Comparison of the effects of novel processing technologies and conventional thermal pasteurisation on the nutritional quality and aroma of Mandarin (*Citrus unshiu*) juice

Chuan-xiang Cheng, Meng Jia, Yao Gui, Yaqin Ma*

Citrus Research Institute, Southwest University, National Citrus Engineering Research Center, Chongqing 400712, China

ABSTRACT

Conventional thermal pasteurisation (90 °C and 30 s), high pressure processing (HPP: 600 MPa, 4 °C and 300 s), ultrasound processing (US: 50 °C, 750 W and 36 min) and microwave processing (MW: 800 W, 80 °C and 70 s) were evaluated by examining their effects on the sensory and nutritional qualities of mandarin juice. The treated samples had < 2 log CFU/mL total aerobic bacteria, which is equivalent to microorganism inactivation. Sugar and acid components were almost constant for all the treated mandarin juices, and no differences between treatments were perceptible. However, the mandarin juice treated with novel technologies maintained better colour (L*, a* and b*), nutritional value (ascorbic acid, total phenolic, total carotenoid content and phenolic components) and aroma than the thermally pasteurised one. This study showed that US, MW and HPP are good novel processing techniques to inactivate microorganisms and maintain the sensory and nutritional quality of mandarin juice.

1. Introduction

Citrus juice is favoured by consumers due to its high nutritional value, bright colour and rich aroma; hence, its market share in China has been increasing every year. Sweet orange, the main citrus variety for juice making, cannot meet the market demand because of its low annual production in China at only 7.3 million tons and a processing capacity of only 570,000 tons in 2018. The output of *Citrus reticulata* Blanco in China is 21.2 million tons, accounting for 67% of the total citrus output (United States Department of Agriculture, Foreign Agricultural Service. Citrus: World Markets, 2018). Therefore, the demand can be satisfied by producing juice or blending juice from *C. reticulata* Blanco.

Conventional thermal pasteurisation is the most common method to extend the shelf life of citrus juice by inactivating microorganisms and enzymes. However, heat processing reduces the sensory and nutritional qualities of juice (Wibowo et al., 2015). As a solution, novel processing technologies, including the applications of high hydrostatic pressure, ultrasonic and microwave, have been developed for juice processing.

High pressure processing (HPP), also known as high hydrostatic pressure, is one of the most promising non-thermal juice processing methods that inactivate bacterial cells, yeasts and moulds without the use of heat and thus minimally affect the sensory and nutritional

qualities associated with 'fresh-like' attributes (Onur et al., 2018). HPP is currently used in the industrial production of fruit juice (Huang, Wu, Lu, et al., 2017) and operates at room or mild temperature with pressures ranging from 100 MPa to 600 MPa. The principle is that the high pressure can change the microbial cell morphology, the biological polymer solid structure of cell wall and non-covalent bonds; inhibit the enzyme activity and kill bacteria and other microorganisms, thereby reducing the microbial populations in orange juice to 2 log CFU/mL (550 MPa to 600 MPa, 55 °C to 60 °C and 330 s to 360 s) (Bisconsin-Junior, Rosenthal, & Monteiro, 2014). In addition to HPP parameters (pressure, temperature and time), microbial safety depends on the food composition, pH, water activity and microorganism species. The effects of HPP on citrus juice quality have been widely studied and even compared with those of conventional heat pasteurisation (Bull et al., 2004; Plaza et al., 2006; Polydera, Stoforos, & Taoukis, 2005; Sánchez-Moreno et al., 2005), which maintains the freshness, sensorial and nutritive value of citrus juice (Baxter, Easton, Schneebeli, & Whitfield, 2005; Bisconsin-Junior et al., 2014; Bull et al., 2004; Vervoort et al., 2012).

Ultrasound (US) is a non-thermal processing method with great potential to replace thermal processing (Anaya-Esparza et al., 2017). US treatment applied to liquid media at high power (1–1000 W/cm²) and low frequency (20–100 kHz) can damage the microbial membrane. Low

frequency US affects the inhibition and destruction of microorganisms due to cavitation, which produces highly localised high temperature and pressure (550 °C, 104–105 kPa) (Suslick, 1989). The intense local energy and high pressure generates a localised sterilisation effect (Cheng, Soh, Liew, & Teh, 2007). Acoustic energy transfer to juice occurs instantaneously and throughout the whole product with reduced processing time, high throughput and low energy consumption, thus leading to cell wall thinning and breakdown, internal disorganisation and increased susceptibility of microorganisms to heat. US treatment has been identified as a potential technology to meet the 5 log reduction in pertinent microorganisms in fruit juice required by the Food and Drug Administration (USA) (Salleh-Mack & Roberts, 2007). US treatment for fruit juices improves the shelf-life and has minimal negative effects on fruit juice quality as compared with conventional thermal processing (Bermúdez-Aguirre, Mobbs, & Barbosa-Cánovas, 2010). The use of sonication to provide fresh, high-quality, microbiologically safe and high-nutritional value fruit juice continues to be a relevant area of research (Ferrante, Guerrero, & Alzamora, 2007; Tiwari, Donnell, Muthukumarappan, & Cullen, 2009; Valero, Recrosio, Saura, Muoz, & Lizama, 2007). As such, the use of single US treatment to kill microorganisms is not ideal (Cordeiro Dias et al., 2015; Gabriel, 2012) and requires a long time. Therefore, additional treatments, such as using mild heat or pressure, are required to increase the effect of sterilisation and inactivate the enzymes.

Microwave (MW) technology is a new thermal processing in which the heat originates from the electromagnetic interaction of the dielectric material in a specific frequency of radiation. This process is also known as volume heating. Under the convection or conduction principle, MW radiation directly penetrates and generates volume heat in the material, resulting in high energy efficiency and low heating time (Zhu, Kuznetsov, & Sandeep, 2007). This technique aims to inactivate enzymes and kill microorganisms in a short time compared with thermal processes while minimising the quality losses (Rayman & Baysal, 2011). Compared with traditional pasteurisation, MW is the only thermal method that generates heat inside the raw material (Claudia Salazar-González, Martín-González, López-Malo, & Sosa-Morales, 2012). Additionally, MW processing is faster and can greatly preserve the quality and nutritional characteristics compared with conventional heating technologies (Chandrasekaran, Ramanathan, & Basak, 2013). Kumar et al. reported that microwave heating can protect the quality characteristics of citrus juice by rapidly inactivating the enzymes and microorganisms compared with traditional heating methods and minimising the quality loses (Kumar & Kohli, 2017).

As novel technologies, HPP, US and MW have been widely studied in the field of juice processing (Putnik et al., 2019; Stratakos, Delgado-Pando, Linton, Patterson, & Koidis, 2016); however, their effects on sterilisation and enzyme inactivation are largely related to the characteristics of fruit juice. Hence, the influence on the quality of all fruit juices may not be consistent. These novel processing technologies have not been applied in the juice processing of the main mandarin variety, *Citrus unshiu*, one of the three main varieties of *C. reticulata* Blanco in China. This study aimed to evaluate and compare the effects of three novel processing technologies and thermal pasteurisation on nutritional and sensory quality of citrus juice produced by mandarin (*C. unshiu*) on a fair basis, using processing conditions leading to an equivalent degree of microbial inactivation, which can provide scientific guidance for their application in industrial production in China.

2. Material and methods

2.1. Citrus juice preparation

Mandarin fruits harvested in Hubei, China were used as the experimental material. The juice was extracted with a manual juicer, filtered using 80 mesh sterile double-layer gauze to remove peel and seeds, placed in a vacuum sterile bag, and then kept at 4 °C until the experiments were carried out (not more than 1 day).

