated temperatures (90–150 °C), using a frequency of 50 Hz and an electric field strength of 8 kV, effectively inactivated PME in orange juice, achieving reductions of 90–98% within short treatment times (0.68–1.13 s). These findings confirm that higher temperatures markedly enhance PME inactivation in citrus juices.

Table 1. Effect of electric field strength on the degradation of ascorbic acid (AA), total polyphenol compounds (TPC), and antioxidant activity (DPPH) in passion fruit juice during Ohmic heating (60 Hz, and 20, 30, 40 V·cm⁻¹)

Electric field strength (V·cm ⁻¹)	Heating rate (20–70 °C)	AA (ppm)	TPC (ppm)	DPPH (%)
20	6 min 57 s	44.0 ± 1.41 ^b	61.05 ± 0.54 ^c	20.89 ± 0.11 ^c
30	2 min 38 s	43.1 ± 4.10 ^b	70.05 ± 4.06 ^b	21.92 ± 0.27 ^{bc}
40	1 min 53 s	26.5 ± 3.54 ^c	79.29 ± 0.88 ^a	22.76 ± 0.44 ^b
Fresh sample	no heating	124.0 ± 5.59 ^a	83.58 ± 1.49 ^a	24.32 ± 1.05 ^a

^{a-c} different letters represent statistically significant differences in the same indicator

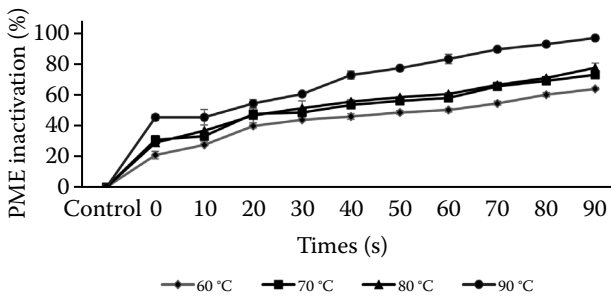


Figure 3. Effect of temperature on pectin methylesterase (PME) inactivation during Ohmic heating of passion fruit juice (Tukey HSD two-way)

In the present study, treatment at 90 °C for 70 s resulted in approximately 90% PME inactivation, indicating its potential applicability for the commercial pasteurisation of passion fruit juice while maintaining juice turbidity.

Comparison of PME inactivation between ohmic heating and conventional heating. To clarify the relative effects of OH and CH, passion fruit juice samples were treated under identical thermal conditions (60–90 °C for 50 s) using CH (Figure 4). PME inactivation by CH was 41.7, 43.3, 48.6, and 57.2% at 60, 70, 80, and 90 °C, respectively, which was consistently 14.4–26.1% lower than that achieved by OH.

These results demonstrate that OH is more effective than CH in inactivating PME due to the synergistic ef-

fects of thermal and electrical fields. The applied electric field is hypothesised to disrupt the tertiary structure and active sites of PME (Samaranayake and Sastry 2021), resulting in protein unfolding and enhanced enzyme denaturation beyond that achieved by thermal treatment alone. Thermal inactivation of PME typically begins at temperatures above 40 °C as a result of hydrogen bond disruption, unfolding of the tertiary protein structure, and amino acid deamidation (Tanaka and Hoshino 2003).

The present findings are consistent with those reported by Yeom et al. (2002), who observed that PME destruction was most pronounced at 90 °C. Abdelmaksoud et al. (2018) compared PME inactivation using OH and CH and reported that OH was more effective. Specifically, PME inactivation reached 96% at an electric field strength of 40 V·cm⁻¹, a temperature of 80 °C, and a holding time of 60 s during OH treatment, compared with 90% inactivation at 90 °C for 60 s using CH. Similarly, Demirdöven and Baysal (2014) reported a 96% reduction in PME activity following OH treatment at 42 V·cm⁻¹ and 69 °C for 60 s, whereas CH at 95 °C for 60 s resulted in only 88.3% inactivation.

The enhanced inactivation of PME observed during OH treatment enables effective enzyme inactivation at moderate temperatures, thereby reducing the risk of adverse sensory and nutritional changes associated with high-temperature processing.

