

Effect of Ohmic Heating on the Rheological Characteristics and Electrical Conductivity of Mulberry (*Morus nigra*) Puree

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The effect of temperatures (30–90°C) and concentrations (50% and 100%) on rheological parameters of mulberry puree processed with ohmic heating (OH) were evaluated. The electrical conductivities of mulberry puree ranged from 0.022 to 0.102 S/m for 50% puree and 0.052 to 0.185 S/m for 100% puree. The best model for rheological parameters of mulberry puree was the power law model ($R^2 > 0.90$). The effects of OH treatment and temperature of puree on the flow behavior index (n) were insignificant ($p \geq 0.05$). However, a significant difference ($p < 0.05$) between consistency coefficient (K) of OH-treated and control sample was observed in 100% puree. The pseudo activation energy (E_a) of ohmic-treated puree was 9.67 kJ/mol for 50% puree and 3.69 kJ/mol for 100% puree, both of these values were significantly lower than that of the unprocessed 100% puree (16.07 kJ/mol). The obtained E_a indicates that after undergoing ohmic heating pretreatment, consistency coefficient of mulberry puree became less sensitive to temperature.

INTRODUCTION

Mulberry (*Morus nigra*) is a fruit-bearing plant that can grow in a wide range of climates, geographical, and soil conditions which allows widespread cultivation of this plant [Rodrigues *et al.*, 2019]. Mulberry fruit is an exotic fruit characterized by a dark-purplish color with a diameter of 10–12 mm. This fruit is known for its sweet and acidic flavor and has been used as an ingredient in folk medicines [Polat & Satil, 2012; Rodrigues *et al.*, 2019]. In addition, mulberry fruit is rich in bioactive compounds such as anthocyanins and phenolic acids, as well as nutrients such as fatty acids, amino acids, and vitamins [Jiang & Nie, 2015]. Increasing customers' demand for functional food and beverages, and the versatility of mulberry plant makes the mulberry fruit a good raw material for the production of the fruit-based functional foods and beverages.

Diversification of fruit-based products has led to the increase in the utilization of fruit puree both for direct consumption and for the manufacture of semi-finished products. For direct consumption, fruit purees are mostly valued for their pleasant sensory and health-promoting properties provided by bioactive compounds which are naturally present in the fruits. These compounds are well known for their antioxidant activity [Marangoni Júnior *et al.*, 2020; Mohammadi-Moghaddam *et al.*, 2020]. Processing fruits into purees is intended to prolong the usability and availability of fruits

beyond their producing regions and harvest season. Fruit purees can be re-processed into various products such as juices, smoothies, baby foods, rehydrated drinks, and sports drinks [Bakke *et al.*, 2020; Tirloni *et al.*, 2020]. One of the important properties that need to be considered in the processing of fruit purees and their end products is rheological properties. Many authors [Bozkurt & Icier, 2009; de Castilhos *et al.*, 2018; Deshmukh *et al.*, 2015] have indicated that rheological properties can be used as a basis for operating design, processing optimization, and quality evaluation. Rheological characteristics of fruit puree are affected by temperature, concentration, ripening stage of fruit, product formulation, and processing method [Gomathy *et al.*, 2015; Lemus-Mondaca *et al.*, 2016]. The use of heat treatment combined with the continual stirring and pumping may result in undesirable effects on the product such as structural breakdown, which in turn can affect sensory quality and consistency coefficient of the product [Gomathy *et al.*, 2015].

Processing fruit purees and their derivative products involves pasteurization or sterilization process which can be conducted by conventional thermal processing, non-thermal processing such as high hydrostatic pressure (HHP), and novel thermal processing such as ohmic heating. The non-thermal and novel thermal processing, such as ohmic and microwave heating, have been rigorously evaluated for processing various types of products and these technologies have been reported to provide comparable or better nutrient and sensory

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profiles compared to the conventional heating [Darvishi *et al.*, 2020; Mannozi *et al.*, 2019; Rinaldi *et al.*, 2020].