2.2. Citrus juice processing

Processing conditions were selected to achieve equivalent microbial safety (Matser, Mastwijk, Bánáti, Vervoort, & Hendrickx, 2010) and defined based on the capacity to reduce total aerobic bacteria count to lower than 2 log CFU/mL.

2.2.1. Thermal pasteurisation

The juice in the vacuum sterile bag was placed in a hot water bath set at 90 °C for 30 s and then cooled to room temperature. These conditions were selected based on literature (Odriozola-Serrano, Soliva-Fortuny, Hernandez-Jover, & Martin-Belloso, 2009).

2.2.2. High-pressure processing

In orange juice, 1–5 min at 350–500 MPa was needed to inactivate the microorganisms (Bayndrl et al., 2006; Dogan & Erkmen, 2004; Linton, Mcclements, & Patterson, 2001). For optimal safety and quality, industrial conditions are 1–2 min at 500–600 MPa. In this work, 1.5 min at 600 MPa was used at an industrial HPP production line (Shanxi, HYPREE Technology Co., Ltd.)

2.2.3. Ultrasound

The US conditions were adopted from the study of Shen, Yaqin, Nannan, and Zhen (2017) using an US processing machine (Model: DP-800, Shanghai, China). The juice was subjected to US for 36 min at a constant frequency of 19 kHz. The temperature was kept constant at 50 °C by using a circulating water bath, and the power output was 750 W.

2.2.4. Microwave

MW conditions were used as previously described (Kumar and Kohli, 2017). Microwave equipment (model HWC-3LA, Huayuan, China) was used for the trials. The processing conditions were as follows: MW power of 800 W, temperature of 90 °C, and processing time of 70 s.

2.3. Methods

2.3.1. Microbiological analyses

Citrus juice (10 mL) was added to 90 mL of sterilised buffered peptone water (BPW). After homogenisation, the aliquots were serially diluted in BPW, and 1 mL of each dilution was inoculated onto Petrifilm™ 3M™ plates for aerobic processes. Aerobic microorganism count was performed after incubation at 35 ± 1 °C for 48 ± 3 h. The minimum level of detection was 1 log CFU/mL (AOAC, 2011). The analyses were performed in triplicate.

2.3.2. pH

Direct pH determination was performed using a Mettler-Toledo FE20 laboratory pH meter.

2.3.3. Total soluble solids (TSS)

Way-2s digital Abbe refractometer manufactured by Shanghai Precision Scientific Instruments Co., Ltd. was used for TSS determination.

2.3.4. Titratable acidity (TA)

Titrable acidity was measured by the standard method of Yashan (2009).

2.3.5. Soluble sugars

High-performance liquid chromatography (HPLC) equipped with a parallax refractive detector was used for the detection of sucrose,

fructose, and glucose contents following Wilson, Work, Bushway, and Bushway's (1981) method.

2.3.6. Colour

Colour assessment of the sample was conducted by a Chromatic meter (Colour i5, Gretag Macbech, Switzerland). Colour values (L*, a*, and b*) of the sample were measured, and total colour difference (ΔE) was calculated by Eq. (1).

$$\Delta E = [(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2]^{1/2} \qquad (1)$$

where ΔE is the total colour difference between the sample and the control, L is the lightness of the sample, L_0 is the lightness of the control, a is the redness of the sample, a_0 is the redness of the control, b is the yellowness of the sample and b_0 is the yellowness of the control.

2.3.7. Ascorbic acid (Vc)

Vc standard (0.1 g) was accurately weighed and fixed in a 100 mL volumetric flask with 2% oxalic acid. The standard solution and juice sample were diluted 10 times with 2% oxalic acid and titrated with 2,6-dichlorindophenol until a pink colour appeared and remained unchanged for 15 s. Vc content was calculated as

$$X = T \times 100 \times (V - V_0), \qquad (2)$$

where V is the volume of 2, 6-dichlorindophenol consumed by sample titration (ml), V_0 is the blank titration (mL) and T is titration degree. The unit of X is mg/100 mL.

2.3.8. Total phenolic content

The total phenolic content of juice was determined by spectrophotometry using Folin–Ciocalteu reagent as proposed by Slinkard and Singleton (1977) with some minor amendments. Briefly, 1 mL of 10% Folin–Ciocalteu reagent was added to 0.5 mL of a known sample concentration. The mixture was mixed well, left to stand for 6 min, and added with 2 mL of 20% sodium carbonate solution. After 60 min at 30 °C, the total phenolic content of the solution was measured at 760 nm using a spectrophotometer (UV 17, Shimadzu Suzhou Industrial Mfg., Co., Ltd., Jiangsu, China) and expressed as μg of gallic acid equivalents (GAE) per gram of sample.

2.3.9. Total carotenoids content

Carotenoids were extracted according to the procedure of Yashan (2009) with some modifications. Briefly, 5 mL of fruit juice and 10 mL of petroleum ether–acetone (1:1 V/V) mixture were placed in a 25 mL plug test tube, oscillated to extract organic part (upper layer), filtered in a 100 mL triangle in a bottle and extracted 3–4 times until the extract was colourless. The filtrates were then combined and transferred to a 250 mL separatory funnel. The organic layer was washed with water. When the filtrate emulsified, it was added with 5 mL of saturated NaCl and oscillated violently. After stratification, the lower water phase was discarded, and the process was repeated several times. The petroleum ether layer was transferred to a 50 mL volumetric flask and shaken well. Light absorption value was measured at 451 nm by using petroleum ether as blank using the formula:

$$X = (E \times V_1 \times 1000)/(E_1 \times V_2), \qquad (3)$$

where X is the total carotenoid content in the juice (calculated by β-carotene) (mg/100 mL); E is the absorbance of the sample at 451 nm; E_1 is the absorption value of 1% β-carotene petroleum ether solution at the wavelength of 451 nm, that is 2500; V_1 is the total carotenoid extraction liquid volume of the sample (mL); and V_2 is the total volume of the sample solution (mL).

2.3.10. Phenolic compounds

Phenolic components were measured following the method of (Mattila & Hellstrom, 2007) with modifications. NaOH solution (16 N, 5 mL) was mixed with 10 mL of fruit juice for 1 h hydrolysis. The mixture was then added with 8 N HCl to adjust the pH to 1–2 and then extracted three times with 10 mL of ethyl acetate blended with ethyl ether (1:1). The extracts were combined and concentrated using a rotary evaporator set at 40 °C, and 80% methanol (2 mL) was used to obtain the final volume. The solutions were passed through a 0.22 μm microporous membrane and allowed to stand. The HPLC conditions were as follows: chromatographic column: Venusil MP C18 (5 μm, 4.6 mm × 250 mm); A phase: pure methanol, B phase: 0.5% acetic acid, flow rate of 1 mL/min and injection volume of 20 μL.

The flavonoid components were analysed following a previous method (Agcam, Akyıldız, & Akdemir Evrendilek, 2014) with some modifications. Ethyl acetate (10 mL) was added to 10 mL of the sample. The solution was stirred for 20 min and centrifuged at 4000 rpm for 15 min. The organic phase was transferred to a centrifuge tube, and the aqueous phase was extracted twice with 10 mL of ethyl acetate. The extracts were merged, concentrated with rotary evaporation apparatus set at 40 °C, added with 2 mL of 60% methanol to reach the final volume, and passed through a 0.22 μm microporous membrane. The HPLC conditions were as follows: chromatographic column: Thermo Fisher chromatographic column (5 μm, 4.6 mm × 250 mm); A phase: pure acetonitrile, B: 1% acetic acid, flow rate of 1 mL/min and injection volume of 20 μL.

