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Effect of different microwave power levels on inactivation of PPO and PME and also on quality changes of peach puree

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ABSTRACT

The effect of microwave (MW) treatment with different power densities (4.4, 7.7, and 11.0 W/g) on polyphenol oxidase (PPO) and pectin methyl esterase (PME) inactivation in peach puree were studied, and the changes in color, rheological properties, total polyphenol and flavonoid and antioxidant capacity were evaluated. By using time/temperature data collected during MW heating, three cook values levels (0.36, 10, 24 min) for each power density were calculated. The PPO was significantly decreased from ca. 50% to ca. 5% when increasing the cook value level, regardless of power density applied. While PME significantly decreased from 40.6% to 10.2% when power density increased from 4.4 to 11.0 W/g at cook value 24 min. MW treatment did not alter the flow behaviour of peach puree. The apparent viscosity values of peach puree significantly increased after MW treatment with increasing cook value, regardless of power density applied. The L* values of peach puree significantly increased from 36.98 to 38.10 or more after MW treatment at cook value 10 min and 24 min. MW treatment could maintain the amount of total polyphenol, total flavonoid and antioxidant capacity, preserving the nutritional and functional values of the product.

1. Introduction

Peaches are rich in polyphenols like chlorogenic acid, neochlorogenic acid, flavan-3-ols and flavanols, which have proven protective effect against cardiovascular disease, and reduction of digestion tract cancer risk (Canalis et al., 2020). Peach puree is a convenient food product, and could be used for baby food, mixed drinks, and a spread on bread and so on. However, shelf-life of unprocessed peach puree is limited due to activities of polyphenol oxidase (PPO), responsible for enzymatic browning and can cause reduction in nutritional quality, and pectin methyl esterase (PME), affecting the rheological properties such as viscosity and texture (Arjmandi et al., 2017; Zhou et al., 2016). Traditional fruit puree processing involves high temperature (>80 °C) processing and affects the color and nutritional quality of material adversely (Garza et al., 1999). Peach puree became darker with the increase of heating temperature from 110 to 135 °C, and the L* and b* values were decreased along with increasing heating time (Ávila and Silva, 1999). In addition, the content of polyphenol in processed peach puree significantly decreased after heating at 100 °C for 5 min, including neochlorogenic acid, chlorogenic acid, catechin and β-carotene (Lavelli et al., 2008).

Microwave treatment (MW) causes rapid increase of the temperature of the product. The MW penetrate into the food and generate heat throughout the whole volume of food, making thermal conductivity and heat transfer coefficients no longer the limit of heat transfer (Qu et al., 2021). MW treatment with pasteurization or sterilization purposes, mainly against inactivation of target microorganisms and enzymes, has been studied in liquid food, such as kiwifruit puree (Benlloch-Tinoco et al., 2015a; 2015b), mamey fruit (Palma-Orozco et al., 2012) and apple puree (Picouet et al., 2009). Volumetric heating during MW processing results in better preservation of organoleptic, nutritional and functional properties (Huang et al., 2007; Benlloch-Tinoco et al., 2015b). Benlloch-Tinoch et al. (2015a) found that MW treatment (2 W/g, 340 s) allowed significantly greater preservation of kiwifruit puree chlorophylls than conventional heating (97 °C, 30 s), which led to 92–100% degradation of these pigments. Based on the sensory attributes evaluated, including appearance, color, odour, taste, sweetness, acidity, consistency and overall acceptance, MW treated kiwifruit puree (2 W/g, 340 s) was preferred. The authors also found that losses of vitamin C, vitamin E, total phenol, total flavonoids and antioxidant activity in kiwifruit puree under MW were all significantly lower than those value of conventional heating (84 °C/300 s), meaning MW treatment resulted

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in a better maintenance of the bioactive compounds. In addition, MW treated sample exhibited smaller color changes, and inactivated total *mesophilic* bacteria, yeast and mould equal to or greater than the conventionally heated sample (Benlloch-Tinoco et al., 2014a). Arjmandi et al. (2017) also found that MW treatment (1900–3150 W/600 mL, 150–180 s) preserved tomato puree's a value better than conventional heating (96 ± 2 °C, 35 s), leading to more retention of antioxidant capacity, vitamin C, and lycopene content. Furthermore, the inactivation of the enzymes responsible for puree quality loss also have been reported in previous studies, and it was found that MW treatment decreased the residual activity of enzymes better than conventional pasteurization. For example, a low residual activity of peroxidase (POD) and PME of 10–20% in tomato puree were detected after MW treatment (1900–3150 W/600 mL, 150–180 s), while polygalacturonase (PG) was more thermo-resistant with a residual activity of 30–56% (Arjmandi et al., 2017). In our previous study we observed that 80% of PPO in defatted avocado puree could be inactivated in 80 s at 11.0 W/g of MW treatment, and the residual activity after treatment remained constant under 20% after 31 days storage (Zhou et al., 2016). PPO in mamey fruit pulp was completely inactivated after long microwave treatment by using a high MW power (3 W/g, 165 s/300 s) (Palma-Orozco, et al., 2012). Pasteurization unit as a measure of the lethal effect of processes was proposed with the aim of to compare conventional heating and MW in Benlloch-Tinoco et al. (2014b) study, and results showed a higher thermal load of 19.27 min was necessary in order to stabilize the kiwifruit puree under conventional heating than MW treatment (0.003–8 min) at any of the conditions studied. The higher effectiveness of MW treatment could be attributed to non-thermal effects associated with the MW treatment.

The purpose of the study was to investigate the inactivation of PPO and PME in peach puree by MW treatment with 3 levels of power densities. Moreover, the effect of MW treatment on the color, rheological property, total polyphenol, total flavonoid and antioxidant capacity of peach puree were evaluated.

2. Materials and methods

2.1. Materials

Peaches (*Prunus persica*) were purchased from a local supermarket in Auckland, New Zealand. They were washed, peeled, deseeded and pureed by using home juicer. The peach puree was stored in bags at −40 °C until used for experiments. Frozen sample was thawed at 4 °C for 12 h prior to experiments.

2.2. Chemicals

Polyvinylpolypyrrolidone (PVPP), catechol, pyrocatechol, gallic acid, Folin-Ciocalteu reagent, pectin, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 1,1-diphenyl-2-picryl-hydrazyl (DPPH), tripyridyl-triazine (TPTZ) and methanol (HPLC) were purchased from Sigma Aldrich, New Zealand. All the other chemicals were obtained from ECP Ltd. (Auckland, New Zealand).

