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The influence of Ohmic-vacuum heating on phenol, ascorbic acid and engineering factors of kiwifruit juice concentration process

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The influence of Ohmic-vacuum heating on phenol, ascorbic acid and engineering factors of kiwifruit juice concentration process

Abstract

The antioxidant, phenol, ascorbic acid, electrode corrosion and engineering factors of concentration process of kiwifruit juice by ohmic heating-vacuum conditions (OHVC) was evaluated and compared with ohmic heating under atmospheric conditions (OHAC). Results showed that the total phenol content was decreased with an increasing voltage gradient for both heating modes. The OHVC can better save the antioxidant capacity and ascorbic acid of concentrated samples than the OHAC. The processing time of OHVC was significantly higher than the OHAC at the same voltage gradient ($p < 0.05$). The electrode corrosion rate at the vacuum mode was 7 to 40- fold higher than the atmospheric mode. The energy efficiency at OHAC was lower than the OHVC. The energy consumption was found in the range of 3.37 to 3.75 MJ/kg water for OHAC and 4.08 to 11.09 MJ/kg water for OHVC. The electrical conductivity under the vacuum mode was lower than the atmospheric mode.

Keywords: Ohmic-vacuum heating; energy consumption; antioxidants; corrosion; kiwifruit juice

Introduction

Kiwifruit juice has a multi-nutrient source of vitamins, polyphenols, antioxidants, and minerals which encouraged its industrials utilization (Cassano et al., 2008; Wang et al., 2019). Once harvested, kiwifruit needs to be kept at low temperatures and such storage entails energy costs and appropriate facilities (Atak and Goksel, 2014). Consequently, it is needed to further expanding kiwifruit processing to get longer shelf life. Processed products are mainly juice and juice concentrate. Also, the concentration of the fruit juices strongly reduces microorganism's growth and costs of packaging, delivery, and storage (Cassano and Drioli, 2007). The production of high-quality concentrated juice is affected by a number of factors including boiling point, heat transfer rate, processing time, energy consumption, and pressure. Conventional heating is a common method in food processing industries. Due to lower heat transfer coefficients of food materials, the processing time is long and resulted quality loss and high energy consumption during conventional heating

(Ahmad et al., 2019; Fadavi et al., 2018). To overcome these problems, the emerging techniques for the concentration process should be developed.

Ohmic heating, which is converting electrical energy to thermal energy, provides a rapid and homogeneous heating in foods (Gavahian, et al., 2019). Along with the principal advantages, the participation of no hot surfaces, high efficiency and probability of control slurries with high solid contents, no need for vapor and water are other rewards of ohmic heating (Cokgezme et al., 2017).

Applying vacuum system for the evaporation process avoids excessive increasing of boiling temperature through the proceeding of concentration and decreases thermal damage to nutrients, color, and quality of the product (Assawarachan and Noomhorm, 2011; Fadavi et al., 2018). A combination of ohmic and vacuum for the concentration of juices might have double effect on decreasing time and boiling temperature of the process, which gives raise to energy-saving and cause less quality loss. Recent studies on combined ohmic-vacuum heating were done under low vacuum pressure. Fadavi et al. (2018) discovered that ohmic heating couples with vacuum (P = 40 kPa) had noteworthy effect on the quality of concentrated tomato. Darvishi et al. (2019) reported that hybrid ohmic-vacuum heating had better effect on the sustaining vitamin C, total phenol content, and antioxidant capacity of orange juice due to lower processing temperature and reduce oxygen accessibility. Conversely, Sabanci et al. (2019) reported that degradation of phenolic and anthocyanin contents of evaporated juice was higher during the running of the ohmic-vacuum process at lower voltage gradients (7.5 - 12.5 V/cm).

According to the best knowledge of the authors in the open literature, no investigation was found on the electrode corrosionin the vacuum state and behavior of kiwifruit juice during the ohmic heating process at atmospheric or vacuum state. Therefore, the aims of this study were (1) to evaluate the effect of ohmic heating under vacuum and atmospheric conditions on theprocessing kinetics, electrical conductivity, energy consumption and performance, electrode corrosion rate, and quality parameters (phenol content, antioxidant activity, and ascorbic acid), and (2) to study the variations of the electrical conductivity as a function of pressure, phase heating, water content, and temperature of the juice sample during the concentration process.

2. Materials and methods

2.1. Sample perpetration

The samples of fresh kiwifruit were obtained from a local fruit market in Sanandaj, Iran. Samples were washed with tap water, peeled, and then the juice extracted using a juice extractor (Sunny Co., China). Immediately after filtering the juice, the concentration process was started. The total soluble solids (TSS) and moisture content of fresh and concentrated samples were measured using a refractometer (ATAGO, Japan) at 20 °C and drying oven (Memmert, Germany) at 103 °C. The TSS and moisture content of fresh sample were obtained as 14.33 ± 0.58 ºBrix and 85.31± 0.56% wet basis, respectively.