2.3.11. Volatile compounds

Prior to analysis, the samples were added with 5 μL of cyclohexanone as an internal standard and were subjected to headspace solid phase microextraction (HS-SPME). Extraction was performed by pouring 10 mL of sample into a 22 mL crimp cap headspace vial. A 50/30 μm DVB/CAR/PDMS (Supelco, Bellefonte, PA, USA) fibre was used in all cases. The samples were pre-incubated for 10 min at 50 °C, and volatiles were extracted from the vial headspace for another 20 min at the same temperature. Desorption was performed for 1 min at 250 °C in the splitless mode.

The volatile compounds were separated using an Agilent 7890 GC (Agilent Technologies, Santa Clara, CA, USA) equipped with DB-5 (30 m length, 0.25 mm i.d., 0.25 μm film thickness; Agilent Technologies) columns coupled with a 5977 N MS detector (Agilent Technologies). The column oven was programmed to increase at 7 °C min^{-1} from the initial 40 °C to 230 °C, ramp at 100 °C min^{-1} to 260 °C and maintain for 11.70 min for a total run time of 60 min. Helium was used as carrier gas at a flow rate of 1.2 mL/ min. Inlet, ionising source and transfer line were kept at 250 °C, 230 °C and 280 °C, respectively. Mass units were monitored from 40 m/z to 350 m/z and ionised at 70 eV. Data were collected using the ChemStation G1701 AA data system (Hewlett–Packard, Palo Alto, CA, USA). Samples were run in triplicate on a DB-5 column, with a blank run between each hybrid to ensure fibre cleanness among the samples.

The volatile compounds were identified by comparing their mass spectra with library entries (NIST/EPA/NIH Mass Spectral Library, version 2.0d; National Institute of Standards and Technology, Gaithersburg, MA, USA). Internal standard method was used to semi-quantitatively calculate the volatile compound content of each sample.

2.4. Statistical analysis

The data were processed with analysis of variance (ANOVA). ANOVA and Duncan's multiple range tests were applied to the data to determine significant differences ($P < 0.05$). Principal component analysis (PCA) was conducted using the physicochemical parameters for TP, US, MW and HPP mandarin juices to discriminate the juices. All statistical analyses were operated using XLSTAT ver.7.5 (Addinsoft, New York, NY, USA).

Table 1
Numbers of total aerobic from untreatment (UT), thermal pasteurisation (TP), ultrasound (US), microwave processing (MW) and high-pressure processing (HPP) mandarin juice.

Treatments	Total aerobic bacteria
UT	$3.75 \pm 0.23^{a,*}$ [***]
TP	ND [***]
US	1.31 ± 0.12^{b}
MW	1.24 ± 0.12^{b}
HPP	ND

[*] Superscript letters on the same column show the significant difference between the treatments ($p < 0.05$).
[**] $\pm$ values are standard deviations.
[***] ND, not detectable (< 1 log CFU/mL).

3. Results and discussion

3.1. Microbiological analysis

Total aerobic bacteria were determined in the mandarin juice before and after processings (Table 1). In the untreated sample, total aerobic bacteria was 3.75 log CFU/mL. Directly after processing, the US and MW samples contained 1.31 and 1.24 log CFU/mL of total aerobic bacteria, respectively, and the TP and HPP samples contained lower 1 log CFU/mL. The total aerobic bacteria in the samples treated by the four processing technologies was < 2 log CFU/mL, thus indicating that all methods achieved an equivalent degree of microbial inactivation.

3.2. Sugar and acid composition

Sugar and acid are the basic nutrients in citrus juice. The pH, TSS, and TA of citrus juice are closely related to its sensory qualities, such as acidity, sweetness, and taste. The results (Table 2) showed no significant difference in pH, TSS, TA, and three kinds of soluble sugars in the juice that underwent four processing treatments ($P > 0.05$) compared with those of untreated juice. This finding indicates that the basic sour and sweet tastes of juice are not affected by novel processing methods and thermal pasteurisation. Similar observations on pH, TA, and TSS were reported in pomegranate juice, blueberry juice, pear juice, strawberry juice, and orange juice treated with novel processing technologies (Aaby, Grimsbo, Hovda, & Rode, 2018; Bisconsin-Junior et al., 2014; Mohideen et al., 2015; Pala, Zorba, & Ozcan, 2015; Saeeduddin et al., 2015). These results were in agreement with those for sucrose, glucose, and fructose levels in carambola juice treated with HPP (Huang, Chen, & Wang, 2018). Abid et al. (2014) also pointed out that US can substantially increase the content of sucrose, fructose, and glucose in apple juice.

3.3. Colour

Colour is the main index for consumers to evaluate the quality of fruit and vegetable juices and an important quality parameter in processing and storage. Carotenoids are one of the factors affecting the colour of citrus juice and are easily degraded or isomerised at high temperature.

Table 3 shows similar effects of different processing methods on the colour change trend of sample juice. Compared with those of the untreated juice, the L*, b* and ΔE increased, whereas a* decreased after the juice underwent different processing methods. This finding indicates that brightness increased, the yellow colour deepened, and the red colour faded in different degrees. The pasteurised juice had significantly higher L* but lower a* than the other treated juice samples ($P < 0.05$). The change in b* of juice was the most significant after US treatment possibly because US generates OH⁻, which causes Redox reactions and isomerisation of coloured substances. The positive effect of cavitation on the colour change of juice has been previously confirmed (Tiwari, Muthukumarappan, O'Donnell, & Cullen, 2008). According to the calculation result of ΔE, the colour difference before and after novel processing is less remarkable than that for thermal pasteurisation, indicating that the proposed method can protect the original colour and lustre of the juice to a great extent. These results are consistent with those for orange juice, carambola juice, grapefruit juice and grape juice (Gomes et al., 2017; Huang et al., 2018; Lee & Coates, 2003; Sulaiman, Farid, & Silva, 2017). US cavitation can inactivate polyphenol oxidase in fruit and vegetable juice, remove dissolved oxygen, inhibit browning caused by enzymes, destroy the cell wall and release natural pigment compounds to some extent, thereby allowing the fruit juice to have a good colour during processing. The cell membrane rupture theory of MW can explain this colour change. The improvement of mandarin juice colour after HPP is due to the inactivation of endogenous enzymes, and HPP can promote the dissolution of chromogenic substances in cells. Our findings conform to the study of Rayman and Baysal (2011) who also reported colour changes during the MW pasteurisation of carrot juice.

3.4. Bioactive compounds

Vc content is one of the most important parameters of nutritional quality in citrus juice, and its antioxidant properties are associated with a reduced risk of cancer and neurological and cardiovascular diseases. Given that enediol is a part of its molecular structure, Vc has an extremely unstable nature and thus is greatly affected by temperature, pressure, light, acid and other factors.

In this research, Vc content was significantly decreased in the juice processed by conventional thermal pasteurisation and the three novel processing technologies compared with that in the control (Table 4). The most significant decrease was caused by pasteurisation with 88.29% retention. Thermal pasteurisation can degrade ascorbic acid through oxidative reaction in most fruit derivatives. Maximum retention was observed under HPP (93.81%) because high pressure cannot destroy covalent bonds and therefore does not directly damage small molecules such as Vc (Ordóñez-Santos, Martínez-Girón, & Arias-

Table 2
Effect of untreatment (UT), thermal pasteurisation (TP), ultrasound (US), microwave processing (MW) and high-pressure processing (HPP) on sugar and acid indicators in mandarin juice.