Ohmic heating technology is considered as a novel thermal processing for inactivation of microbial contaminants in food products. With this technology, the heat is generated internally due to the passage of electric current through the processed product, which in turn brings about the movement of ions contained in the product. The passage of electric current generates heat due to the electrical resistance of the product. Therefore, the effectiveness of this technology is greatly dependent on the electrical conductivity of the product. Electrical conductivity is affected by product composition and characteristics, such as pH and acidity, salt and sugar content, and solid content [Castro *et al.*, 2003; Icier & Ilicali, 2005; Poojitha & Athmaselvi, 2018; Varghese *et al.*, 2014]. Ohmic heating is generally considered as a fast and uniform heating process. This phenomenon has been reported by numerous researchers [Fadavi *et al.*, 2018; Salengke & Sastry, 2007; Sarkis *et al.*, 2013]. The effectiveness of ohmic heating in inactivation of microorganism has also been reported [Hashemi & Roohi, 2019; Hashemi *et al.*, 2019; Park & Kang, 2013]. Therefore, it is important to evaluate the electrical conductivity of individual products under ohmic heating prior to implementing it to the real processing steps in order to achieve the desirable heating effects.

The implementation of ohmic heating in various processes has been reported in numerous studies. These processes include pasteurization and sterilization [Cappato *et al.*, 2018; Hardinasinta *et al.*, 2021], evaporation [Sabanci & Icier, 2020], blanching and pre-treatment [Mannozi *et al.*, 2019], extraction [Hasizah *et al.*, 2018], thawing [Fattahi & Zamindar, 2020], and fermentation [Salengke *et al.*, 2019]. Studies evaluating the application of ohmic heating for food processing mainly focused on the change in electrical conductivity, bioactive compound profile, antioxidant activity, color, and enzymatic inactivation in correlation to the product composition. Currently, there is limited information that can be found regarding the effect of ohmic heating on rheological characteristics of fruit-based products. Only papaya pulp [Gomathy *et al.*, 2015], quince nectar [Bozkurt & Icier, 2009], sour cherry juice concentrate [Sabanci & Icier, 2020], and peach cubes in syrup [Rinaldi *et al.*, 2020] have been studied in this respect. To the best of the author's knowledge, no studies were found regarding the effect of ohmic pretreatment on rheological characteristics of mulberry puree. Therefore, it is important to determine the influence of ohmic pretreatment on rheological characteristics of mulberry puree. This study is an important step in the early-stage development of ohmic heating for processing mulberry fruit product.

This study was aimed at determining the effect of ohmic heating and puree concentration on rheological characteristics and electrical conductivity of mulberry puree.

MATERIALS AND METHOD

Sample preparation

Mulberry puree was processed from frozen mulberry fruit purchased from a local market. Prior to processing, 10 kg

TABLE 1. Characteristics of mulberry puree at different concentrations.

Puree concentration	Total soluble solid (°Bx)	Moisture content (g/100 g)	pH
50%	3.17±0.06 ^b	95±0.103 ^a	3.55±0.01 ^a
100%	6.73±0.06 ^a	88±0.454 ^b	3.50±0.13 ^a

Data are expressed in mean ± standard deviation of 2 replicates. ^{a-b}Different letters indicate a significant difference between samples ($p < 0.05$).

of mulberry fruits were thawed with running water and then washed to remove foreign materials. The fruits were then separated based on maturity level and ripe fruits displaying a dark-purplish color were selected. Two concentrations (50% and 100% puree) of mulberry puree were used in this experiment. The 100% puree was made by crushing the whole fruit using a commercial blender without the addition of water. The obtained puree was collected in a bucket and blended again to obtain homogenous consistency. The 50% puree was processed by mixing the 100% puree and distilled water with the ratio of 1:1 (w/w). Samples were stored in 500 mL polytetrafluoroethylene (PTFE) bottles and kept in a freezer at -18°C until used. The characteristics of the material used in the experiment, such as pH, total soluble solid, and moisture content, are listed in Table 1.

Ohmic heating treatment

The ohmic heating system used in this experiment consisted of a static ohmic heating chamber, a power supply equipped with a temperature control and a data acquisition system. The heating chamber was made from PTFE with internal diameter of 4 cm, outer diameter of 8.89 cm, and length of 16 cm. The maximum volume of the heating chamber was 150 mL. The ohmic heating chamber was fitted with two stainless steel electrodes (custom-made of SS304 rod) at both ends of the chamber. The temperature of the sample during heating was measured using a thermocouple which was installed at the center of the chamber. The applied voltage, electric current, and temperature were recorded every 2 s using a data acquisition system. The schematic diagram of ohmic heating system is illustrated in Figure 1.