2.3. Microwave treatment

The microwave treatment of the puree was carried out in a modified domestic microwave oven (MicrowaveWork Station-240, FISO Technologies Inc., Canada). 100 g of sample was tempered to an initial temperature of 10 ± 0.5 °C and then was treated in the microwave oven in a 150 mL glass beaker at different power densities (4.4, 7.7, and 11.0 W/g) under was 2450 MHz. The glass beaker was placed in the middle of a turntable plate in the oven. The temperature during treatment was measured using fiber optic probes (FOD-NS-967 A; FISO Technologies Inc., Canada) with an accuracy of ±0.5 °C. The tip of the fiber optic probe was placed at the radial-center of the beaker and was fixed with a plastic holder and the temperature data was collected approximately every 0.5 s by a computer. The treated samples were immediately submerged in ice-water.

2.4. Dielectric properties measurement

Dielectric properties (dielectric constant, ε' and dielectric loss factor, ε'') of peach puree were measured using open-ended coaxial probe (85070 E, Agilent Technologies, Malaysia) connected to a network analyser (E5062A, Agilent Technologies, Malaysia). The dielectric properties of sample under 2450 MHz were measured after samples reached a temperature in the range of 20–90 °C (about 5 °C intervals) in a water bath.

2.5. Cook value

Cook value (CV) is the cumulative heat impact of a complex time/temperature history on a food's quality attributes, which was first used by Mansfield (1962). Using the time/temperature data collected during microwave heating, the CV (min) could be calculated by the following Eq. (1):

$$F_{100} = \mathrm{CV} = \int_0^t 10^{(T-100/z)} dt \tag{1}$$

Where F_{100} is the equivalent thermal treatment time (min) at 100 °C, T is the temperature (°C) at time t (min). The z value, ranging from 25 °C to 47 °C, corresponds to sensory attributes, texture softening, and color changes. A z value of 33 °C is often used to compute a cook value describing the overall quality loss (Wang et al., 2003; Bornhorst et al., 2017). In this study, the treatment time to heat the puree to 100 °C at 4.4, 7.7 and 204 11.0 W/g power densities were chosen as 3 cook value levels for every power density.

2.6. Polyphenol oxidase assay

The extraction of polyphenol oxidase (PPO) from peach puree and analysis of PPO activity were performed according to the method described by Baltacıoğlu and Coruk (2021) with small modifications. Briefly, 3 g of peach puree was homogenized with 10 mL phosphate buffer (0.1 M, pH 6.5, containing 5% poly(vinylpolypyrrolidone) (PVPP)), and the mixture was centrifuged at 5525 g at 4 °C for 15 min (4 K15, Sigma, Germany). The supernatant was collected and the crude extract was kept at 4 °C before analysis. The assay mixture consisted of 3 mL 0.1 M pyrocatechol dissolved in 0.1 M phosphate buffer and 0.5 mL crude extract. The absorbance change at 420 nm at 25 °C was recorded for 1 min using a UV-VIS spectrometer (Lambda 35 UV/VIS, PerkinElmer, USA). An enzyme activity unit was defined as an increase of 0.1 in absorbance at 420 nm per min. The residual activity (RA) was defined as:

$$\text{Residual activity } (\%) = \frac{\text{specific activity after treatment}}{\text{specific activity before treatemnt}} \times 100 \tag{2}$$

2.7. Pectin methylesterase assay

Pectin methylesterase (PME) activity was determined by auto titrator (800 Dosino, Metrohm, Switzerland) using the method previously described by Benlloch-Tinoco et al. (2013) with some modifications. Firstly, peach puree was diluted twice with ultrapure water. Then, the reaction mixture consisting of 5 mL of peach puree solution and 20 mL of 1% apple pectin (70–75% esterification, Fluka) containing 0.1 M NaCl, which was previously adjusted to pH 7 was added with 0.05 M NaOH. PME activity was measured at 25 °C by recording the amount of 0.05 M NaOH required for static titration at pH 7 for 5 min. One unit of PME activity (U/mL) was calculated by:

$$\mathrm{PME(U/mL)} = \frac{V \times N \times 1000}{V_s \times t_r} \quad (3)$$

where V and N are the volume (mL) and normality of NaOH, respectively, V_s is volume of sample (mL) and t_r is the reaction time (min).

2.8. Color measurement

The color of untreated and MW treated sample was measured with a Minolta Chroma meter (Model CR, Minolta, Japan). The equipment was calibrated using a standard white reflector plate. Readings were obtained using the standard CIE L* a* b* color system. All measurements were made in triplicate and results were averaged. The total color difference (ΔE) was calculated using Eq. (4), where L_0*, a_0*, and b_0* were the values for untreated samples.

$$\Delta E = \sqrt{\left(L^* - L_0^*\right)^2 + \left(a^* - a_0^*\right)^2 + \left(b^* - b_0^*\right)^2} \quad (4)$$

2.9. Rheological measurements

Rheological measurements were carried out using a rheometer (AR G2, TA Instruments, UK) as described by Dankar et al. (2018) and Liu et al. (2013) with small modification, and parallel plates (40-mm diameter) with a gap size of 1 mm were used. The temperature was maintained constant at 25 °C by using a Peltier system. The steady-state shear experiments were carried out in the shear rate range of 0.01–100 s^{-1}. After rest, the samples were submitted to shearing at 300 s^{-1} for 5 min to avoid any thixotropy (data not shown). Then, a logarithmic decreasing stepped protocol (100-0.01 s^{-1}) was used in order to guarantee the steady-state condition.

For dynamic rheological studies, to ensure that all measurements were carried out within the linear viscoelastic region, strain sweep tests were first performed (data not shown) in oscillation mode at 25 °C. Then, frequency sweep measurements were carried out at 1.0 Pa, a shear stress value within the linear viscoelastic range. The storage modulus (G') and loss modulus (G") were obtained over the angular frequency range of 1–100 rad/s.

2.10. Total phenolic assay

The extraction of total phenols was carried out according to the method reported by Cantín et al. (2009) with minor modification. Five grams of peach puree were mixed with the extraction solution, consisting of 0.5 N HCl in methanol/mili-Q water (80% v/v). The homogenate was sonicated at 1200 W for 15 min (Sonorex digital 10 P, Bandelin, Germany) and then centrifuged at 5525 g at 4 °C for 15 min. The supernatant was collected and methanol (80% v/v) was added to a final volume of 15 mL. The hydroalcoholic extract was used for total phenolic, total flavonoid and antioxidant capacity assays.

Total phenolic content was determined by the Folin–Ciocalteu assay method using a plate reader (EnSpire 2300, PerkinElmer, USA). Twenty microliters of extract were mixed with 100 μL of Folin-Ciocalteu reagent. After exactly 5 min, 90 μL of 7.5% (w/v) Na_2CO_3 was added. After 1 h reaction in dark, the detection of the mixture was performed at 765 nm. Results of total phenolic content were expressed as μg gallic acid equivalents (GAE) per gram of sample.

2.11. Total flavonoid assay

Total flavonoid content was determined based on the method of Cantín et al. (2009). One hundred microliter of the methanolic extract was added with 15 μL of 5% $NaNO_2$. After 5 min, 15 μL of 10% $AlCl_3$ was added. After 1 min, 100 μL of 1 N NaOH was added. Absorbance at 510 nm was measured against a blank with a plate reader (EnSpire 2300, PerkinElmer, USA). Results of total flavonoid were expressed as μg of catechin equivalents (CE) per gram of sample.