2.2. Heating setup

The schematic diagram of the ohmic -vacuum heating setup is shown in Fig. 1. The experimental setup consists of a Pyrex glass cell (rectangular cube: 15 cm height; 10 cm width; 10 cm length, two 316L stainless steel electrodes with 2 mm thickness and 10 cm gap between them, a voltage regulating transformer (1 kW, 0–330 V, 50 Hz, MST–3, Japan), three coated type-K thermocouples, a power analyzer (Dina Co, Iran), a vacuum pump (Platinum DV-42N, USA), a buffer tank to damp the pulsation of pump operation, a vacuum gage, a digital balance (FX-3000i model, A&D, Japan) with an accuracy of ± 0.01 g for mass determination, a microcontroller, and a personal computer. The temperature, sample mass, current, and voltage were recorded in 1 s time intervals. The heating process was carried out in two ohmic heating modes of operation (1) under vacuum (OHVC) and (2) atmospheric conditions (OHAC) at four different voltage gradients (15, 20, 25, 30 V/cm). The altitude of the laboratory, place of experiments,is about 1459 meters above sea level and the boiling temperature of tap water is 92.7 ± 0.5 ºC in the laboratory which means that the ambient pressureis less than 101.3 kPa. About 100 g of kiwifruit juice was poured into the cell in each run treatment. Before starting any treatment, the vacuum pump was worked about 2 min to stabilize the state (12.3 kPa absolute pressures) on the surface of the juice sample. The ohmic cell was washed with a toothbrush and distilled water after each experiment. The concentrating process was continued until TSS of sample reached around 60.67 ± 1.50 ºBrix (or water content of samples reached to 39.21 ± 1.27% wet basis). The concentrate samples were keptat 4 °C about 24 h for further biochemical analysis.

2.3. Electrical conductivity

The electrical conductivity was calculated as (Fadavi et al., 2018):

$$\sigma = \frac{I \times L}{V \times A} \qquad (1)$$

where σ is the electrical conductivity (S/m), I is the electrical current passed from the sample (A), V is the electrical voltage (Volte), L is the gap between two electrodes (m), and A is the contact surface between the juice sample and electrode (m^2). The contact surface reduced during the evaporation process. Therefore, the contact surface was computed as follows (Fadavi et al., 2018; Darvishi et al., 2015):

$$A = \frac{m_t}{\rho_t \times L} \qquad (2)$$

Where A is the contact surface between sample and electrode (m^2), m_t and ρ_t are the sample mass (kg) and sample density (kg/m^3) at any time of heating process, respectively.

2.4. Electrode corrosion rate

The concentration of Fe migrated into the sample was taken as measures of electrode corrosion for the stainless steel electrode. The complete details of sample perpetration for measuring trace metal concentration in juice samples was described by Gad and Jayaram (2014). The analytical equipment used in this study is an Inductively Coupled PlasmaAtomic Emission Spectrometer (ICP-AES) with a radial configuration. The corrosion rate by the average flux of Fe ions was calculated as follows:

$$ECR = \frac{C_{mi}}{t} \qquad (3)$$

Where ECR is the electrode corrosion rate (ppb/s); t is the heating time (s), and C_{mi} is the actual concentration of Fe (ppb) released from the electrodes into the solution during OH was evaluated as the difference between the concentrations measured in heated and unheated samples.

2.5. Energy consumption and performance

The energy consumption was calculated as follows (Cokgezme et al., 2017):

$$E = P_{vp} \times t_{on} + \sum (VI \times \Delta t) \qquad (4)$$

where E is the energy consumption (J), P_{vp} is the power consumption (W) of the vacuum pump, t_{on} is the time (s) of switched on of the vacuum pump, I is the electrical current passed from the sample (A), V is the electrical voltage (Volte), and Δt is the time interval for measuring current and voltage (s).

The performance of heating system was calculated as (Hosainpour et al., 2015):

$$\eta = \left(\frac{m_0 C_p \Delta T + m_w h_{gf}}{E}\right) \times 100 \qquad (5)$$

where m_0 is the initial mass of sample (kg), C_p is the specific heat capacity (J/kg K), ΔT is the difference temperature of sample (ºC), m_w is the mass of water evaporation (kg), h_{gf} is the latent heat (J/kg), and η is the energy efficiency of heating system (%).