Treatments	pH	TA	TSS	Fructose	Glucose	Sucrose
		(g/100 mL)	(Brix)	(g/100 mL)	(g/100 mL)	(g/100 mL)
UT	$3.43 \pm 0.00^{a,*}$ [**]	0.78 ± 0.00^{a}	13.31 ± 0.05^{a}	2.93 ± 0.03^{a}	2.93 ± 0.02^{a}	5.64 ± 0.25^{a}
TP	3.45 ± 0.00^{a}	0.82 ± 0.00^{a}	13.30 ± 0.05^{a}	2.92 ± 0.05^{a}	2.90 ± 0.04^{a}	5.31 ± 0.09^{a}
US	3.45 ± 0.00^{a}	0.77 ± 0.01^{a}	13.43 ± 0.05^{a}	2.95 ± 0.00^{a}	2.85 ± 0.02^{a}	5.37 ± 0.01^{a}
MW	3.45 ± 0.00^{a}	0.78 ± 0.02^{a}	13.33 ± 0.05^{a}	2.97 ± 0.00^{a}	2.89 ± 0.01^{a}	5.48 ± 0.00^{a}
HPP	3.42 ± 0.00^{a}	0.80 ± 0.01^{a}	13.33 ± 0.10^{a}	2.95 ± 0.00^{a}	2.90 ± 0.02^{a}	5.43 ± 0.00^{a}

[*] Superscript letters on the same column show the significant difference between the treatments ($p < 0.05$).
[**] $\pm$ values are standard deviations.

Table 3

Effect of untreatment (UT), thermal pasteurisation (TP), ultrasound (US), microwave processing (MW) and high-pressure processing (HPP) on colour indicators in mandarin juice.

Treatments	L_*	a_*	b_*	ΔE
UT	43.88 ± 0.03[d]*,**	9.95 ± 0.02[a]	28.01 ± 0.09[d]	0
TP	47.15 ± 0.03[a]	6.91 ± 0.02[d]	30.06 ± 0.05[b]	2.69 ± 0.04[a]
US	45.80 ± 0.07[b]	7.17 ± 0.03[c]	31.86 ± 0.05[a]	2.60 ± 0.02[a]
MW	44.85 ± 0.04[c]	7.86 ± 0.03[b]	29.51 ± 0.05[c]	0.61 ± 0.04[b]
HPP	44.31 ± 0.07[c]	7.16 ± 0.03[c]	29.49 ± 0.09[c]	2.26 ± 0.06[a]

* Superscript letters on the same column show the significant difference between the treatments ($p < 0.05$).

** ± values are standard deviations.

Jaramillo, 2017), followed by MP (92.47%) and US (91.31%). In the study of Cinquanta, a slight decrease in Vc content was observed after MW heating (Cinquanta, Albanese, Cuccurullo, & Di Matteo, 2010). The variation of Vc content in the processed mandarin juice was consistent with that in processed cactus juice (HPP: 600 MPa, 10 min, 15 °C) (Moussa-Ayoub et al., 2017), blueberry juice (HPP: 600 MPa, 15 min) (Barba, Esteve, & Frigola, 2013) and carrot juice (US: 24 kHz, 54 °C, 10 min, 2155.72 mW/mL) (Martinez-Flores, Guadalupe Garnica-Romo, Bermudez-Aguirre, Pokhrel, & Barbosa-Canovas, 2015). However, Saeeduddin observed that US (20 kHz, 750 W, 10 min) at 45 °C–65 °C remarkably reduces the Vc content in pear juice, and this action may be associated with its cavitation effect to remove dissolved oxygen in fruits (Saeeduddin et al., 2015).

Next to vitamin C, also carotenoids are important quality indicators for citrus juice. Apart from being responsible for the colour of the juice, a number of them have provitamin A activity (e.g. β-cryptoxanthin, α-carotene and β-carotene) (Cortés, Esteve, Rodrigo, Torregrosa, & Frígola, 2006) and some have an antioxidant capacity (e.g. β-cryptoxanthin, β-carotene, zeaxanthin and lutein) (Rao & Rao, 2007). Citrus are a complex source of carotenoids and contain the largest amount of these pigments among all fruit species (Meléndez-Martínez, Britton, Vicario, & Heredia, 2008; Meléndez-Martínez, Vicario, & Heredia, 2007). However, carotenoids are highly unsaturated compounds with an extensive conjugated double-bonds system and thus are susceptible to oxidation, isomerisation and other chemical changes during processing (Shi & Le Maguer, 2000). And the majority of carotenoids are xanthophylls like β-cryptoxanthin, which are more sensitive to heat treatment than carotenes (α-carotene and β-carotene).

Table 4 shows that the total carotenoid content was the lowest in the pasteurised juice with only 59.84% retention. HPP and MW treatments had minimal effect on the degradation of total carotenoids with retention rates of 89.34% and 80.32%, respectively. The total carotenoid content in the US-treated samples was higher than that in the untreated samples possibly due to US cavitation and mechanical effects. The cell structure may have been destroyed and led to an adequate release of carotenoids, or the enzyme may have inhibited the activity of related degradation enzymes. Jabbar et al. (2014) obtained the same results, and Aadil (Sulaiman et al., 2017) found that high pressure can

also increase the carotenoid content.

In addition to carotenoids, other antioxidant compounds such as phenolics also contribute to the beneficial effects of citrus juice. Phenolics possess reducing character, capacity of sequestering reactive oxygen species and several electrophiles, tendency to self-oxidation and capacity to modulate the activity of some cell enzymes (Robards, Prenzler, Tucker, Swatsitang, & Glover, 1999).

As shown in Table 3, a significant decrease in total phenols was observed in all juice samples compared with those in the control. The phenolic content retentions in juice samples were TP = 51.39%, US = 73.25%, MW = 66.62%, and HPP = 71.29%, indicating that the amount of retained total phenols under the novel processing technologies was significantly higher than that under pasteurisation ($P < 0.05$). The most significant decrease in total phenol content was observed in the juice processed by thermal pasteurisation. Chen, Yu, and Rupasinghe (2013) reported that complex physical and chemical reactions, including the release of phenolic compounds from their binding forms, the degradation of polyphenols and the decomposition and transformation of phenolic compounds, will occur after the juice is pasteurised and thus affect the composition of phenolic compounds. US treatment can largely retain the content of total phenols in juice (Bhat, Kamaruddin, Min-Tze, & Karim, 2011; Ordóñez-Santos et al., 2017) possibly due to the generated strong shear force, leading to the destruction of cell walls and the release of polyphenols from cells. Additionally, the hydroxyl radicals formed through cavitation are added to adjacent or opposite positions of aromatic rings of phenolic compounds, resulting in structural changes (Abid et al., 2013). Apichartsrangkoon (Apichartsrangkoon, Chattong, & Chunthanom, 2012) found that high pressure processing (400 MPa, < 30 °C, 20 min) could remarkably retain the total phenolic content and antioxidant capacity in juice compared with pasteurisation (90 °C, 3 min) and high-temperature, short-time sterilisation (121 °C, 4 min). Barba et al. (2013) treated blueberry juice with 200, 400 and 600 Mpa for 5, 9, and 14 min, respectively, and found that the total phenol content increased by 13%–27% after treatment possibly due to the increase in the extractability of some antioxidant components after the high pressure treatment. The total phenol content of fresh grapefruit juice was 710 mg GAE/L, whereas those for juices that underwent conventional pasteurisation and MW

Table 4

Effect of untreatment (UT), thermal pasteurisation (TP), ultrasound (US),microwave processing (MW) and high-pressure processing (HPP) on Vc, the total phenolics, and the total carotenoids content in mandarin juice.