2.12. Antioxidant capacity analysis

2.12.1. DPPH radical scavenging ability assay

The method was performed as described by Wang et al. (2012) and Guan et al. (2016) with small modification. Forty microliters of methanolic extract were mixed with 260 μL DPPH solution, and then the mixed solution was reacted in dark for 45 min. The absorbance was measured at 517 nm with a plate reader (EnSpire 2300, PerkinElmer, USA). The results were expressed as μmol of Trolox equivalent (TE) per gram of peach puree (μmol TE/g).

2.12.2. Ferric reducing antioxidant power (FRAP) assay

The method by Moreno-Montoro et al. (2015) and Guan et al. (2016) was carried out with a plate reader (EnSpire 2300, PerkinElmer, USA). Forty microliters of methanolic extract were mixed with 260 μL TPTZ solution, and then the absorbance was measured at 593 nm after 30 min of reaction at 37 °C. The results were expressed as μmol of Trolox equivalent (TE) per gram of peach puree (μmol TE/g).

2.13. Statistical analysis

One-way analysis of variance (ANOVA) at a significance level of $\alpha = 0.05$ was carried out by Microcal Origin 8.0 (Microcal Software, Inc., USA). Rheological properties were measured in duplicate, and all other experiments were performed in triplicate, and the results were reported as mean ± standard deviation (SD).

3. Results and discussions

3.1. The temperature profile and cook value

Fig. 1 shows the temperature profile of peach puree treated by MW treatment at 4.4, 7.7 and 11.0 W/g power densities. It is seen from Fig. 1a that it took 34 s, 50 s, and 101 s at 4.4, 7.7 and 11.0 W/g power densities, respectively, to heat the puree to 100 °C which shows that the power density considerably increased the heating rate. Fig. 1b shows the changes of dielectric constant (ε') and dielectric and loss factor (ε'') of peach puree at a temperature range of 10–100 °C. The value of ε' showed no significant changes along the temperature range investigated, while the ε'' value decreased with an increase in temperature from 10 °C to 50 °C, and then it did not change after 50 °C. Based on the time-temperature profiles presented in Fig. 1a, cook values 0.36, 10, 24 min for 4.4, 7.7 and 11.0 W/g power densities, respectively, were calculated. The three cook values were denoted as cook value level 1, 2, and 3. Benlloch-Tinoco et al. (2014b) proposed the use of pasteurization units as a measure of the lethal effect to compare the inactivation effect of *L. monocytogenes* and peroxidase (POD) activity in kiwifruit puree, and results showed that conventional heating mode required a significantly higher thermal load of 19.27 min to achieve the pre-set level of POD inactivation than MW treatment (0.046 min, 2 W/g for 200 s). In the study of Bornhorst et al. (2017), microwave-assisted pasteurization system at 95 °C was the best process for mashed potato and green pea, because it had the smallest hot spot cook values (6.5 min for mashed potato, 13.6 min for green pea) and least color change, while the 90 °C hot water was the worst (11.3 min for mashed potato, 18.2 min for green pea). Marszałek et al. (2015) reported that the vitamin C of strawberry decreased by 62% and 4–22% after conventional heating (90 °C for 15 min) and continuous MW treatment (2.0–3.5 L/min, 7–10 s), respectively, and it was possibly due to the much lower pasteurization unit delivered to product by MW treatment (0.15–1.04 min for MW treatment, 162.73 min for conventional heating method).

3.2. The inactivation of PPO activity

As shown in Fig. 2, MW treatment significantly reduced the activity of PPO in peach puree. The residual activity of PPO was significantly

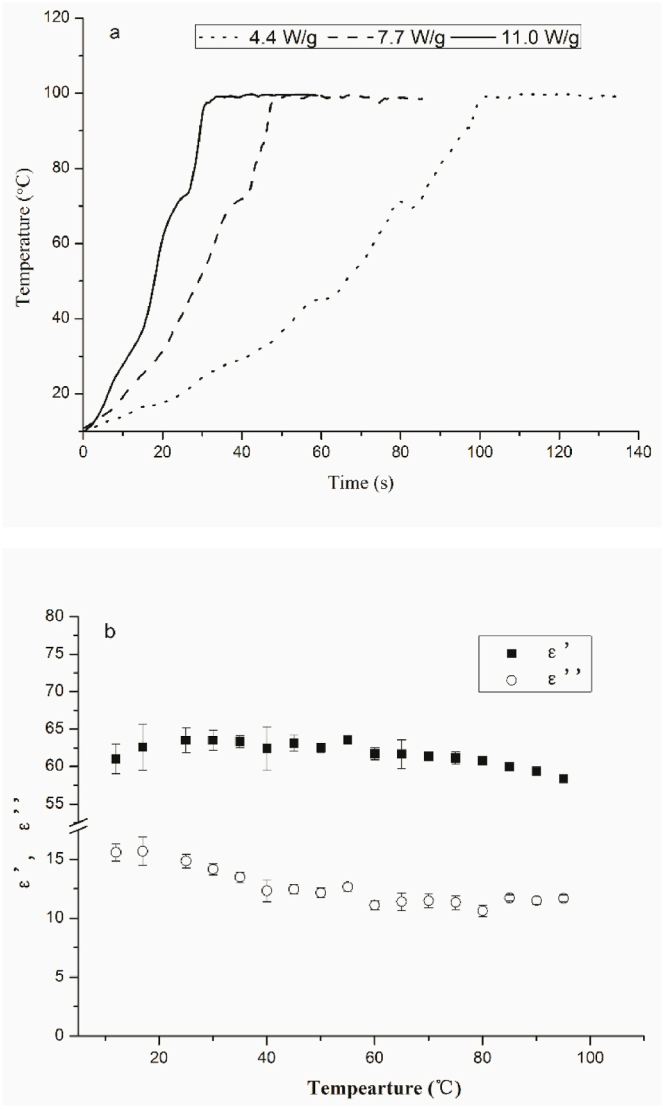

Fig. 1. a) Temperature profile at the radial centre and b) dielectric properties of peach puree.