2.6. Ascorbic acid measurement

AA of samples was extracted by homogenization of 0.5 mL juice sample in 1 mL 5% metaphosphoric acid (MA). AA was measured in prepared sample according to Koushesh Saba and Moradi (2016) as follow: 500 µL of extracted sample or AA calibration solutions were added to 500 µL 10% MA, 300 µL of citrate buffer (pH 4.2), and 300 µL of the 2,6-dichloroindophenol (DCIP) (0.1 mg mL-1). After 30 min, the absorbance was read using spectrophotometer (Unico, UV - 2100, USA) at 510 nm. The AA data were stated as mg ascorbic acid per 100 mL of kiwifruit juice using standard curve obtained by calibration solutions.

2.7. Total phenol content measurement

Sample extraction was carried out by homogenization of 1 mL kiwifruit juice in pre-cold solution (distilled water – HCl-methanol, 19-1-80% v/v) flowed by centrifugation at 4 ºC for 20 min at 11000 g. Total phenol content (TPC) in the supernatant was measured according to the Folin–Ciocalteu (Singleton et al., 1999), and gallic acid was applied for the standard curve. The TPC data were stated as mg gallic acid per 100 mL of sample (Koushesh Saba and Amini, 2017).

2.9. Antioxidant capacity measurement

Antioxidant capacity (AC) was determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging method according to Sánchez-Moreno et al. (1999). The absorbance was measured at 517 nm, using a spectrophotometer. AC was determined using the following equation:

$$AC = \frac{AB_c - AB_s}{AB_c} \times 100 \qquad (6)$$

Where AB_c and AB_s are the absorbances at 517 nm of the control and sample, respectively, and AC is the antioxidant capacity (%);

2.8. Statistical analysis

A 2×4 factorial design was used to plan and perform the experiments. All experiments and measurements were performed in triplicate and are reported as mean and standard deviation. The statistical evaluation (ANOVA and Duncan test) was performed by using SPSS V.18 software at the 5% significance level. Microsoft Excel software was used to plotting 2D view of the results.

3. Results and decision

3.1. Engineering parameters

The temperature of juice sample is shown in Fig. 2 during the heating process. The sample temperature rose to 94.5 ± 0.3ºC for OHAC and 50.5 ± 0.7 °C for OHVC and stayed constant until the end of the concentration process. As can be seen, the sample temperature at the vacuum mode is 44 ºC lower than the atmospheric mode during evaporation. The processing time varied between 220 - 934 s for OHAC and 380 – 1446 s for OHVC (Table 1). The processing time of OHVC was significantly higher than the OHAC at the same voltage gradient ($p < 0.05$). The reason for higher processing time at vacuum mode is the electrical current (Fig. 3) through the sample during heating that was very lower than the atmospheric mode. Therefore, the generated energy in OHVC is lower than OHAC which leads to a decline in the evaporation rate. The result of this phenomenon was an increase in processing time. The reason for the low electrical current passing through sample at OHVC can be attributed to the rate of bubbles expansion (Fadavi et al., 2020; Fadavi and Salari, 2019). The effect of vacuum decreases the pressure difference inside and outside the bubbles, therefore, bubbles expansion will be more rapid and as a result their escape from the surface of media is facilitated, interrupting the passage of current through the sample (Fadavi and Salari, 2019). Also, it could be noted that the sample heat capacity and latent heat of vaporization were a function of the pressure inside the heating chamber. It has been noted that in lower pressure inside the heating chamber, the heat capacity of the sample decreased while the latent heat of vaporization increased (Thermexcel, 2019). The latent heat of water vaporization in vacuum mode was 118 kJ/kg higher than the atmospheric mode (h_{gf} = 2375 kJ/kg in 12.3 kPa, and h_{gf} = 2256 kJ/kg in ambient pressure). It means that the sample needed more energy for water evaporation in vacuum mode. This energy (Δh_{gf} = 118 kJ/kg) generated with a slow rate at the vacuum mode due to the lower electrical current through the sample and finally has resulted in a lower water evaporation rate and

higher processing time. The processing time decreased with increasing of voltage gradient for both heating modes ($p < 0.05$). When the samples were subjected to a higher voltage gradient, the high energy generation increased the activity of the water molecules and led to an increase of the evaporation rate and decreased the processing time (Darvishi et al., 2020; Fadavi et al., 2018).