Ohmic heating treatment was carried out at 110°C with a 30 s holding time. This temperature is in the range of the sterilization temperature generally used for fruit juices [Petruzzi *et al.*, 2017; Renard & Maingonnat, 2012]. The average voltage gradient applied to the product was 18.5 V/cm.

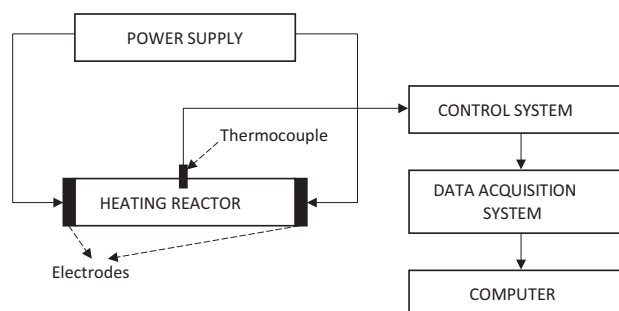


FIGURE 1. Schematic diagram of ohmic heating system.

Rheological measurement

The rheological behavior of ohmic-heated puree and unprocessed puree (control) at the concentration of 50 and 100% was measured using a concentric cylinder type viscometer (LV DV-I Prime, Brookfield Engineering, Middleborough, MA, USA). The viscometer was operated using rotational speed of 0–100 rpm and 10–100% torque using a specific spindle from the low viscosity (LV) and regular viscosity (RV) spindle set. The viscosity (cP) and % torque (T) values were collected at each rotational speed. The experiment was conducted at four temperatures of 30, 50, 70, and 90°C and each experiment was repeated in duplicate.

The torque and rotational speed obtained from the measurement were converted into shear stress and shear rate value using two different methods depending on the type of spindle used during measurement. Mitschka method [Mitschka, 1982] was used for the RV spindle set which was a disk-type spindle, while the method described in the Brookfield AM-ETEK guidelines was used for the LV cylindrical-type spindle [Brookfield, 2017].

In order to determine the rheological parameters of mulberry puree, several rheological models were applied. The rheological models were power law (Equation 1), and Herschel-Bulkley (Equation 2) [Bozkurt & Icier, 2009].

$$\sigma = K\dot{\gamma}^n \quad (1)$$

$$\sigma = \sigma_0 + K\dot{\gamma}^n \quad (2)$$

where: σ is shear stress (Pa), $\dot{\gamma}$ is shear rate (1/s), K is consistency coefficient ($\text{Pa} \times \text{s}^n$), n is flow behavior index, and σ_0 is yield stress (Pa).

The effect of temperature on the viscosity of mulberry puree was determined using the consistency coefficient value with the pseudo Arrhenius equation below [Kobus *et al.*, 2019]:

$$K = K_0 \exp \frac{E_a}{RT} \quad (3)$$

where: K_0 is consistency coefficient, E_a is pseudo activation energy, R is universal gas constant (0.008314 kJ/mol \times K), and T is absolute temperature.

Statistical analysis

Statistical analysis was conducted to determine the best-fitted rheological model for mulberry puree. The residual standard error (RSE) and coefficient of determination (R^2) were calculated by using a linear regression model. The model that provided the best fit was determined based on statistical criteria such as highest R^2 and lowest RSE. The effect of temperature and concentration treatment on the rheological parameters of mulberry puree were analyzed using one-way ANOVA followed by the Tukey contrast multiple comparison test with a 95% confidence level. A paired t-test was also conducted to analyze the effect of ohmic heating on the rheological parameters. All statistical analyses were conducted by using RStudio software (RStudio, PBC, Boston, MA, USA).