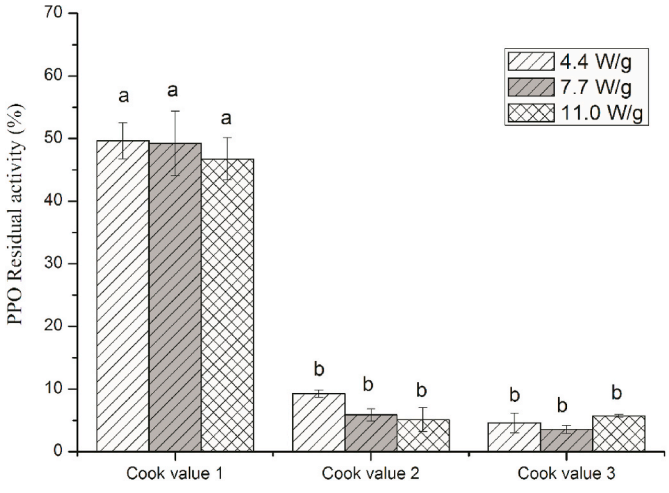

Fig. 2. The effect of microwave treatment under same cook value on PPO residual activity of peach puree.

decreased from ca. 50%–5% when increasing the cook value from level 1 to level 2, regardless of power density applied. Meanwhile the residual activity in peach puree treated by MW treatment at cook value level 2 and level 3 showed no significant difference. PPO, one of the major oxidative enzymes involved in browning reaction, affects the color and flavour of peach puree (Chakraborty et al., 2014). The resistance of PPO to the MW treatment was dependent on the enzyme source, medium composition, and so on (Matsui et al., 2008). In their study, the residual PPO activity was decreased to 49.2% after MW treatment at 7.7 W/g for 38 s. On the other hand, the activity of PPO in defatted avocado puree significantly increased by 52.6% maximally when the sample was treated by MW treatment for less than 40 s at 7.7 W/g. Then, the residual activity significantly decreased to ca. 20% when increasing the heating time to 100 s (Zhou et al., 2016). Benlloch-Tinoco et al. (2013) reported that MW treatment could significantly inactivate PPO in kiwifruit puree, and the level of residual activity of PPO significantly decreased from ca. 80% to ca. 10% as the kiwifruit treated by MW from 0.6 W/g to 1.8 W/g for 100 s. Thus, PPO from different sources showed significantly different resistance to the MW treatment, possibly due to iso-enzymes, existing state, environmental and physical-chemical conditions such as pH, soluble solids content (Mayer and Harel, 1979; Zhang et al., 2010). Furthermore, results showed that there was no significant difference among three power densities at a cook value level, indicating the heating rate of MW treatment had no significant effect on the residual PPO activity. In the previous studies, as compared with conventional heating, MW treatment showed greater effectiveness for inactivation of PPO and POD in green coconut water (Matsui et al., 2008). Benlloch-Tinoco et al. (2013) and Soysal and Söylemez (2005) both found the inactivation level of kiwifruit PPO and carrot increased as the MW power increased. In MW treatment, time required for approximately 90% reduction in carrot POD activity was shorter than conventional heating at the same temperature (Soysal and Söylemez, 2005). However, the effect of thermal load was not considered in the above studies. Benlloch-Tinoco et al. (2014b) reported conventional heating required a significantly higher thermal load to achieve the pre-set level of POD inactivation in the kiwifruit puree than any of MW treatments, irrespective of whether the comparison was carried out at the coldest or hottest spot of the sample. However, the effect of heating rate on enzyme inactivation was not discussed. In this study, it was indicated that the same thermal load caused by MW treatment induced the same inactivation level of PPO in peach puree, regardless of the power densities applied. Thermal load played a key role in inactivation of PPO in peach puree by MW treatment.

3.3. The inactivation of PME activity

As shown in Fig. 3, the inactivation of PME by MW treatment was different than the inactivation of PPO. After MW treatment at 4.4 W/g power densities for cook value level 1, the residual activity of PME was 72.1%, higher than the value of 49.7% detected for the PPO. PME turned out to be more resistant to MW treatment than PPO in peach puree. Benlloch-Tinoco et al. (2013) also found the inactivation percentage of PPO and PME were 97.5% and 77.2% after an optimum MW treatment at 2 W/g for 340 s, respectively. PME was a highly heat stable enzyme, as intense heat treatment was necessary to inactivate it. According to previous and this study, MW treatment could be an alternative technique to inactive PME. In Arjmandi et al. (2017) study, continuous MW treatment, in particular high power/short time (3.2 W/mL for 180 s, 4.5 W/mL for 160 s and 5.2 W/mL for 150 s), significantly decreased the PME residual activity to 14.65–15.02%. The PME activity in kava juice after continuous MW treatment at 41.4 °C, 52.3 °C and 65.2 °C were decreased to 83%, 73% and 34%, respectively (Abdullah et al., 2013). Tajchakavit and Ramaswamy (1997) reported the PME inactivation in orange juice was significantly faster in the MW treatment mode than in conventional heating mode, such as the D-values were 154 s and 7.37 s for conventional heating and MW treatment at the common temperature

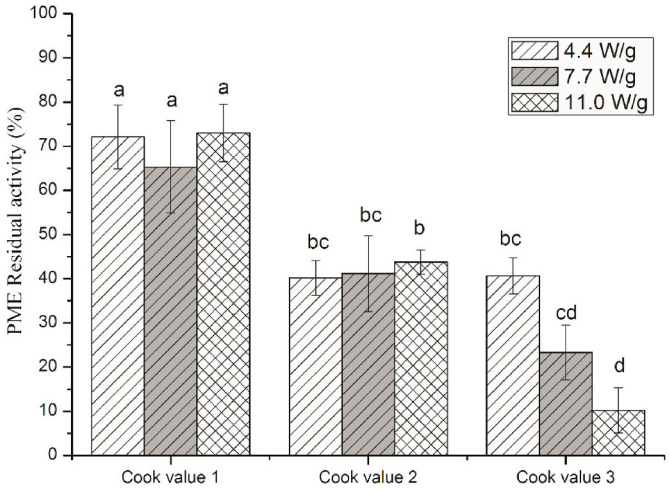

Fig. 3. The effect of microwave treatment under same cook value on PME residual activity of peach puree.

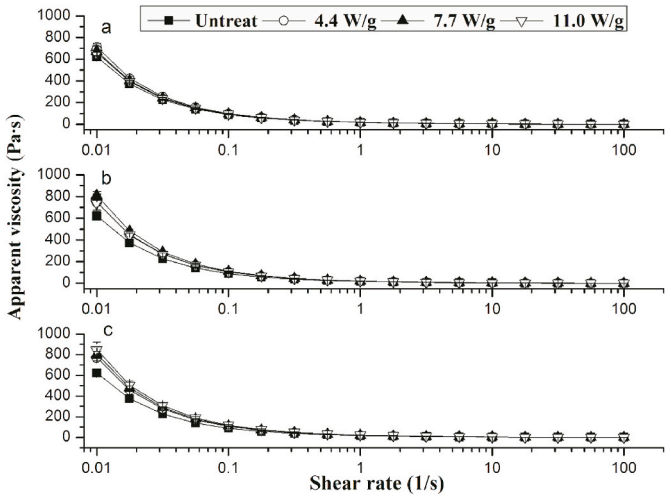

Fig. 4. The effect of microwave treatment under same cook value on apparent viscosity of peach puree against shear rate. (a: Cook value 0.36 min; b: Cook value 10 min; c: Cook value 24 min).

of 60 °C as the basis, respectively.