3.2. Electrical conductivity

Variations of the electrical conductivity as a function of heating conditions are shown in Fig. 4. The changes in electrical conductivity at OHAC were different than OHVC. At atmospheric mode, the electrical conductivity increased from 0.60 to 1.67 S/m with increasing sample temperature from 26.0 ºC until boiling point due to reduced drag for the movement of ions. As the boiling process begins, the electrical conductivity drops sharply due to the gas bubbles formation (e.g. H_2 or O_2 gas due to the electrolysis reaction) which worked as electrical insulation (Darvishi et al., 2019; Samaranayake and Sastry, 2005). The intensity of drop in electrical conductivity increased with raising voltage gradient due to higher boiling rates. According to Fig. 4, the electrical conductivity increased with decreasing water content of the juice sample during the evaporation process (especially at higher voltage gradient) due to an increase of ions concentration in the juice sample. Darvishi et al. (2015) found that the moisture content had more effect on the electrical conductivity of tomato juice than the temperature especially at high concentrations at atmospheric pressure. They also reported that there was no insignificant effect of the voltage gradient on the electrical conductivity. Boldaji et al. (2015) showed that increasing the voltage gradient led to a decrease in the electrical conductivity of tomato paste which could be due to the increasing rates of vapor formation at higher voltage gradient at atmospheric conditions.

At vacuum mode (Fig. 4), the electrical conductivity increased at the initial few seconds of heating, and then it decreased with increasing sample temperature until 46 ± 1.5 ºC during the warming up period. Although the boiling process was clearly observed at 50.5 ± 0.7 °C, the boiling action had no effect on the electrical conductivity. Unlike atmospheric conditions, the boiling process did not decrease the electrical conductivity and electrical current passed from the sample. During the evaporation period, the electrical conductivity increased with decreasing water content of the juice sample for OHVC as in the OHAC mode. The values of electrical conductivity at OHAC were

higher than OHVC at the same water content. The electrical conductivity varied between 0.5 – 1.8 S/m for OHAC and 0.30 – 0.88 S/m for OHVC.

3.3. Electrode corrosion rate

According to statistical analysis, the pressure and voltage gradient were significant effects on the electrode corrosion rate ($p < 0.05$). The electrode corrosion rate was obtained in the range of 19.27 – 426.11 ppb/s for OHVC, and 0.48 – 61.58 ppb/s for OHAC (Table 1). The electrode corrosion rate at OHVC was 7– 40–fold higher than OHAC. The higher corrosion rate at the vacuum mode was probably due to the lower current density in the OHVC relative to the OHAC. It should be noted that the use of OHVC for a long time causes more corrosion of the electrodes rather than the values reported in this study. So, the accumulation of metals in the concentrated samples may have an adversely effect on the health of consumers. According to the literature review (Wu et al., 1998; Reznick, 1996), the corrosion rate could be reduced by increasing current density. It was also observed that the electrode corrosion increased with increasing voltage gradient for both heating mode. These results agree with the fact that the rate of charge transfer through the electrode-solution interface is strongly related to the applied potential (Stancl and Zitny, 2010;Pataro et al., 2014). Lima et al. (1999) reported that by using stainless steel electrodes, iron concentration in orange juice increased during Ohmic heating. This trend can be explained bearing in mind that under alternating current when the polarity of the potential is reversed, the electrode solution interface behaves like a capacitor which charges and discharges according to the frequency (Amatore et al., 1998). Thus, the use of low-frequency current signal may determine the full charging of the electrodes double layer up to exceeding the threshold value corresponding to the onset of electrode reactions. This will cause electrode corrosion and an increased metal release into the solution and, hence, food contamination (Amatore et al., 1998).

3.4. Energy consumption and performance

According to Table 1, the energy consumption varied from 3.41 to 3.75 MJ/kg water for OHAC and 4.08 to 11.09 MJ/kg water for OHVC. The energy consumed at the vacuum mode was 0.68 – 7.34 MJ/kg water higher than the atmospheric mode at the same voltage gradient. At vacuum mode, the energy consumed by vacuum pump was 59% to 81% of total energy consumption. The energy consumption by the ohmic heater was 2.06 MJ/kg water for 15 V/cm, 1.84 MJ/kg water for 20 V/cm, 1.76 MJ/kg water for 25 V/cm, and

1.68 MJ/kg water for 30 V/cm. The energy consumption decreased with increasing voltage gradient ($p < 0.05$) due to the reduction of processing time. Hosainpour et al. (2015) reported energy consumptionreduced about 1.6-fold by increasing the voltage gradient from 6 to 16 V/cm during ohmic concentration of tomato paste at atmospheric pressure due to increasing salt concentration in juice samples. Darvishi et al. (2020) showed that the voltage gradient had no significant effect on energy consumption ($p > 0.05$) of the ohmic concentration process of grape juice at atmospheric pressure although processing time reduced about 3–fold by increasing the voltage gradient from 15 to 30 V/cm.