RESULTS AND DISCUSSIONS

The electrical conductivity of mulberry puree

The heating characteristics of mulberry puree at different concentrations are shown in Figure 2. A linear increase in electrical conductivity was observed following the temperature elevation during ohmic heating. The result obtained in this study was consistent with the previous studies which demonstrated that electrical conductivity of tomato concentrate increased linearly with the heating temperature as a result of reduced drag force of ionic compounds inside the product [Fadavi & Salari, 2019]. Electrical conductivity is affected by the ionic compounds of the product. Applying electric current on a product initiates the movement of the ionic compounds inside it towards the opposite direction of its charge and increases its temperature. The temperature elevation decreases the viscosity of the aqueous phase and consequently reduces the drag force of the ions and increases the product's electrical conductivity [Srivastav & Roy, 2014].

The electrical conductivities of mulberry puree at 30–110°C were in the range of 0.022–0.102 S/m for 50% puree and 0.052–0.185 S/m for 100% puree (Figure 2). Statistical analysis conducted for electrical conductivity of 50% and 100% puree at 30, 50, 70, 90, and 110°C indicated that at these treatment conditions the electrical conductivities were significantly ($p < 0.05$) different (Table 2). Mulberry puree at the concentration of 100% exhibited higher electrical conductivity compared to that of 50% puree. Moreover, the electrical conductivity of mulberry puree found in this study was lower than the electrical conductivity of mulberry juice treated by ohmic heating (0.1–0.4 S/m) [Darvishi *et al.*, 2020]. In a study reported by Icier & Ilicali [2005], the electrical conductivity of orange juice concentrates decreased as the solid concentration increased. Since the mass fraction of pure juice was lower than that of puree, higher electrical conductivity value was expected in the pure juice product. Meanwhile, the difference in electrical conductivity between 100% and 50% purees (Figure 2, Table 2) could be due to the decreasing content of ions per volume of the product. Fruits have been reported to contain anions and cations, *i.e.* F^- , NO_3^- , NO_2^- , Br^- and PO_4^{3-} ; as well as NH_4^+ , Ca^+ , and Mg^+ , respectively [Hajar *et al.*, 2010]. These ions provided a specific level of electrical conductivity of the fruit juices, depending on

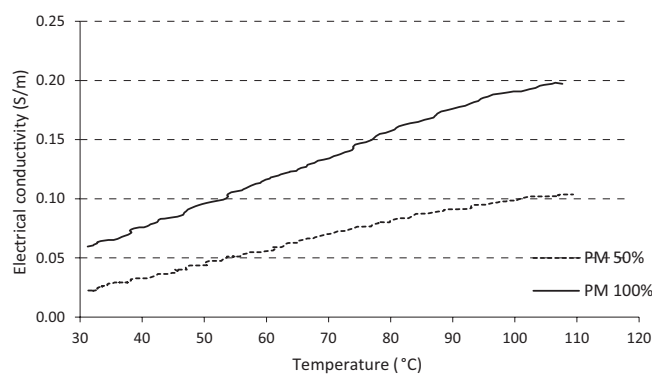


FIGURE 2. The electrical conductivity of mulberry puree (MP) during ohmic heating.

TABLE 2. Electrical conductivity (S/m) of mulberry puree at different concentrations and temperatures.

Puree concentration	Temperature				
	30°C	50°C	70°C	90°C	110°C
50%	0.022±0.000 ^e	0.042±0.003 ^g	0.068±0.004 ^{def}	0.089±0.003 ^{ce}	0.102±0.002 ^{cd}
100%	0.052±0.008 ^{eg}	0.087±0.015 ^{ec}	0.125±0.014 ^{bc}	0.163±0.018 ^{ab}	0.185±0.013 ^a

Data are expressed as mean ± standard deviation of 2 replicates. ^{a-g}Different letters indicate a significant difference between samples (p<0.05).

the types of ions and their concentration [Almeida & Huber, 1999; Hajar *et al.*, 2010]. In our study, dilution of puree during the sample preparation step decreased the ion concentration and simultaneously decreased the electrical conductivity of 50% puree. Another effect of the dilution was the decrease in the total soluble solid content (Table 1).