The average residual activity of PME in peach puree treated by MW treatment decreased from 70.1% to 41.7% when increasing the cook value level from 1 to 2. Meanwhile the residual activity showed no significant difference among different power densities applied at cook value levels at 1 and 2. The residual activity significantly decreased from 40.6% to 10.2% when power density increased from 4.4 to 11.0 W/g at cook value level 3. It was deduced that the thermal load was not the only factor that affected the PME inactivation by MW treatment, and heating rate was the possible reason for the phenomenon. Tajchakavit and Ramaswamy (1997) suggested that the remarkable difference in inactivation effect between MW treatment and conventional heating showed the possibility of some contributory non-thermal effects under the MW heating condition. Benlloch-Tinoco et al. (2014b) also proposed some contributory non-thermal effects associated with the MW treatment, as MW treatment heating required a lower thermal load than conventional heating to inactivate microorganism and enzyme at power levels studied. It has been reported that the non-thermal impact of MW treatment on the microorganisms would be more effective than on the surrounding medium; thus, destroying microbial cells (Heddleson and Doores, 1994; Kozempel et al., 1998).

3.4. The change of rheological property

Fig. 4 shows that the apparent viscosities of all peach puree samples decreased with increasing shear rate from 0.01 to 100 1/s, exhibiting a non-Newtonian characteristic of a pseudoplastic nature. The pectin and fibre content in peach puree provided to the puree a kind of internal structure which resulted in shear-thinning (Massa et al., 2010). From a rheological point of view, peach puree could be considered as a weak gel; its viscosity is not stable and is influenced by changing the degree of shear rate (Arjmandi et al., 2017). Massa et al. (2010) and Maceiras et al. (2007) both found that peach puree showed a shear-thinning behaviour along the decreasing shear rate. Compared with untreated sample, the apparent viscosities of peach puree were not significantly altered by MW treatment at cook value 1, while the values significantly increased after MW treatment at cook value 2 and 3. The MW treatment with different power densities at a common cook value level showed no significant effect on apparent viscosity. The result meant that increasing the thermal load significantly boosted the apparent viscosity, regardless of power density applied. Similar result was found by Arjmandi et al. (2017) that MW treatment, in particular, high power combined with low time (2700 W/160 s, 3150 W/150 s) provided the tomato juice with higher viscosity compared to untreated samples. The viscosity of kiwifruit puree also increased when a higher intensity MW treatment was applied, and sample treated by MW treatment at 1.2 W/g for 340 s, 1.8 W/g for 300 s and 2 W/g for 200 s showed significantly higher viscosity values than the rest of the samples (Benlloch-Tinoco et al., 2012). Our previous study also showed the apparent viscosity of MW treated (11.0 W/g, 60–80 s) defatted avocado puree was slightly higher than that of control samples (Zhou et al., 2016). Viscosity is influenced by the presence of pectin, and inactivation of PME and PG after the thermal treatment. Owing to disruption of the cell wall in samples during thermal treatment, soluble pectin could be increased (Arjmandi et al., 2017). Furthermore, Maran et al. (2013) reported that the extraction efficiency of pectin could be improved by raising MW power from 160 W to 480 W under the same solid-liquid ratio, caused by the direct effects of MW energy on the plant materials. The phenomenon could be explained by that more electromagnetic energy by increasing MW power was transferred on biomolecules by ionic conduction and dipole rotations, which result in more power dissipated inside the solvent and plant material and then generate molecular movement and heating on the traction system quickly, and improved the pectin extraction efficiency (Maran et al., 2013). Thus, higher intensity of MW treatment could result in a product with a higher viscosity. On the other hand, further inactivation of PME by MW treatment with higher cook value also contributed to the enhancement of apparent viscosity. A lower PME residual activity at cook value 2 and 3 was corresponding to the higher value of apparent viscosity.

Fig. 5 shows the change of dynamic rheological characteristics of peach puree treated by MW treatment. For all samples, the storage modulus G′ was greater than the loss modulus G″ throughout the frequency range, indicating peach puree could be characterized as a week gel network. As compared with untreated peach puree, the G′ and G″ of sample after different MW treatment showed no significance difference. Some factors affecting the elastic behaviour of puree are particle concentration, morphology, flexibility, and the way particles agglomerate (Lopez-Sanchez et al., 2011). The change in G' and G" after MW treatment was consistent with the result of particle size distribution (PSD) in peach puree, which showed that PSD of peach puree was not altered by MW treatment (data not shown).

3.5. The change of color

Table 1 shows the change of L*, a*, b* and ΔE values of peach puree after MW treatment. The L*, a* and b* values of peach puree were not significantly changed by MW treatment at cook value 1, except the L*

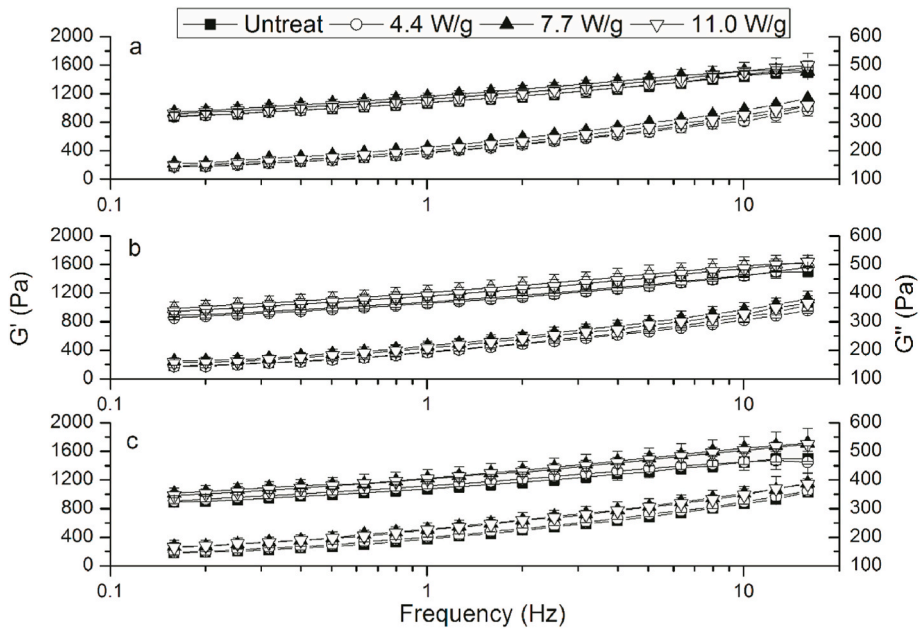

Fig. 5. The effect of microwave treatment under same cook value on the storage modulus and the loss modulus of peach puree. (a: Cook value 0.36 min; b: Cook value 10 min; c: Cook value 24 min).

Table 1
The effect of microwave treatment under the same cook value on L*, a*, b* and ΔE of peach puree.