The energy efficiency calculated in the range of 71.83 – 80.07% for OHAC and 22.38 – 60.87% for OHVC (Table 1). The energy efficiency of OHAC was 18.30 –49.59% higher than OHVC. The reasons for lower energy efficiency at vacuum mode can be due to the high energy consumption by the vacuum pump and the low energy generation in the sample due to the low electrical conductivity of the sample. Similar to our results, Icier (2003) reported that the energy efficiency of OHAC for the liquid samples was in the range of 47 – 92%. Cokgezme et al. (2017) reported that the energy efficiency of the concentration process of pomegranate juice using OHVC was varied between 23.94- – 55.12%. Darvishi et al. (2015) reported that the average energy efficiency of tomato paste production using OHAC was increased from 67.07 to 85.50% with increasing voltage gradient (6 to 16 V/cm).

3.5.Ascorbic acid

The effect of heating conditions on the quality of concentration kiwifruit juice is shown in Fig. 5. Results showed that the AA content of concentrated samples was lower than the fresh juice (370.9 ± 23.6 mg AA/100 mL). Generally, the heating process reduced the AA content in fruit juice because vitamin C is sensitive to heat and environmental conditions (Hashemi et al., 2019). AA declines in OHVC treatments were lower than OHAC ($p < 0.05$). The vitamin C is easily destroyed by heating and oxidized in the presence of air (El-Ishaq and Obirinakem, 2015). The greater level of AA in OHVC might be the effect of vacuum state that decreased boiling point temperature and air (reduce oxygen availability) inside the ohmic cell thus might induce lower decomposition of vitamin C (Darvishi et al., 2019). It can also be stated that the solubility of gases in the sample at OHAC decreases with increasing temperature. While the rate of ascorbic acid degradation

augmented with increasing temperature from 61 – 92 °C (Laing et al., 1978; Kadakal et al., 2017). The increase in voltage gradient led to a less AA decrease, which might be because the duration of processing facilitated the degradation of AA.

3.6. Total phenol content

TPC of concentrated juices was lower than fresh kiwifruit juice. TPC of concentrated juices using OHVC was lower than OHAC at the same voltage gradient (Fig. 5A). As stated, the processing temperature in the OHVC was 44 ºC lower than OHAC during the evaporation period, but the longer processing time in the OHVC might cause higher TPC decline. Also, TPC decline increased with increasing voltage gradient for both heating modes. The rate of corrosion and electrochemical changes increased with increasing voltage gradient (Pataro et al., 2014) resulting in a decrease in total phenol content.

3.7. Antioxidant capacity

The antioxidant capacity (AC) of treated samples was lower than the fresh sample ($p < 0.05$). However, the AC of samples treated using OHVC (82.69 – 84.39%) was higher than OHAC (78.37 – 83.37%) at the same voltage gradient (Fig. 5C). The temperature and duration of the process are two important factors on the change of quality parameters of fruit juice during the concentration process (Jayathunge et al., 2019). The process temperature in the OHVC was much lower than OHAC, but the processing time in the vacuum state was longer. It could be concluded that the effect of sample temperature on the reduction of AC was greater than the effect of the process duration. The higher AC in OHAC also could be explained by the AA level as high correlation has been reported between AC and AA in kiwifruit cultivars (Park et al., 2011).

4. Conclusion

Kiwifruit juice was concentrated via ohmic heating at atmospheric and vacuum conditions. Results showed that the high vacuum pressure showed a negative effect on the processing time, electrode corrosion, energy consumption, thermal efficiency, phenol content and electrical conductivity of the juice samples. The combined of vacuum pressure and high gradient voltage can more preserve the antioxidant capacity and ascorbic acid of concentrated samples. According to the results, the use of OHVC under high vacuum is not recommended because it is associated with increasing processing time, corrosion of electrodes, and energy consumption and decreasing the total phenol content. Consequently, it is recommended to use an ohmic heating system at atmospheric

pressure or a combination of ohmic heating with low vacuum. Also, it is suggested that the effect of vacuum level on the different aspects of concentration process be optimized in future studies by researchers.

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Conflict of Interest

The authors declare no competing interests.

Ethical statement

This article does not contain any human and animals studies**.**

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Note: This article has been used to compare the results obtained in sections of electrical conductivity, energy consumption and thermal efficiency. It has also been used to complete the introduction and materials of the methods.

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Note: They reported the mechanism of electrode corrosion during Ohmic heating, and effect of electrode corrosion on pH change of sample. According to section3, we cited of this paper for presented of corrosion details.