Rheological behavior of mulberry puree

Generally, both power law and Herschel-Bulkley models displayed a satisfactory R² value of over 0.95 for all treatment conditions. However, the power law model showed lower RSE values (RSE<0.038) compared to the Herschel-Bulkley model (RSE<0.267), which implies that statistically, this model is more applicable for mulberry puree at all conditions. In the Herschel-Bulkley model, the yield stress value significantly affected the model accuracy and applicability. Several studies have neglected the yield stress value measured during experiment if the value is considered to be low or statistically not different with 0 [Lemus-Mondaca *et al.*, 2016; Payne & Reyes-de-Corcuera, 2021]. The rheological study conducted

for murtilla berries (*Ugni molinae* Turcz) showed that the yield stress ranging from 6.31×10^{-12} to 3.47×10^2 Pa was considered low. Similarly, the yield stress values obtained in this study fell in the same range as that of murtilla berries (1.9 Pa to 9.0×10^1 Pa) and therefore they can be neglected. Therefore, the power law model can be chosen as the best-fitted model for describing the rheological characteristics of mulberry puree. Several studies have reported that the power law model was the best-fitted model for rheological behaviors of cloudy apple juice [Kobus *et al.*, 2019], malbec grape juice concentrates [Evangelista *et al.*, 2020], and orange pulp [Payne & Reyes-de-Corcuera, 2021].

The power law model was fitted by plotting the logarithms of shear stress and shear rate. The slope and y-intercept obtained from the graph described the flow behavior index (n) and consistency coefficient (K) of the puree, respectively. The flow curves (Figure 3 and Figure 4) roughly illustrated that the application of ohmic heating affected the temperature dependence of mulberry puree's rheological characteristic. It can be explained by how the flow curve of control sample at 30°C was lower than those at the other temperature levels, while the flow curve of ohmic-heated sample at

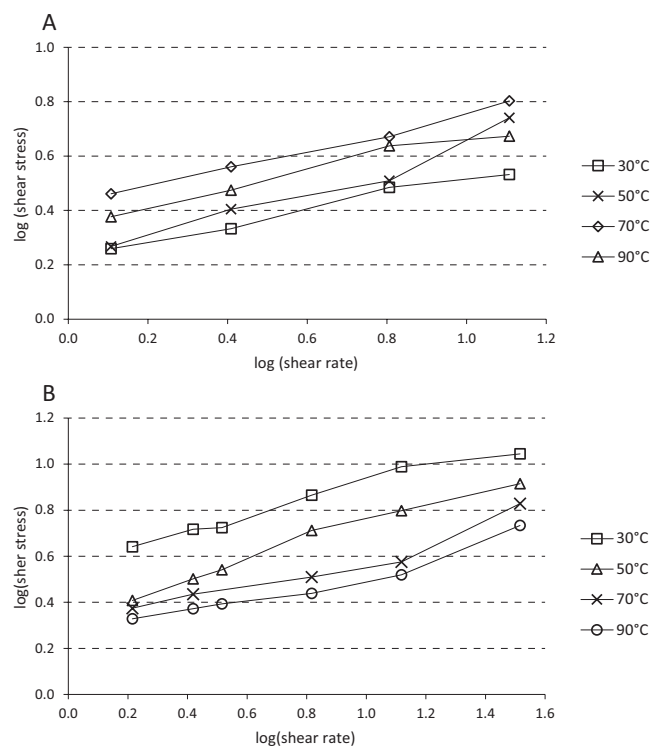


FIGURE 3. Flow curves of 50% mulberry puree; (A) control and (B) ohmic heating.

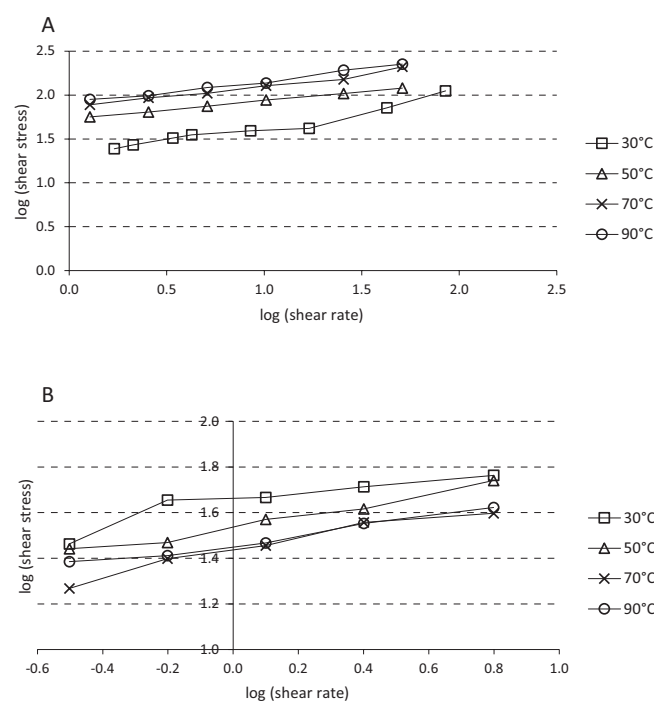


FIGURE 4. Flow curves of 100% mulberry puree; (A) control and (B) ohmic heating.