Cook value	MW treatment condition	L*	a*	b*	ΔE
Untreated	–	36.98 ± 0.31a	1.35 ± 0.50 ab	14.19 ± 0.12a	–
Cook value 0.36 min	4.4 W/g	37.72 ± 0.23 ab	1.24 ± 0.06 ab	14.79 ± 0.16 ab	1.63 ± 0.21a
	7.7 W/g	38.22 ± 0.42 b	0.99 ± 0.27a	15.13 ± 0.61 ab	2.11 ± 0.50a
	11.0 W/g	37.97 ± 0.30 ab	1.13 ± 0.16 ab	14.63 ± 0.19a	1.78 ± 0.34a
Cook value 10 min	4.4 W/g	38.10 ± 0.15 b	0.88 ± 0.19a	14.52 ± 0.37a	1.84 ± 0.12a
	7.7 W/g	38.56 ± 0.43 b	0.74 ± 0.13a	15.64 ± 0.36 b	2.52 ± 0.57a
	11.0 W/g	38.29 ± 0.43 b	1.15 ± 0.10 ab	14.88 ± 0.39 ab	2.13 ± 0.42a
Cook value 24 min	4.4 W/g	38.46 ± 0.40 b	1.66 ± 0.30 b	14.27 ± 0.44a	2.48 ± 0.51a
	7.7 W/g	38.33 ± 0.41 b	1.08 ± 0.01 ab	15.16 ± 0.20 ab	2.19 ± 0.42a
	11.0 W/g	38.18 ± 0.36 b	1.32 ± 0.18 ab	14.73 ± 0.07 ab	2.06 ± 0.39a

Values with different letters within the same column denotes significant difference according to Tukey test ($P < 0.05$).

value at 7.7 W/g. The L* values of peach puree significantly increased from 36.98 to 38.10 or more after MW treatment at cook value 2 and 3, while no significant difference was observed among the samples with different power densities applied at a common cook value. Meanwhile, the a* and b* values of peach puree were not changed after all MW treatments as compared with the untreated sample, which in the range of 0.74–1.66, and 14.52–15.64, respectively, except the b* value at 7.7 W/g. It was indicated that the MW treatment at higher cook value resulted the peach puree with a brighter color than untreated sample, mainly due to the further inactivation of PPO by intense MW treatment as shown above. The ΔE values of peach puree were all under 3, and no significant difference in ΔE values were shown among all MW treatments. Thus, MW treatment could better preserve the color of peach puree. Marszałek et al. (2015) found color changes of MW treated strawberry puree were insignificant (ΔE < 2), whereas conventional heating processing (90 °C/15 min) caused significant changes (ΔE > 3). Igual et al. (2014) reported that MW treatment (45 W/mL, 30 s) decreased the L* value of grapefruit juice from 27.29 to 25.20, and increased the a* and b* from 23.63 to 37.70 to 24.13 and 38.41, respectively. de Ancos et al. (1999) compared the color of papaya, strawberry, and kiwifruit purees after MW treatment, and different changes in color were observed for those three purees. Strawberry puree after MW treatment exhibited similar changes as peach puree in this study, where L* values increased from 30.15 to 33.46 or more after MW at 9.5 W/g for 15–60 s, and a* and b* values showed no significant difference. However, papaya, strawberry, and kiwifruit purees after MW treatment all exhibited slight color changes (de Ancos et al., 1999). In the study of Palma-Orozco et al. (2012), as compared to the untreated sample, the L* value of mamey fruit after MW treatment (0.3–3.1 W/g, 30–300 s) was not altered, but both a* and b* values decreased significantly; therefore, ΔE values increased when exposure time was increased. In addition, MW treatment (652 W, 35 s) decreased the L* value of Granny Smith apple puree from 66.8 to 51.5, and increased the a* value from −9.5 to −5.8 (Picouet et al., 2009). From the above studies, it could be deduced that the color change after MW treatment is closely related to the source of puree, since different purees have a wide range of enzyme, anthocyanin, and chlorophyll, as well as the original color. Thus, the effect of MW treatment on puree resulted from a comprehensive effect of enzyme inactivation and pigments degradation.

3.6. The change of total phenolic, total flavonoid and antioxidant capacity

Table 2 shows the change of total phenolic, total flavonoid and antioxidant capacity in peach puree after MW treatment. The initial content of total phenolic and total flavonoid in peach puree were 156.41 ± 11.03 μg GAE/g and 37.28 ± 5.53 μg CE/g, respectively, which is in the range reported by the Cantín et al. (2009). Cantín et al. (2009) reported that total phenolic and total flavonoids in 15 peach and nectarines ranged from 127 to 713 μg GAE/g and 18 to 309 μg CE/g, respectively. The total phenolic content in the peach puree after MW treatment showed a decreasing trend, however no significant change was observed, except the value in peach puree after MW treatment with

Table 2
The effect of microwave treatment under same cook value on total phenolic, total flavonoid and antioxidant capacity of peach puree.

Cook value	MW treatment condition	Total phenolic (ug GAE/g)	Total flavonoid (ug CE/g)	DPPH (μmol TE/mg)	FRAP (μmol TE/mg)
Untreated	–	156.41 ± 11.03 b	37.28 ± 5.53a	722.00 ± 29.49 b	874.72 ± 34.88 ab
Cook value 0.36 min	4.4 W/g	138.24 ± 4.41 ab	39.69 ± 1.58a	622.56 ± 46.85 ab	806.77 ± 28.15a
	7.7 W/g	139.27 ± 7.75 ab	38.36 ± 7.13a	633.11 ± 34.25 ab	851.13 ± 17.34 ab
	11.0 W/g	139.06 ± 2.83 ab	36.80 ± 2.61a	613.11 ± 59.40 ab	819.08 ± 43.71a
Cook value 10 min	4.4 W/g	136.20 ± 5.13a	35.83 ± 1.50a	674.22 ± 43.60 ab	823.18 ± 19.60 ab
	7.7 W/g	134.37 ± 9.35a	37.52 ± 6.39a	614.22 ± 34.25 ab	844.46 ± 16.87 ab
	11.0 W/g	138.45 ± 1.77 ab	35.95 ± 4.65a	638.67 ± 30.87 ab	871.38 ± 17.42 ab
Cook value 24 min	4.4 W/g	137.63 ± 0.61 ab	39.93 ± 1.78a	599.78 ± 14.17a	824.97 ± 34.16 ab
	7.7 W/g	140.49 ± 3.89 ab	38.00 ± 5.27a	608.67 ± 35.47 ab	865.74 ± 23.08 ab
	11.0 W/g	146.00 ± 9.69 ab	40.29 ± 3.01a	594.78 ± 46.68a	906.51 ± 43.79 b

Values with different letters within the same column denotes significant difference according to Tukey test ($P < 0.05$).