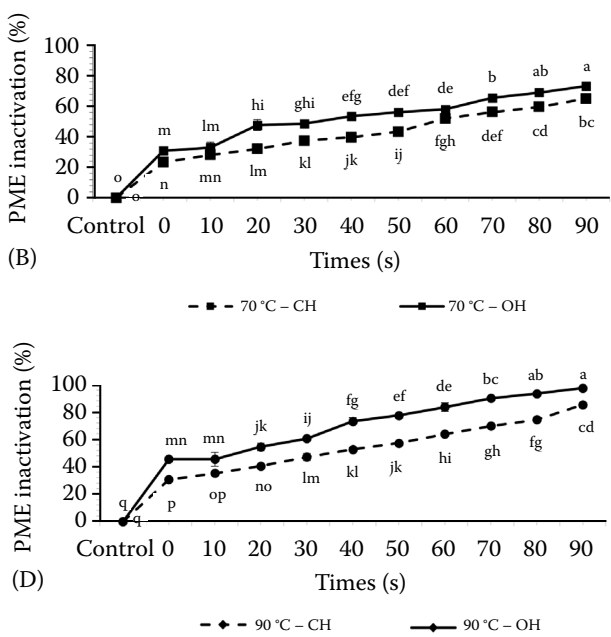
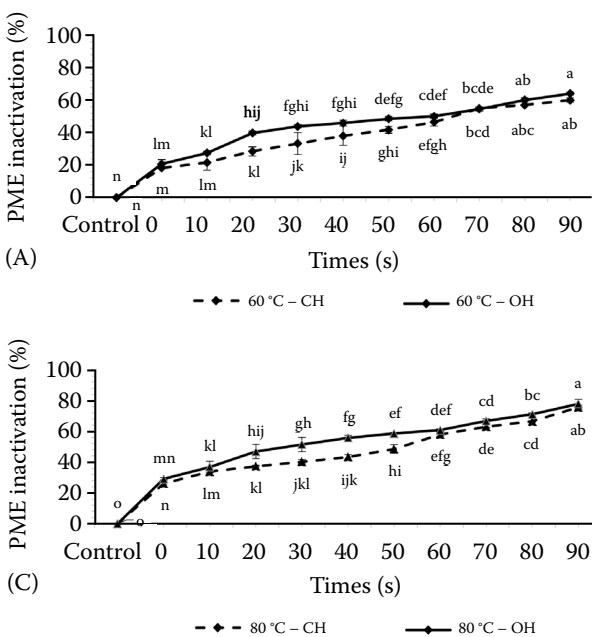


Figure 4. Comparison of pectin methylesterase (PME) inactivation at 60 (A), 70 (B), 80 (C) and 90 °C (D) between ohmic heating (OH) and conventional heating (CH)

^{a–q}two-way ANOVA followed by Tukey’s HSD test ($P < 0.05$)