TABLE 3. Rheological parameters of ohmic-heated and unprocessed (control) mulberry puree.

Puree concentration	Temperature (°C)	Control		Ohmic heating	
		Flow behavior index, n	Consistency coefficient, K (Pa×s ⁿ)	Flow behavior index, n	Consistency coefficient, K (Pa×s ⁿ)
50%	30	0.24±0.07 ^a	2.14±0.63 ^a	0.37±0.10 ^a	3.01±1.52 ^a
	50	0.27±0.24 ^a	2.98±1.91 ^a	0.33±0.01 ^a	2.36±0.21 ^a
	70	0.25±0.09 ^a	2.99±0.19 ^a	0.30±0.00 ^a	1.75±0.01 ^a
	90	0.22±0.13 ^a	3.04±1.11 ^a	0.25±0.02 ^a	1.65±0.31 ^a
100%	30	0.25±0.14 ^a	44.53±34.71 ^a	0.20±0.00 ^a	42.48±0.01 ^a
	50	0.13±0.09 ^a	107.36±73.54 ^a	0.17±0.09 ^a	39.35±6.97 ^a
	70	0.16±0.12 ^a	122.95±71.49 ^a	0.13±0.00 ^a	35.24±0.01 ^a
	90	0.14±0.12 ^a	133.32±65.45 ^a	0.17±0.05 ^a	33.71±5.50 ^a

Data are expressed as mean ± standard deviation of 2 replicates. ^aThe same letter in the same group indicates an insignificant difference between samples ($p \geq 0.05$).

30°C was higher. However, ohmic heating did not cause any change in the flow behavior of mulberry puree since both control and ohmic-treated products followed the same rheological model. Studies on various processing methods for fruit juice and puree, such as ultrasound [Rojas *et al.*, 2016], vacuum evaporation [Sabanci & Icier, 2020], and high hydrostatic pressure [Lemus-Mondaca *et al.*, 2016], have reported that processing methods did not cause an overall change in the flow behavior. However, distinct changes were observed in the rheological characteristics, such as consistency coefficient, flow behavior index, and yield stress.

The effect of processing conditions and temperature on rheological characteristics of mulberry puree

The flow behavior index (n) and consistency coefficient (K) at different temperatures and concentrations of mulberry puree were listed in Table 3. Based on the flow behavior index obtained, $0 < n < 1$, the mulberry puree was classified as a non-Newtonian pseudoplastic fluid. The pseudoplastic fluid is distinguished by the decreasing value of apparent viscosity following the increase in shear stress. Fruit juice and puree, in general, are heterogeneous solutions containing a significant amount of solid particles that are dispersed in the liquid phase rich in soluble compounds. Therefore, when subjected to shear stress, it creates a momentum transfer among particles which affects the apparent viscosity of the product. The apparent viscosity of mulberry puree decreased following the increase of shear stress. The viscosity reduction is a result of structural damage of the molecular chain by hydrodynamic forces, causing the molecular constituent alignment parallel to the current lines and reducing the flow resistance of a fluid [Evangelista *et al.*, 2020; Ribeiro *et al.*, 2018].