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Table 1 Average values of processing time, energy consumption, energy efficiency and corrosion rate at different heating conditions

∇V (V/m)	Processing time (s)		Energy consumption (MJ/kg water)		Energy efficiency (%)		Corrosion rate (ppb/s)	
	OHAC	OHVC	OHAC	OHVC	OHAC	OHVC	OHAC	OHVC
15	934 (±5)^{b}	1446(±15)^{a}	3.75(±0.05)^{e}	11.09(±0.10)^{a}	71.83(±0.05)^{c}	22.38(±0.15)^{g}	0.48(±0.05)^{h}	19.27(±1.36)^{e}
20	505 (±3)^{e}	848(±10)^{c}	3.46(±0.04)^{f}	7.11(±0.07)^{b}	77.99(±0.98)^{b}	34.93(±0.32)^{f}	7.20(±0.03)^{gf}	140.95(±29.20)^{c}
25	312 (±15)^{g}	578(±5)^{d}	3.37(±0.08)^{f}	5.37(±0.05)^{c}	80.07(±0.81)^{a}	46.23(±0.27)^{e}	9.15(±2.52)^{f}	189.76(±5.33)^{b}
30	220 (±5)^{h}	380(±11)^{f}	3.41(±0.07)^{f}	4.08(±0.08)^{d}	79.17(±0.44)^{a}	60.87(±1.23)^{d}	61.85(±8.00)^{d}	426.11(±54.70)^{a}

$^{a–h}$ Different superscripts in the same parameter indicate significant differences (P< 0.05)

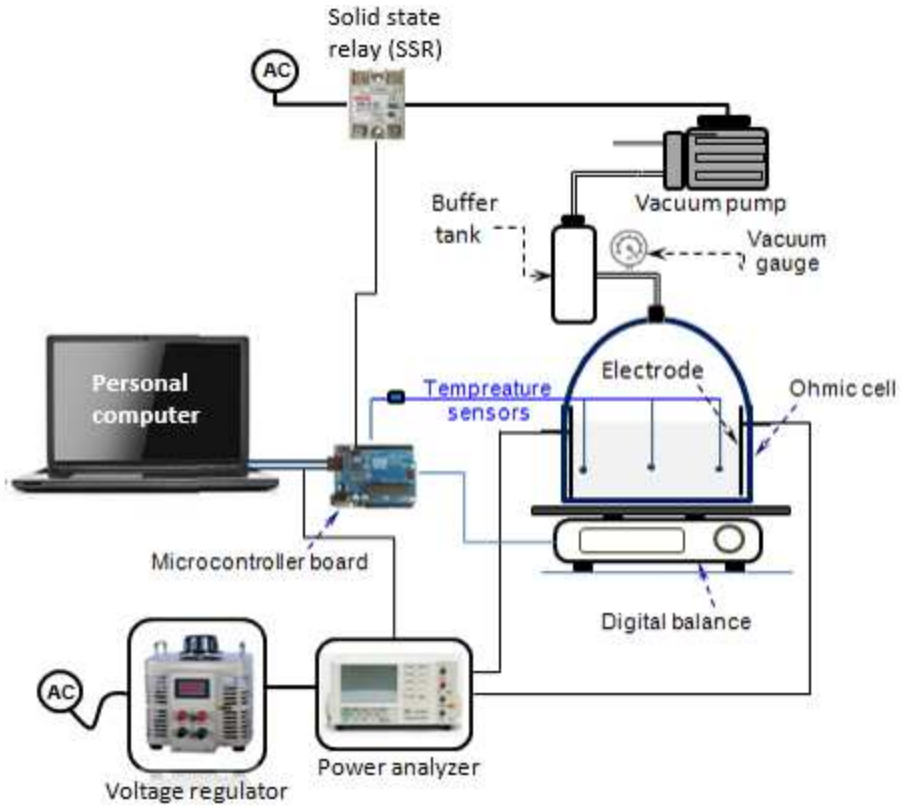

Figure 1 Schematic diagram of the ohmic –vacuum heating system

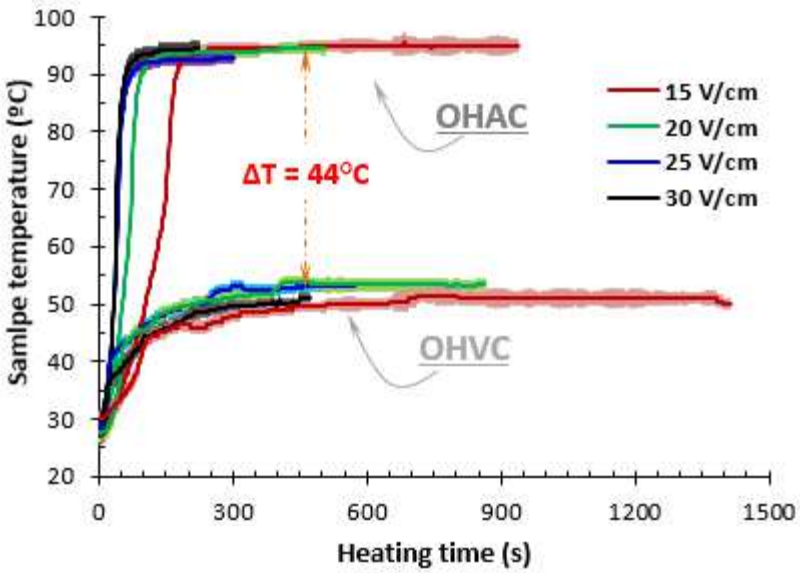

Figure 2 Sample temperatures (± standard deviation) during concentration process as function of heating conditions