power densities of 4.4 and 7.7 W/g at cook value 2. MW treatment did not alter the content of total flavonoid and antioxidant capacity of peach puree, regardless of the power density and cook value applied. Total phenolic and total flavonoid are widely known to be common substrates of enzymes, such as PPO and POD. The effective inactivation of PPO in a short treatment time partly contributed to the better preservation of total phenolic, total flavonoid and antioxidant capacity. Since total phenolic and total flavonoids are important bioactive compounds contributing to the antioxidant capacity of peaches (Gil et al., 2002), the change of antioxidant capacity was in accordance with total phenolic and total flavonoid in peach puree after MW treatment. Picouet et al. (2009) also found that the total phenolic in apple puree was not altered by MW treatment (652 W, 35 s), and its content was similar: 1124 and 1166 mg/GAE kg, respectively. Benlloch-Tinoco et al. (2015b) found that MW treatment (2 W/g, 340 s) did not cause significant losses in the total phenolics of kiwifruit puree, while it reduced the total flavonoid content by 28.80%. In the study of Igual et al. (2010), MW treatment (45 W/mL, 30 s) and conventional heating (80 °C, 11 s) caused a similar decrease of total phenolic content (34.64%) and % DPPH (40%), but MW treated grapefruit juices better preserved total phenolic and antioxidant capacity when compared with fresh or conventional pasteurised ones during storage. Arjmandi et al. (2016) reported that the maximum total phenolic was obtained in semi-industrial MW treated orange-colored smoothies (1.0–18 w/mL, 93–646 s) without significant differences among MW treatments. Meanwhile the loss of antioxidant capacity was only 5% under the combination of high power/short time, and the value was 28% of that observed in conventional pasteurization (90 °C, 35 s) sample (Arjmandi et al., 2016). Thus, MW treatment was superior in preserving the nutritional and functional values of the product, mainly due to its inactivation of enzymes characteristic of high heating rate.

4. Conclusion

MW treatment can be considered as a suitable means of processing peach puree and preserving the quality of the product. PPO and PME in peach puree could be effectively inactivated by MW treatment, while PME turned out to be more resistant to MW treatment than PPO. Same level of thermal load calculated by cook value resulted in similar inactivation level of PPO in peach puree, regardless of the power densities applied, possibly indicating heating rate had no effect on inactivation of PPO. However, a different situation was observed for PME inactivation by MW treatment. The residual activity of PME significantly decreased when power density increased from 4.4 to 11.0 W/g at cook value 3, suggesting thermal load was not the only factor that affected the PME inactivation by MW treatment. As compared to untreated sample, MW treatment at higher cook value resulted the peach puree with a brighter color, while the amounts of total polyphenol, total flavonoid and antioxidant capacities were higher after treatment. The apparent viscosity values significantly increased after MW treatment at higher cook value, regardless of power density applied. Accordingly, the use of MW treatment offers a good alternative to conventional pasteurization for enzyme inactivation.

CRediT authorship contribution statement

Linyan Zhou: Conceptualization, Formal analysis, Investigation, Data curation, Visualization, Writing, Writing – review & editing. **Chia Ying Tey:** Methodology, Resources. **Gokhan Bingol:** Methodology, Writing – review & editing, Review. **Murat O. Balaban:** Methodology, editing, Review. **Shengbao Cai:** Review.

Declaration of competing interest

The authors do not have any conflict of interest to declare.

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References

Abdullah, S.A., Lee, S.H., Cho, I.K., Li, Q.X., Jun, S., Choi, W., 2013. Pasteurization of kava juice using novel continuous flow microwave heating technique. Food Sci. Biotechnol. 22 (4), 961–966.
Arjmandi, M., Otón, M., Artés, F., Artés-Hernández, F., Gómez, P.A., Aguayo, E., 2016. Semi-industrial microwave treatments positively affect the quality of orange-colored smoothies. J. Food Sci. Technol. 53 (10), 3695–3703.
Arjmandi, M., Otón, M., Artés, F., Artés-Hernández, F., Gómez, P.A., Aguayo, E., 2017. Microwave flow and conventional heating effects on the physicochemical properties, bioactive compounds and enzymatic activity of tomato puree. J. Sci. Food Agric. 97 (3), 984–990.
Ávila, I.M.L.B., Silva, C.L.M., 1999. Modelling kinetics of thermal degradation of colour in peach puree. J. Food Eng. 39 (2), 161–166.
Baltacıoğlu, H., Coruk, K.S., 2021. Determination of conformational changes of polyphenol oxidase and peroxidase in peach juice during mild heat treatment using FTIR spectroscopy coupled with chemometrics. Int. J. Food Sci. Technol. 56 (6), 2915–2925.
Benlloch-Tinoco, M., Varela, P., Salvador, A., Martínez-Navarrete, N., 2012. Effects of microwave heating on sensory characteristics of kiwifruit puree. Food Bioprocess Technol. 5 (8), 3021–3031.
Benlloch-Tinoco, M., Igual, M., Rodrigo, D., Martínez-Navarrete, N., 2013. Comparison of microwaves and conventional thermal treatment on enzymes activity and antioxidant capacity of kiwifruit puree. Innovat. Food Sci. Emerg. Technol. 19, 166–172.
Benlloch-Tinoco, M., Igual, M., Salvador, A., Rodrigo, D., Martínez-Navarrete, N., 2014a. Quality and acceptability of microwave and conventionally pasteurised kiwifruit puree. Small Rumin. Res. 122, 10–17.
Benlloch-Tinoco, M., Martínez-Navarrete, N., Rodrigo, D., 2014b. Impact of temperature on lethality of kiwifruit puree pasteurization by thermal and microwave processing. Food Control 35 (1), 22–25.
Benlloch-Tinoco, M., Kaulmann, A., Corte-Real, J., Rodrigo, D., Martínez-Navarrete, N., Bohn, T., 2015a. Chlorophylls and carotenoids of kiwifruit puree are affected