The effect of temperature and ohmic heating treatment on flow behavior index was statistically not significant ($p \geq 0.05$) (Table 3 and Table 4), indicating that the pseudoplastic behavior was independent of temperature and the non-thermal effect of electricity can be neglected particularly at the voltage gradient of 18.5 V/cm. Nevertheless, there was a decreasing tendency of flow behavior index as the temperature increased

with the most noticeable effect in the fresh puree. The independence of flow behavior index on temperature was also shown for guava juice concentrates [Abdullah *et al.*, 2018], grape juice [de Castilhos *et al.*, 2018], and cloudy apple juice [Kobus *et al.*, 2019]. Findings from studies reporting the effect of ohmic heating on rheological behaviors of fruit products varied. Bozkurt & Icier [2009] reported that no significant difference in flow behavior index value was observed between ohmic and conventional heating of quince nectar. In addition, evaluation of ohmic heating for sweet whey processing under different electric fields showed that the flow behavior index was similar for all treatments applied [Costa *et al.*, 2018]. However, ohmic heating of papaya pulp did result in a higher flow behavior index compared to the fresh papaya pulp [Gomathy *et al.*, 2015].

The consistency coefficients (K) of mulberry puree at different temperatures and concentrations are shown in Table 3. One-way ANOVA results indicated an insignificant effect of temperature treatment on K-value [$F(3, 4) = 1.587$, $p = 0.325$] (Table 3). Nevertheless, reverse tendencies for this relationship were noticeable between control and ohmic-heated sample. With the control samples, an increase in consistency coefficient was observed as temperature was increased. On the other hand, the K-value of puree undergoing ohmic heating decreased as the temperature increased, implying that the product becomes less viscous at higher temperature. Most studies reported that temperature

TABLE 4. The pseudo activation energy (E_a) of ohmic-heated and unprocessed (control) mulberry puree at different concentrations.

Puree concentration	Parameter	Control	Ohmic heating
50%	E_a (kJ/mol)	5.03	9.67
	R^2	0.70	0.96
100%	E_a (kJ/mol)	16.07	3.69
	R^2	0.80	0.98

R^2 – coefficient of determination.

elevation significantly decreased the consistency coefficient and the overall viscosity of fruit juice and puree [de Castilhos *et al.*, 2018; Deshmukh *et al.*, 2015; Evangelista *et al.*, 2020; Kobus *et al.*, 2019; Ribeiro *et al.*, 2018]. Temperature elevation in fluid enhances the thermal energy of molecules, which results in a higher degree of molecular agitation and reduction of the intermolecular force, hence decreasing the fluid viscosity [Abdullah *et al.*, 2018; Deshmukh *et al.*, 2015; Evangelista *et al.*, 2020; Kobus *et al.*, 2019]. The tendency of increasing K-value which was observed in the control sample (Table 3) can be explained by the larger amount of insoluble solid and particle size found in unprocessed puree which tends to form clumps. A study conducted by Lukhmana *et al.* [2018] described that cherry puree consisted of smaller micronized particles exhibiting a lower viscosity compared to the puree sample which did not undergo any micronization. This study further explained that the non-uniformity of cell cluster surface led to the agglomeration of cells into larger clusters and therefore increased the viscosity of puree. The heat applied during ohmic processing could lead to the membrane destruction inside the cells and cause structural changes of the sample [Castro *et al.*, 2004; Hardinasinta *et al.*, 2021].

The structural changes that happened during heating are the main reason for the different trend shown by the K-value of the control sample and the ohmic-treated sample (Table 3). As the temperature increased, the mulberry puree processed with ohmic heating exhibited a lower consistency coefficient compared to the fresh puree. Similarly, in comparison to the fresh pulp, a lower consistency coefficient was obtained in ohmic-heated papaya pulp as the result of heat treatment [Gomathy *et al.*, 2015]. Several studies have been conducted to compare the effect of ohmic heating and conventional processing method on the consistency coefficient and the results varied depending on the applied treatment. There was no significant difference between the processing methods used in quince nectar [Bozkurt & Icier, 2009] and sour cherry juice concentrate [Sabanci & Icier, 2020]. However, the application of ohmic heating in processing a syrup containing peach cubes resulted in a lower consistency coefficient compared to the conventional heating. It was reported that the significant decrease in viscosity was caused by the degradation of β -eliminative and rapid hydrolysis of water-soluble pectin at low pH [Rinaldi *et al.*, 2020].