Treatments	Vc (mg/100 mL)	Total phenolics (mg/100 mL)	Total carotenoids (mg/100 mL)
UT	26.82 ± 1.56[a]*,**,***	43.78 ± 0.42[a]	1.22 ± 0.01[b]
TP	23.68 ± 0.00[c](88.29%)**	22.50 ± 0.89[d](51.39%)	0.73 ± 0.01[e](59.84%)
US	24.49 ± 0.13[bc](91.31%)	32.07 ± 0.99[b](73.25%)	1.25 ± 0.00[a](102.45%)
MW	24.80 ± 0.15[bc](92.47%)	29.17 ± 0.65[c](66.62%)	1.09 ± 0.00[c](89.34%)
HPP	25.16 ± 0.13[bc](93.81%)	31.21 ± 0.31[b](71.29%)	0.98 ± 0.00[d](80.32%)

* What's in the brackets is the retention rate of each indicator.

** Superscript letters on the same column show the significant difference between the treatments ($p < 0.05$).

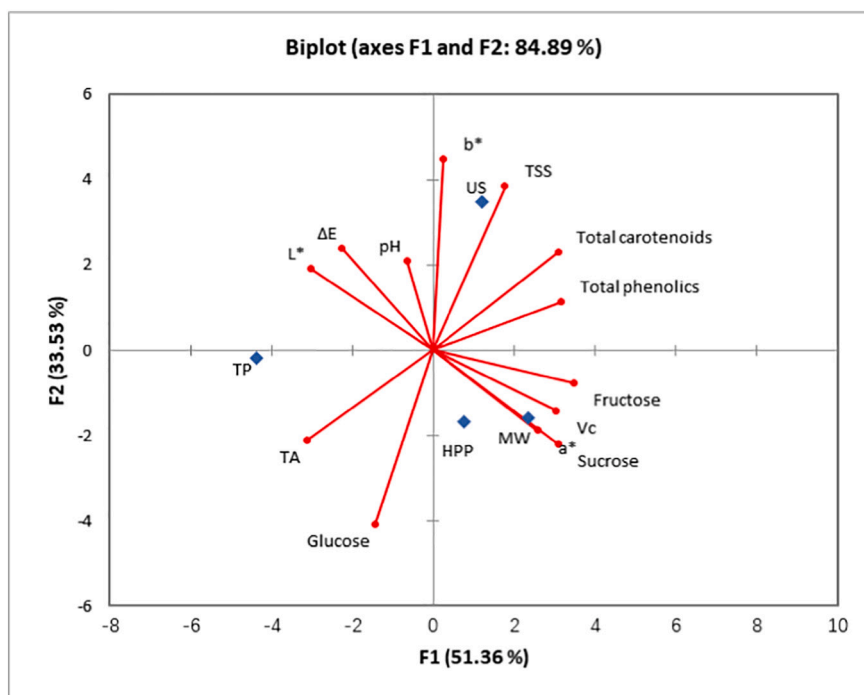*** ± values are standard deviations.

Fig. 1. Principal components plot of thermal pasteurisation (TP), ultrasound (US), microwave processing (MW) and high-pressure processing (HPP) mandarin juices.

Table 5
Effect of untreatment (UT), thermal pasteurisation (TP), ultrasound (US), microwave processing (MW) and high-pressure processing (HPP) on phenolic acids in mandarin juice.

Treatments	Gallic acid (mg/L)	Protocatechuic acid (mg/L)	p-hydroxybenzoic acid(mg/L)	Caffeic acid(mg/L)	p-coumaric acid(mg/L)	Ferulic acid (mg/L)	Erucic acid (mg/L)
UT	1.82 ± 0.00[ab]***	0.19 ± 0.00[ab]	0.90 ± 0.10[a]	2.90 ± 0.00[ab]	3.38 ± 0.03[a]	63.34 ± 0.68[b]	2.98 ± 0.46[a]
TP	1.03 ± 0.03[c]	0.16 ± 0.01[b]	0.81 ± 0.00[a]	2.59 ± 0.05[c]	3.13 ± 0.01[b]	61.22 ± 0.43[b]	2.72 ± 0.00[a]
US	1.10 ± 0.04[c]	0.19 ± 0.03[ab]	0.80 ± 0.03[a]	2.79 ± 0.14[bc]	3.42 ± 0.19[a]	63.73 ± 4.26[b]	2.73 ± 0.17[a]
MW	1.88 ± 0.16[a]	0.22 ± 0.02[a]	0.89 ± 0.01[a]	3.10 ± 0.11[a]	3.41 ± 0.03[a]	69.08 ± 1.13[a]	2.97 ± 0.05[a]
HPP	1.63 ± 0.02[b]	0.19 ± 0.00[ab]	0.88 ± 0.00[a]	2.82 ± 0.01[b]	3.44 ± 0.00[a]	62.84 ± 0.13[b]	2.97 ± 0.02[a]

* Superscript letters on the same column show the significant difference between the treatments ($p < 0.05$).

** ± values are standard deviations.

heating pasteurisation were 690.5 and 705.3 mg GAE/L, respectively (Rasoulian-Shabestari, Aminifar, & Rashidi, 2017). Igual, Garcia-Martinez, Camacho, & Martinez-Navarrete (2010) indicated that the frozen grapefruit juice samples preserved by MW have total phenol content and antioxidant capacity of 82% and 33%, respectively, which were superior to those of juice under conventional sterilisation (75% and 20%, respectively).

Principal Component Analysis (PCA) was used to represent data of physicochemical parameters to discriminate TP, US, MW and HPP mandarin juices (Fig. 1). PCA was suitable to differentiate the juices and to group the physicochemical parameters according to their spatial location. The US processed mandarin juice was loaded positively in PC1 and PC2, the HPP and MW mandarin juices were loaded positively in PC1 and negatively in PC2 and the TP mandarin juice was loaded negatively in PC1 and PC2. PC1 allowed to differentiate conventional thermal pasteurized from novel processing technologies processed juice, while PC2 allowed the discrimination of US from MW and HPP juice. PC1 was mainly influenced by loading positively the parameters total carotenoids, total phenolics, fructose, Vc and sucrose, characterizing both US, MW and HPP processed juice; and negatively the parameters TA, L* and ΔE, characterizing TP processed juice. PC2 was mainly influenced by loading positively b* and TSS, characterizing US

Table 6
Effect of untreatment (UT), thermal pasteurisation (TP), ultrasound (US), microwave processing (MW) and high-pressure processing (HPP) on flavonoids in mandarin juice.

Treatments	Narirutin (mg/L)	Naringin (mg/L)	Hesperidin (mg/L)	Neohesperidin (mg/L)	Nobiletin (mg/L)
UT	81.95 ± 1.79[a]***	0.81 ± 0.07[a]	16.12 ± 0.75[a]	1.26 ± 0.01[a]	2.09 ± 0.43[a]
TP	72.17 ± 8.82[b]	0.42 ± 0.04[b]	6.77 ± 0.00[c]	1.20 ± 0.04[ab]	0.90 ± 0.00[b]
US	70.48 ± 1.11[b]	0.86 ± 0.13[a]	6.81 ± 0.00[c]	1.24 ± 0.00[ab]	1.10 ± 0.00[b]
MW	74.77 ± 2.83[b]	0.92 ± 0.00[a]	6.84 ± 0.00[c]	1.07 ± 0.03[b]	1.10 ± 0.00[b]
HPP	72.33 ± 2.82[b]	0.97 ± 0.01[a]	8.82 ± 0.18[b]	1.14 ± 0.13[ab]	1.10 ± 0.00[b]

* Superscript letters on the same column show the significant difference between the treatments ($p < 0.05$).

** ± values are standard deviations.

processed juice, and negatively glucose characterizing HPP and MW processed juice.