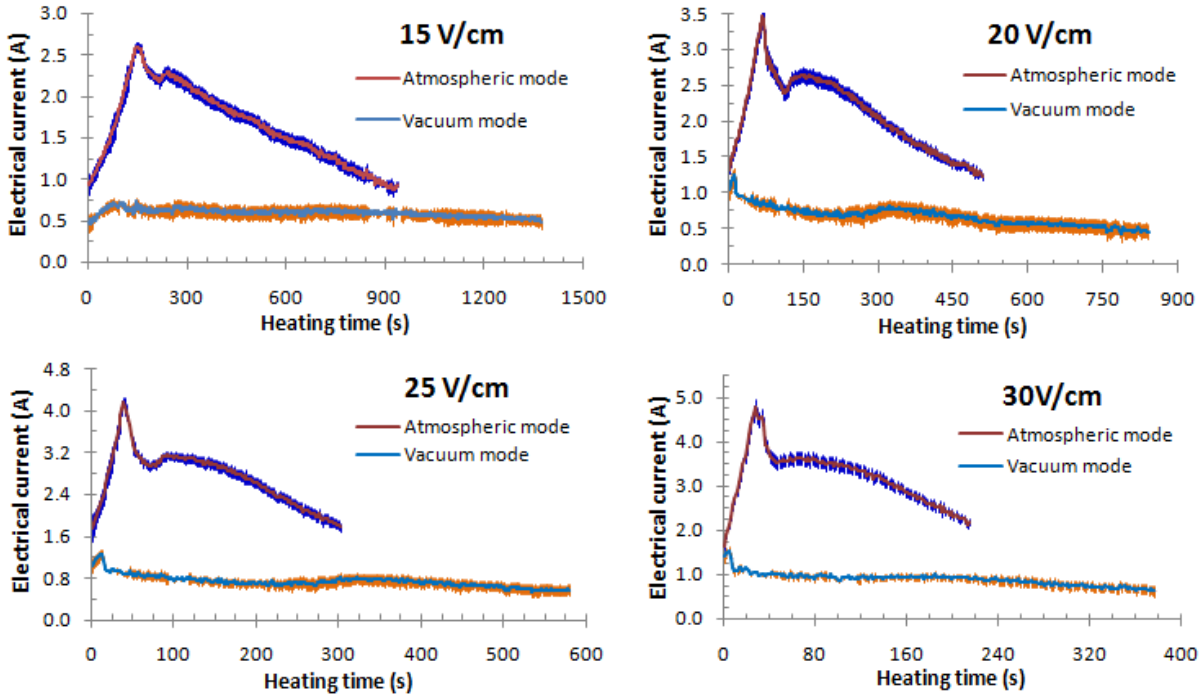

Figure 3 Variations of electrical current (± standard deviation) through the sample at different heating conditions