In addition, the non-thermal effect of ohmic heating has also been evaluated for sweet whey processing. Costa *et al.* [2018] reported that a significant difference of K-value was obtained in sweet whey samples processed at the highest voltage gradient (9 V/cm) and no significant difference with the conventional heating was observed when ohmic heating was done at lower voltage gradients (2–7 V/cm). Other alternative processing methods, such as pulsed electric field (PEF) and HHP, also evoked inconsistent effects on the product viscosity and consistency coefficient. For instance, the HHP processing assisted with ohmic pre-treatment did not affect the viscosity of the product significantly [Rinaldi *et al.*, 2020]. However, another study conducted with murtilla berries reported that a notable increase of consistency coefficient was obtained after HHP treatment at 500 MPa due to increasing pectin particles interaction [Lemus-Mondaca *et al.*, 2016]. Meanwhile, PEF treatment of almond milk decreased its consistency index at 7–21 kV/cm, but increased it at the highest voltage gradient of 28 kV/cm [Manzoor *et al.*, 2019].

The high pseudo activation energy (E_a) was found for K in the control sample at 100% concentration (Table 4). Higher E_a indicates higher sensitivity of the K-value towards temperature [Bozkurt & Icier, 2009; Evangelista *et al.*, 2020; Kobus *et al.*, 2019]. The significant difference between E_a of the control samples at 50% and 100% (Table 4) implies that at higher concentration, the K-value of unprocessed mulberry puree exhibited higher sensitivity over temperature. It can be explained by the combination effect provided by the temperature and concentration treatment which enhance the effect of temperature at higher concentration. Paired t-test also showed that the difference between rheological parameters (n and K value) of the control and ohmic-heated sample was significant only for the K-value of 100% puree (Table 5).

An opposite trend was observed for the ohmic-heated sample, where the E_a decreased as the concentration increased (Table 4), indicating that the influence of temperature in the viscosity reduction of mulberry puree is highly noticeable at lower solid concentrations. A similar declining trend of E_a vs. concentration was obtained in merlot and malbec grape juice [de Castilhos *et al.*, 2018; Evangelista *et al.*, 2020], while other studies reported a positive correlation between E_a and concentration [Bozdogan *et al.*, 2020; Deshmukh *et al.*, 2015]. Comparable E_a values were reported in sapotapa

TABLE 5. Paired t-test result for the effect of ohmic heating on rheological parameters of mulberry puree.

	Puree concentration	Mean \pm SD		n	95% confidence interval for mean difference		t	df
		Control	Ohmic heating					
(Pa \times s ⁿ)								
Consistency coefficient (K)	50%	2.78 \pm 0.95	2.19 \pm 0.83	8	-0.08	0.27	1.27	7
	100%	102.03 \pm 60.37	37.83 \pm 4.96	8	0.07	0.62	2.94*	7
(-)								
Flow behavior index (n)	50%	0.24 \pm 0.11	0.31 \pm 0.06	8	-0.16	0.03	-1.58	7
	100%	0.17 \pm 0.10	0.16 \pm 0.04	8	-0.06	0.07	0.14	7

SD – standard deviation, n – total number of data, t – t-test statistic value, df – degree of freedom; *p < 0.05.

juice at 10.2–38.9°Bx [Deshmukh *et al.*, 2015] and gongura leave puree [Meher *et al.*, 2019], except for the ohmic-treated puree at 100% concentration which had a significantly higher E_a value. For this specific condition, a similar E_a value was acquired from sumac extract at 45.65% total solids [Bozdogan *et al.*, 2020], sapotapa juice at 49.4°Bx [Deshmukh *et al.*, 2015], and merlot juice at 45°Bx [de Castilhos *et al.*, 2018].

CONCLUSIONS

The electrical conductivity of mulberry puree increased with temperature and concentration. The higher electrical conductivity obtained at a lower concentration was the result of dilution process during samples' preparation, which lowered the content of ionic compounds in the sample. Mulberry puree can be categorized as a pseudoplastic fluid with a shear-thinning behavior and its rheological properties can be modeled using the power law model. Flow behavior index displayed an independent tendency towards temperature and processing method, implying that both thermal and non-thermal effect was insignificant for the pseudoplastic behavior of mulberry puree. Coefficient of consistency, on the other hand, exhibited a correlation with the processing method, where opposite trends were observed between the K-value of ohmic-heated and control samples. The obtained E_a further explains that the effect of temperature was more visible for the unprocessed mulberry puree and that ohmic heating process could be used to maintain the consistency of mulberry puree especially at high concentration.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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