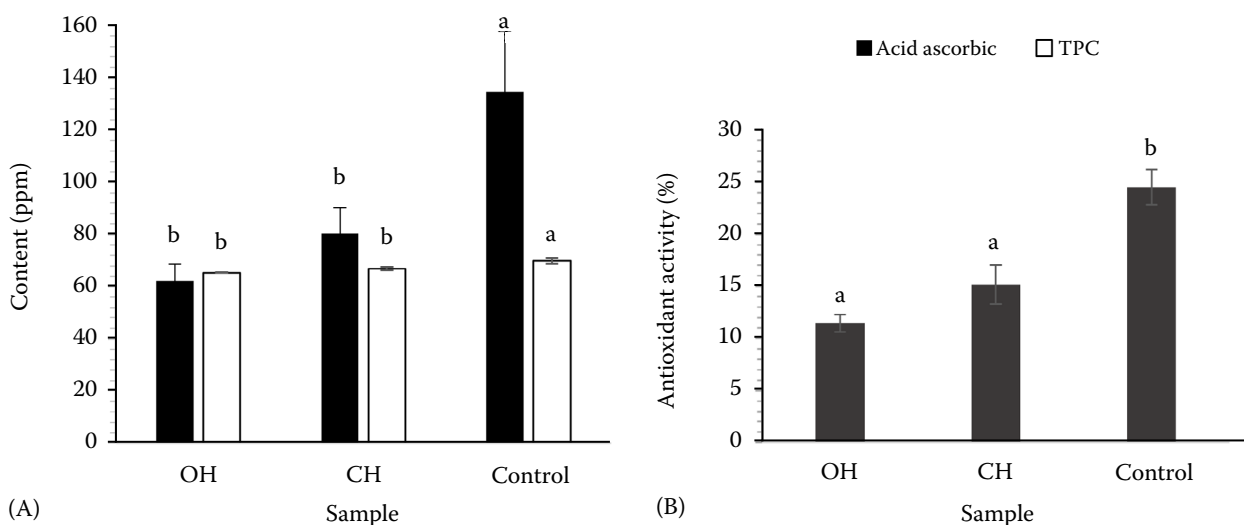


Figure 5. Effects of non-thermal factors on total polyphenol (TPC) and ascorbic acid contents (A) and antioxidant activity (B) in passion fruit juice

^{a, b} different letters on the same parameter indicate significant difference ($P < 0.05$)

CH – conventional heating; OH – ohmic heating

Effect of ohmic and conventional heating on juice quality attributes

In addition to PME inactivation, this study evaluated the effects of OH and CH on ascorbic acid (AA), total polyphenol content (TPC), and antioxidant activity. As shown in Figure 5, both OH and CH resulted in significant reductions in AA, TPC, and antioxidant activity compared with the fresh juice ($P < 0.05$). However, no significant differences were observed between OH and CH ($P > 0.05$), indicating that the applied electric field did not cause additional degradation beyond the effects of thermal treatment.

At 90 °C for 70 s, OH achieved approximately 90% PME inactivation, compared with 72% achieved by conventional heating. This finding suggests that OH enhances PME inactivation efficiency through non-thermal effects, without inducing additional degradation of heat-sensitive bioactive compounds. Specifically, the TPC of OH-treated juice decreased by 6.62%, which was comparable to that observed after CH treatment. Ascorbic acid content decreased by more than 54% following pasteurisation, with no significant difference between the two heating methods. Antioxidant activity also declined significantly after treatment but was not significantly affected by the heating method.

These findings are consistent with previous studies. Yildiz et al. (2009) and Darvishi et al. (2020) reported that the presence of an electric field had no significant effect on TPC during OH treatment. Similarly, Bar-

rón-García et al. (2021), Rinaldi et al. (2020) observed no significant differences in bioactive compound retention or antioxidant capacity between OH- and CH-treated fruit products. Therefore, the observed degradation of quality attributes can be primarily attributed to thermal effects rather than non-thermal factors during ohmic heating. Nevertheless, the presence of an electric field during OH treatment enhanced PME inactivation at moderate temperatures, thereby contributing to the preservation of the sensory attributes and nutritional quality of the juice.

Recent studies published in 2025 further support this trend, demonstrating that increasing the electric field strength from 10 to 20 V·cm⁻¹ resulted in only a slight additional reduction in TPC and AA during OH treatment, while still preserving these bioactive compounds more effectively than conventional heating (Gülsoy et al. 2025). Notably, higher electric field intensity also contributed to improved colour retention and markedly lower hydroxymethylfurfural (HMF) formation compared with traditional thermal processing, further highlighting the advantages of OH for maintaining juice quality.

CONCLUSION

This study demonstrated that OH is more effective than CH in inactivating PME in passion fruit juice, owing to the synergistic effects of thermal and elec-

trical fields. Suitable OH conditions were identified as a frequency of 60 Hz and an electric field strength of 30 V·cm⁻¹, which achieved substantial PME inactivation while minimising losses of ascorbic acid, total polyphenols, and antioxidant activity. The results confirmed that both thermal factors (temperature and holding time) and non-thermal factors (electric field strength and frequency) significantly influence PME inactivation and juice quality.

This study contributes to the optimisation of ohmic heating parameters for the commercial pasteurisation of passion fruit juice. Given the five-fold dilution applied to match consumer pH preferences, the resulting reduction in juice conductivity may limit heating efficiency. Future studies will therefore focus on enhancing electrical conductivity through ionic fortification in order to improve heating uniformity and further preserve juice quality during ohmic heating.

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