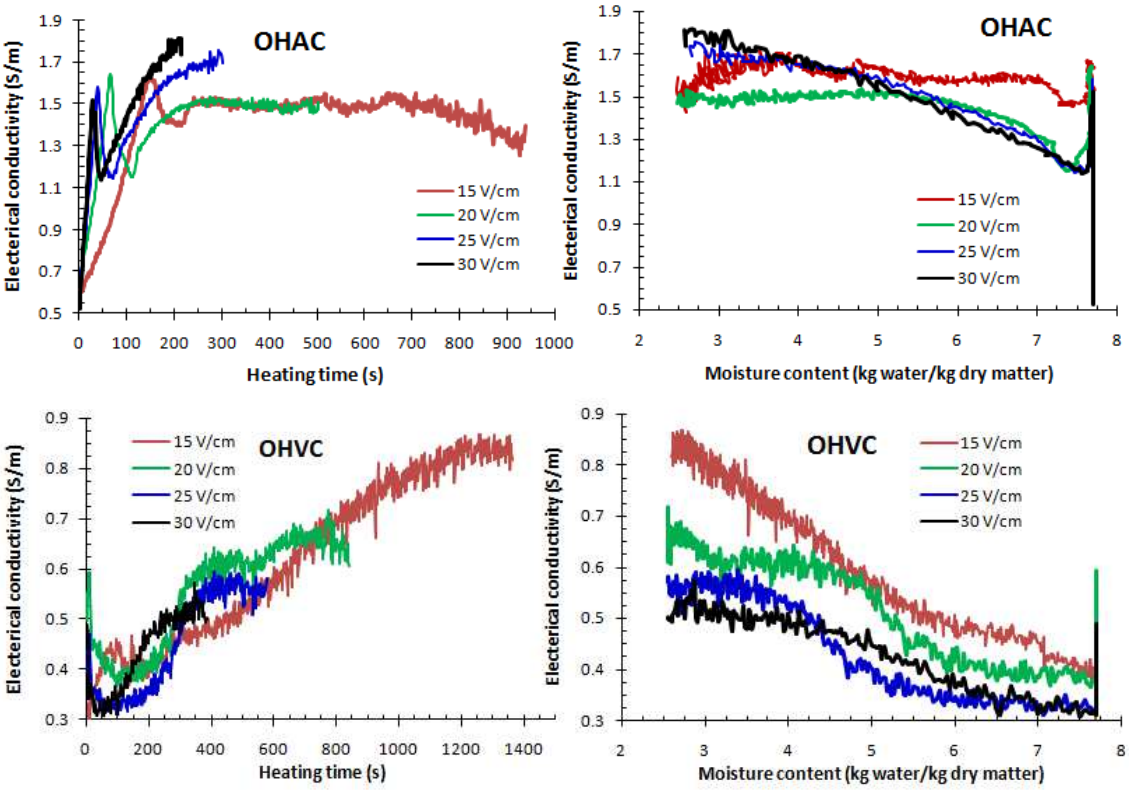

Figure 4 Variations of electrical conductivity at different heating conditions

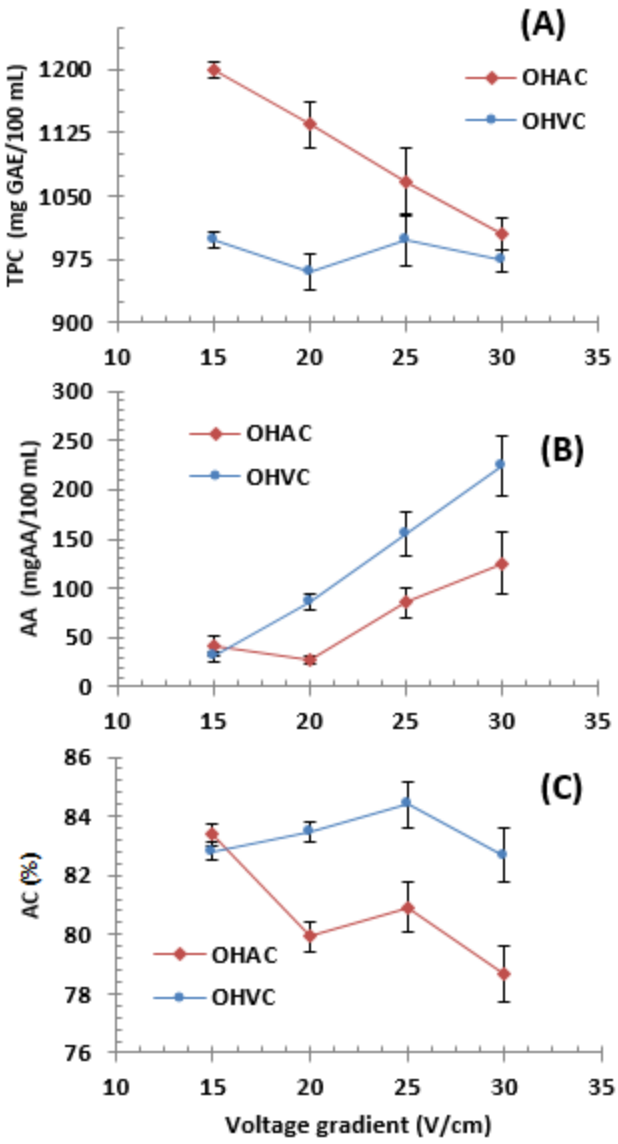

Figure 5 Effect of heating conditions on quality of concentrated kiwifruit juice (Since 54% water content of fresh sample was evaporated, the values of AA, AC, and TPC of concentrated sample should be multiplied at 0.54 by readers to comparison results at the same moisture content between fresh and concentrated samples). The quality parameters of fresh sample are AC = 86.24 ± 0.80 (%); TPC = 1200 ± 37.2 (mg GAE/100 mL); AA = 370.93 ± 23.56(mg AA/100 mL).