Tables 5 and 6 show the changes in phenolic compounds including seven phenolic acids (gallic acid, protocatechuic acid, *p*-hydroxy benzoic acid, caffeic acid, *p*-coumaric acid, ferulic acid and erucic acid) and five flavonoids (narirutin, naringin, hesperidin, neohesperidin and nobiletin). The most abundant phenolic acid was ferulic acid (63.34 mg/L), followed by *p*-coumaric acid (3.38 mg/L), erucic acid (2.98 mg/L) and caffeic acid (2.90 mg/L). Agcam et al. (2014) reported that in orange juice, the most abundant flavonoid and phenolic acid are hesperidin and chlorogenic acid, respectively. Kelebek and Selli reported that gallic acid (3.01 mg/L), vanillic acid (2.93 mg/L), ferric acid (23.05 mg/L), erucic acid (17.75 mg/L) and caffeic acid (16.27 mg/L) are hydroxybenzoic acids with highest content in orange juice (Kelebek & Selli, 2011). No significant difference in *p*-hydroxybenzoic acid and erucic acid concentrations was observed from the samples treated by novel treatments or thermal pasteurisation ($p > 0.05$). However, a significant difference was detected for other phenolic acid components ($p < 0.05$). Except for *p*-hydroxybenzoic acid and erucic acid, the concentrations of phenolic compounds identified in mandarin juice were enhanced after US and WP. The TP-processed juice had lower phenolic acid content than the untreated juice, and this finding was in disagreement with the study of Sentandreu, Navarro, and Sendra (2007). HPP had less effect on phenolic acid concentration. Five flavonoids and the most abundant phenolic compound narirutin (81.95 mg/L) were determined in the mandarin juice samples. The concentration of most flavonoids significantly differed between the samples under novel processing treatments and thermal pasteurisation ($P < 0.05$). Except for naringin, the content of other flavonoids decreased after all treatments. The effect of thermal pasteurisation on flavonoid content was not significantly different from that of novel processing and was consistent with its influence on phenolic acid. Sentandreu et al. (2007) reported that the thermal pasteurisation (90 °C for 30 s) of orange juice had negligible effects on its phenolic substance content, and Agcam et al. (2014) showed that the orange juice treated with pulsed electric fields had more stable flavonoids and phenolic acids than those treated with thermal pasteurisation. These novel processing technologies restricted the degradation of phenolic acids and flavonoids and further promoted the release of various phenolic components.

3.5. Aroma components

Citrus juice flavour is largely determined by its aroma components, which are secondary metabolites that are formed during fruit ripening and mostly originated from fatty acids, amino acids and their precursors (Schwab, Davidovich-Rikanati, & Lewinsohn, 2008). Aroma components can be divided into two categories: free aroma components which are mainly composed of terpenes, esters, aldehydes, alcohols and ketones and are directly felt by consumers; and non-volatile components which are combined with sugars by glycosidic bond. The aroma precursors in the form of glycosides are called glycosidic bond aroma components. This substance is interpreted and released under the action of acid or enzyme and then volatilised, that is, free aroma components. Free aroma components are usually released only when the enzyme is separated before the ruptured cell interacts with the substrate. The content of glycoside bound aroma substances is usually higher than that of free aroma substances, making the former an important potential source of aroma components (Hadi et al., 2013). Volatile aglycones can be released from the sugar part during ripening, processing and storage or under the action of enzymes, acids or heat (Fan, Qiao, Yao, et al., 2009). Generally, orange juice has > 200 aroma substances mainly including aldehydes, esters, alcohols, ketones and terpenes (Lotong, Chambers, & Chambers, 2003) which also endow mandarin juice with unique citrus, sweet and floral flavour.

Forty-nine compounds were identified by GC–MS in the five samples

(Table 7). The number of aroma compounds was 25 in the untreated sample juice, and 25, 34, 33 and 26 in the TP-, US-, MW- and HPP-treated samples, respectively. The untreated sample juice had the highest content of aroma components at 91.89 μg/g. Among all the processed samples, the pasteurised juice had the lowest aroma content at only 43.97 μg/g, and the aroma contents in US-, MW- and HPP-processed juices were 61.71, 76.1 and 88.12 μg/g, respectively.

The terpene content in the untreated juice was 86.95 μg/g, which was higher than that in the processed juice. The terpene content in the pasteurised juice was the lowest at only 37.88 μg/g, which was 56.43% lower than that in the untreated juice sample. Meanwhile, the terpene content in the HPP-processed juice was 74.23 μg/g (Fig. 2). The

Table 7
Effect of untreatment (UT), thermal pasteurisation (TP), ultrasound (US), microwave processing (MW) and high-pressure processing (HPP) on contents and species of aroma substance in mandarin juice.

|	UT (μg/g)	TP (μg/g)	US (μg/g)	MW (μg/g)	HPP (μg/g)
Terpenes					
α-Pinene	0.53	0.3	0.48	0.63	0.77
β-Pinene	0.23	0.11	0.08	0.23	0.57
Myrcene	2.02	1.46	1.46	1.9	2.67
α-Terpinene	0.17	0.16	0.13	0.17	0.27
ᴅ-limonene	68.76	29.48	43.87	53.84	58.11
γ-Terpinene	6.56	2.74	4.17	5.28	8.49
Terpinolene	0.49	0.17	0.23	0.4	0.74
(-)-β-elemene	1.88	0.67	0.6	1.31	0.69
(-)-a-Cubebene	0.27	0.05	0.19	0.23	n.d[a]
Valencen	1.18	0.48	0.64	0.82	0.41
Selinene	0.7	0.23	0.17	0.42	0.27
α-Farnesene	1.76	0.94	1.06	1.39	0.54
δ-cadinene	0.89	0.37	0.58	0.6	0.24
p-Cymene	0.65	0.46	0.55	0.59	n.d
β-Caryophyllene	0.25	0.11	0.13	n. d	0.11
α-Caryophyllene	0.47	n. d	0.25	0.32	n. d
α-muurolene	0.14	n. d	n. d	n. d	n. d
α-Phellanderene	n. d	n. d	0.12	0.13	0.14
β-selinene	n. d	0.15	0.17	n. d	0.21
Alcohols					
Linalool	2.67	2.16	1.65	3.02	7.25
Terpinen-4-ol	0.62	0.5	0.61	0.69	2.18
α-Terpineol	0.75	1.55	1.67	0.77	1.81
1-Nonanol	0.2	n.d	n.d	0.34	n.d
1-Octanol	n.d	n.d	0.12	0.24	n.d
β-Terpineol	n.d	n.d	0.27	n.d	n.d
Cis-Carveol	n.d	n.d	0.25	n.d	n.d
Citronellol	n.d	0.1	0.15	0.14	0.58
2-Menthyl-1-pentanol	n.d	n.d	n.d	0.38	n.d
Cis-3-Hexen-1-o	n.d	n.d	n.d	0.3	n.d
Isooctyl alcohol	n.d	n.d	n.d	0.62	n.d
1-Heptanol	n.d	n.d	n.d	0.12	n.d
Phenylethyl alcohol	n.d	n.d	n.d	0.4	n.d
Aldehydes					
Nonanal	0.14	0.63	0.53	0.12	0.57
2-Hexenal	0.28	0.47	0.51	n.d	n.d
Caproaldehyde	n.d	0.5	0.5	n.d	n.d
Octanal	n.d	n.d	0.09	n.d	n.d
3-Methylbutyraldehyde	n.d	n.d	n.d	0.08	n.d
2-Methylbutyraldehyde	n.d	n.d	n.d	0.31	n.d
n-Undecanal	n.d	n.d	n.d	n.d	0.23
L-perillaldehyde	n.d	n.d	n.d	n.d	0.56
Ketones					
3-Nonanone	0.11	0.09	0.07	0.11	n.d
3-Undecanone	n.d	n.d	0.05	n.d	n.d
3-Pentanone	n.d	n.d	n.d	0.05	n.d
D(+)-Carvone	n.d	n.d	n.d	n.d	0.16
Esters					
Octyl formate	0.17	n.d	0.1	n.d	0.07
Ethylpropanoate	n.d	0.09	n.d	n.d	n.d
Isoamyl acetate	n.d	n.d	0.1	0.15	n.d
Acetic acid octyl ester	n.d	n.d	n.d	n.d	0.02
Geranyl acetate	n.d	n.d	0.16	n.d	0.25