similarly or less by microwave than by conventional heat processing and storage. Food Chem. 187, 254–262.
Benlloch-Tinoco, M., Igual, M., Rodrigo, D., Martínez-Navarrete, N., 2015b. Superiority of microwaves over conventional heating to preserve shelf-life and quality of kiwifruit puree. Food Control 50, 620–629.
Bornhorst, E.R., Liu, F., Tang, J., Sablani, S.S., Barbosa-Cánovas, G.V., 2017. Food quality evaluation using model foods: a comparison study between microwave-assisted and conventional thermal pasteurization processes. Food Bioprocess Technol. 10, 1248–1256.
Canalis, M.S.B., Baroni, M.V., León, A.E., Ribotta, P.D., 2020. Effect of peach puree incorportion on cookie quality and on simulated digestion of polyphenols and antioxidant properties. Food Chem. 333, 127464.
Cantín, C.M., Moreno, M.A., Gogorcena, Y., 2009. Evaluation of the antioxidant capacity, phenolic compounds, and vitamin C content of different peach and nectarine [Prunus persica (L.) Batsch] breeding progenies. J. Agric. Food Chem. 57 (11), 4586–4592.
Chakraborty, S., Kaushik, N., Rao, P.S., Mishra, H.N., 2014. High-pressure inactivation of enzymes: a review on its recent applications on fruit purees and juices. Compr. Rev. Food Sci. Food Saf. 13 (4), 578–596.
Dankar, I., Haddarah, A., El Omar, F., Sepulcre, F., Pujolà, M., 2018. Assessing the microstructural and rheological changes induced by food additives on potato puree. Food Chem. 240, 304–313.
de Ancos, B., Cano, M.P., Hernandez, A., Monreal, M., 1999. Effects of microwave heating on pigment composition and colour of fruit purees. J. Sci. Food Agric. 79 (5), 663–670.
Garza, S., Ibarz, A., Pagan, J., Giner, J., 1999. Non-enzymatic browning in peach puree during heating. Food Res. Int. 32, 335–343.
Gil, M.I., Tomás-Barberán, F.A., Hess-Pierce, B., Kader, A.A., 2002. Antioxidant capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach, and plum cultivars from California. J. Agric. Food Chem. 50, 4976–4982.
Guan, Y., Zhou, L., Bi, J., Yi, J., Liu, X., Chen, Q., Wu, X.Y., Zhou, M., 2016. Change of microbial and quality attributes of mango juice treated by high pressure homogenization combined with moderate inlet temperatures during storage. Innovat. Food Sci. Emerg. Technol. 36, 320–329.
Heddleson, R.A., Doores, S., 1994. Factors affecting microwave heating of foods and microwave induced destruction of foodborne pathogens-a review. J. Food Protect. 57 (11), 1025–1037.
Huang, Y., Sheng, J., Yang, F., Hu, Q., 2007. Effect of enzyme inactivation by microwave and oven heating on preservation quality of green tea. J. Food Eng. 78, 687–692.
Igual, M., García-Martínez, E., Camacho, M.M., Martínez-Navarrete, N., 2010. Effect of thermal treatment and storage on the stability of organic acids and the functional value of grapefruit juice. Food Chem. 118 (2), 291–299.
Igual, M., Contreras, C., Camacho, M.M., Martínez-Navarrete, N., 2014. Effect of thermal treatment and storage conditions on the physical and sensory properties of grapefruit juice. Food Bioprocess Technol. 7 (1), 191–203.
Kozempel, M.F., Annous, B.A., Cook, R.D., Scullen, O.J., Whiting, R.C., 1998. Inactivation of microorganisms with microwaves at reduced temperatures. J. Food Protect. 61, 582–585.
Lavelli, V., Pompei, C., Casadei, M.A., 2008. Optimization of color and antioxidant activity of peach and nectarine puree: scale-up study from pilot to industrial plant. J. Agric. Food Chem. 56 (16), 7091–7099.
Liu, F.X., Wang, Y.T., Bi, X.F., Guo, X.F., Fu, S.F., Liao, X.J., 2013. Comparison of microbial inactivation and rheological characteristics of mango pulp after high hydrostatic pressure treatment and high temperature short time treatment. Food Bioprocess Technol. 6, 2675–2684.
Lopez-Sanchez, P., Svelander, C., Bialek, L., Schumm, S., Langton, M., 2011. Rheology and microstructure of carrot and tomato emulsions as a result of high-pressure homogenization conditions. J. Food Sci. 76, E130–E140.
Maceiras, R., Alvarez, E., Cancela, M.A., 2007. Rheological properties of fruit purees: effect of cooking. J. Food Eng. 80 (3), 763–769.
Mansfield, T., 1962. High temperature-short time sterilization. In: Leitch, J.M. (Ed.), Food Science and Technology. Proc. 1st Intl. Congress of Food Science and Technology, vol. IV. Gordon and Breach Science Publisher, London, U.K. New York, pp. 311–316, 18-21 Sept. 1962.
Maran, J.P., Sivakumar, V., Thirugnanasambandham, K., Sridhar, R., 2013. Optimization of microwave assisted extraction of pectin from orange peel. Carbohydr. Polym. 97 (2), 703–709.
Marszałek, K., Mitek, M., Skąpska, S., 2015. Effect of continuous flow microwave and conventional heating on the bioactive compounds, colour, enzymes activity, microbial and Palma-Orozco.
Massa, A., González, C., Maestro, A., Labanda, J., Ibarz, A., 2010. Rheological characterization of peach purees. J. Texture Stud. 41 (4), 532–548.
Matsui, K.N., Gut, J.A.W., De Oliveira, P.V., Tadini, C.C., 2008. Inactivation kinetics of polyphenol oxidase and peroxidase in green coconut water by microwave processing. J. Food Eng. 88 (2), 169–176.
Mayer, A.M., Harel, E., 1979. Polyphenol oxidases in plants. Phytochemistry 18, 193–225.
Moreno-Montoro, M., Olalla-Herrera, M., Gimenez-Martinez, R., Navarro-Alarcon, M., Rufián-Henares, J.A., 2015. Phenolic compounds and antioxidant activity of Spanish commercial grape juices. J. Food Compos. Anal. 38, 19–26.
Picouet, P.A., Landl, A., Abadias, M., Castellari, M., Viñas, I., 2009. Minimal processing of a Granny Smith apple purée by microwave heating. Innovat. Food Sci. Emerg. Technol. 10 (4), 545–550.
Qu, Z., Tang, Z.W., Liu, F., Sablani, S.S., Ross, C.F., Sankaran, S., Tang, J., 2021. Quality of green beans (*Phaseolus vulgaris* L.) influenced by microwave and hot water pasteurization. Food Control 124, 107936.
Soysal, Ç., Söylemez, Z., 2005. Kinetics and inactivation of carrot peroxidase by heat treatment. J. Food Eng. 68 (3), 349–356.
Tajchakavit, S., Ramaswamy, H.S., 1997. Thermal vs. microwave inactivation kinetics of pectin methylesterase in orange juice under batch mode heating conditions. LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 30 (1), 85–93.
Wang, Y., Wig, T.D., Tang, J., Hallberg, L.M., 2003. Sterilization of foodstuffs using radio frequency heating. J. Food Sci. 68 (2), 539–544.
Wang, Y., Liu, F., Cao, X., Chen, F., Hu, X., Liao, X., 2012. Comparison of high hydrostatic pressure and high temperature short time processing on quality of purple sweet potato nectar. LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 16 (39), 326–334.
Zhang, Y., Wang, Y., Zhou, L., Liao, X., 2010. A comparative study of inactivation of peach polyphenol oxidase and carrot polyphenol oxidase induced by high-pressure carbon dioxide. Int. J. Food Sci. Technol. 45 (11), 2297–2305.
Zhou, L.Y., Tey, C.Y., Bingol, G., Bi, J.F., 2016. Effect of microwave treatment on enzyme inactivation and quality change of defatted avocado puree during storage. LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 37, 61–67.