[a] n.d, not detectable (< 1 log CFU/mL).
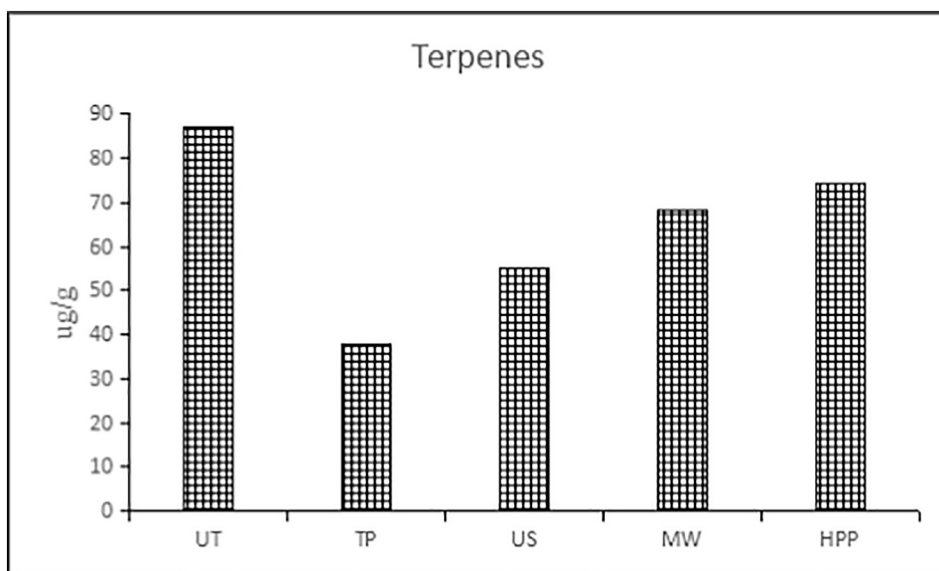
Fig. 2. The content of terpene aroma compounds in five samples.
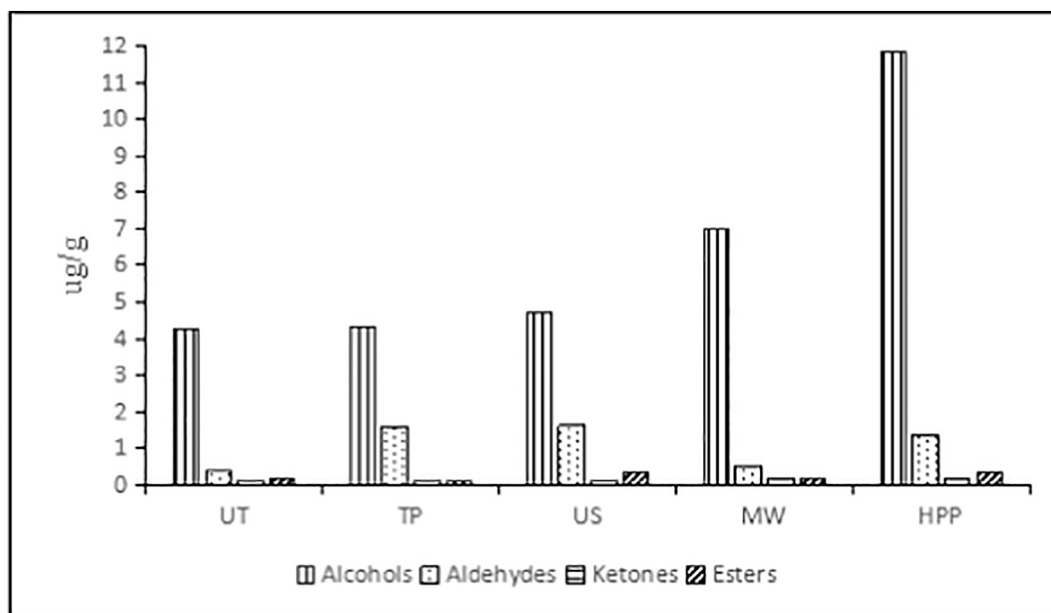

Fig. 3. The content of alcohol, aldehydes, ketone and ester aroma compounds in five samples.

untreated juice had 17 kinds of terpenes, and the PT-, US-, MW- and HPP-processed juices had 16, 18, 16 and 15 kinds of terpenes, respectively (Fig. 4). P-cymene, α-caryophyllene and α-muurolene were not detected in the processed samples, whereas α-phellanderene and β-selinene were newly detected in the treated juice. Among them, α-phellanderene has a positive effect on aroma (Xiao et al., 2017). The terpenes in the aroma components were mainly D-limonene, myrcene, valencen and α-pinene. As the most important terpene in citrus juice, the content of D-limonene decreased after processing, especially after pasteurisation; this phenomenon can be explained as the conversion of α-terpineol (Rouseff, Ruiz Perez-Cacho, & Jabalpurwala, 2009). Heating increases the rate at which a range of alcohols such as α-terpineol are produced from the acid-catalysed hydration of terpenes. In the same way, the terpene content of Valencia tangerine decreased after processing. Pasteurisation resulted in the most decrease, which can explain the oxidation of nootkatone (Vervoort et al., 2012).

The content of alcohol in the untreated juice was 4.24 μg/g, and that in the sample juice treated by MW and HPP was higher than that in the untreated juice at 7.02 and 11.82 μg/g, respectively. The content of alcohol after PT and US treatments was almost the same as that in the fresh juice (Fig. 3). Four kinds of alcohol aroma components were found in the untreated juice, and 4, 7, 11 and 4 kinds were discovered in the PT-, US-, MW- and HPP-processed juices, respectively (Fig. 4). Linalool, terpinen-4-ol and α-terpineol can be detected in all samples, and seven kinds of alcohol aroma components such as 1-octanol, β-terpineol, Cis-carveol and citronellol can only be detected in the processed samples. Linalool is the most important aroma components in citrus juice with higher content in the HPP-treated juice than in the untreated juice. The reason may be that HPP changes the activity of some enzymes and promotes the transformation of bonded aroma components. α-Terpineol is also an important aroma components in citrus juice. Its content increased after four processing methods, which can be explained by the degradation of D-limonene and linalool, resulting in the increase in α-terpineol content.
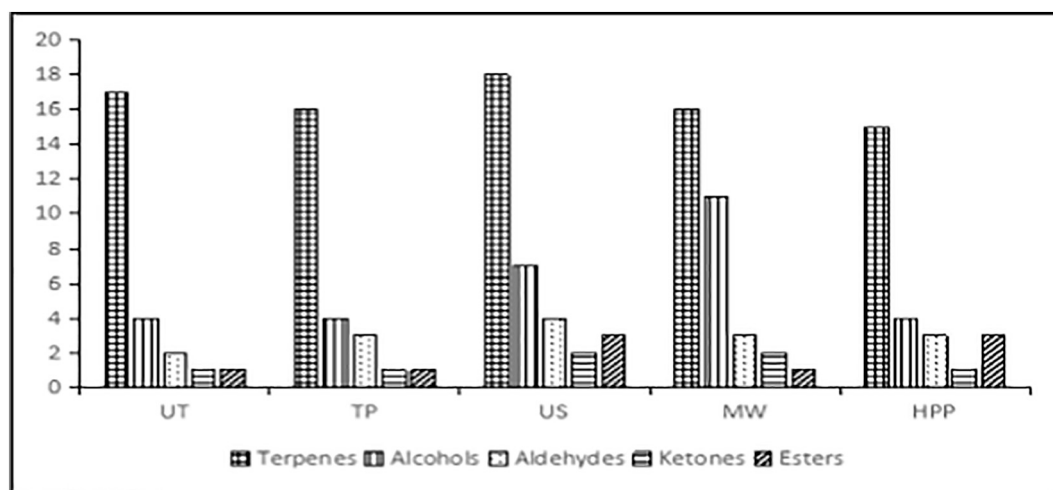
Fig. 4. The amount of terpene, alcohol, aldehydes, ketone and ester aroma compounds in five samples.

The content of aldehyde aroma components in untreated juice was 0.42 μg/g, which was lower than that in the sample juices treated by processing technologies. The content of aldehydes from US-treated juice was the most significant which increased by nearly three times compared with that from the untreated juice. The content of aldehydes increased slightly after MW treatment (Fig. 3). Two kinds of aldehydes were found in the untreated juice, and 3, 4, 3 and 3 kinds of aldehydes were found in the in sample juices after PT, US, MW and HPP treatments, respectively (Fig. 4). The main aldehydes aroma components were nonanal and 2-hexenal. Six aldehyde aroma components including caproaldehyde, octanal and n-undecanal were newly detected. Rouseff et al. (2009) reported that direct chain aldehydes increase with heating, resulting in their high levels in processed orange juice. Long-chain unsaturated fatty acids are precursors of many volatile compounds, including aliphatic saturated aldehydes.

The contents and numbers of ketones and esters were lower than those of other aroma compounds. The content of ketones in the untreated juice was 0.11 μg/g, which was higher than that in the PT-processed juice (0.09 μg/g). The ketone content in the three new processed juices was higher than that in the untreated juice, and that in the MW- and HPP-processed juices was up to 0.16 μg/g (Fig. 3). Only one kind of ketone was found in the untreated juice, and 1, 2, 2, and 1 ketones types were observed in the PT-, US-, MW- and HPP-processed sample juices, respectively (Fig. 4). Three new ketones were detected, namely 3-undecanone, 3-pentanone and D(+)-carvone. D(+)-Carvone is also an important off-flavour component in citrus juice (Hinterholzer & Schieberle, 1998) and was only detected in HPP-processed juice.

The content of ester aroma components in the untreated juice was 0.17 μg/g, which was higher than in the PT- and MW-processed juices. The content of ester aroma components in the US- and HPP-processed juices was twice higher than that in the untreated juice (Fig. 3). Only one ester component, namely, octyl formate was found in the untreated juice. Meanwhile, four new ester components, namely, ethylpropanoate, isoamyl acetate, acetic acid octyl ester and geranyl acetate were detected in the processed sample juices. These new detected esters have natural flower and fruit flavour. Processing technologies can reduce the content of octyl formate but can promote the formation of new esters. Esters are the main components of the attractive flavour of citrus juice (Xiao et al., 2017), which lead to the improvement of overall aroma.

In conclusion, pasteurisation has the most significant effect on the content and numbers of aroma components. Compared with pasteurisation, US, MW and HPP have stronger ability to maintain aroma components and promote the conversion of terpenes, alcohols and aldehydes into esters to improve the overall aroma. The high temperature

of pasteurisation can inactivate related enzymes, affect the release of aroma components and lead to the degradation of carotenoids, ascorbic acids, unsaturated fatty acids, amino acids, sugars, thiamine and other substances in citrus juice. This action promotes the hydration reaction catalysed by terpenes and acids, thus increasing the alcohol content (Janzantti & MachadoT, 2011; Vikram, Ramesh, & Prapulla, 2005); however, not all the reaction products have positive effects on the aroma of citrus juice. For example, α-terpineol can also promote the degradation of cinnamic acid to produce aromatic aldehydes and alcohols and the degradation of carbohydrates to produce odour substances furaldehyde and furanone, thereby affecting the overall aroma. US treatment can release bonding aroma components to some extent by affecting the enzyme activity, thus causing changes in the aroma. The kinds of aroma components in citrus juice treated by US were almost the same, but the relative content changed greatly (Wenwen et al., 2016). US treatment also promoted the transformation of alcohol and aldehydes in citrus juice into esters, improved the overall aroma of citrus juice and increased the content of α-terpineol and carvone, the typical off-flavour components in citrus juice. The combination of US and MW treatment for orange juice can achieve the effects of sterilisation and enzyme passivation and does not generate off-flavour components caused by overheating. Its evaluated flavour is remarkably better than that of traditional pasteurisation (Samani, Khoshtaghaza, Lorigooini, Minaei, & Zareiforoush, 2015). US can also be combined with heat or hydrostatic treatment to produce optimal germicidal and enzyme passivation effect on citrus juice. As an electrothermal process (Rayman & Baysal, 2011), MW does not overheat similar to pasteurisation and has limited influence on the structure of enzymes and aroma components. High pressure does not directly affect the structure of aroma components in citrus juice but can enhance or weaken the enzymatic reaction, which indirectly alters the content of some aroma components and destroys the balance of the whole flavour. Compared with that in fresh orange juice, 17 kinds of aroma components had decreased, and 15 kinds of new aroma components increased in the treated samples. The changes in the total content of hydrocarbons, alcohols and esters are relatively less, the content of aldehydes increases more than three times, and the content of other components has no significant change (Jian, Haixiang, Huiming, Yi, & Qingmei, 2011). Compared with heat treatment, HPP is more conducive to maintaining the natural flavour of orange juice (Mastello, Janzantti, Bisconsin-Júnior, & Monteiro, 2017) but still produces traces of off-flavour from α-terpineol and carvone. Oey, Lille, Loey, and Hendrickx (2008) proposed that β-glucosidase activity could be activated by HPP to enhance the release of aroma components in orange juice. Pan reported that HPP-processed orange juice has high contents of the following volatile

compounds: limonene, valencene, linalool, octanal and decanal. Decanal is the only major component not affected by HPP. Limonene and valencene are highly abundant in the untreated orange juice, and valencene, linalool and octanal are highly abundant in the HPP-treated orange juice (Jian et al., 2011).

4. Conclusions

Comparative evaluation regarding the microorganism inactivation was conducted for single-batch freshly squeezed mandarin juices prepared using conventional thermal pasteurisation and three novel processing technologies. The total aerobic bacteria content in the samples treated by the four processing technologies was < 2 log CFU/mL, thus achieving an equivalent degree of microorganism inactivation.

The sugar and acid composition was almost constant in all treated mandarin juices with no significant differences between treatments. Mandarin juices treated with the novel technologies maintained better colour, nutritional value, and aroma than the pasteurised mandarin juice. Additionally, US and HPP could induce the bound aroma compounds to preserve the original flavour of the juice. This study showed that US, MW and HPP are excellent new processing techniques to inactivate microorganisms and maintain the sensory and nutritional quality of mandarin juice.

Declaration of competing interest

We have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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检 索 报 告

项目名称：论文被 SCI 收录情况

委 托 人：西南大学柑桔研究所　　马亚琴

日　　期：2021 年 08 月 17 日

认证单位：教育部科技查新工作站 N08

二〇二〇年制

检索项目 名称	委托人提交论文被 SCI 收录情况			
查新机构	名　称	教育部科技查新工作站 N08	邮　编	400715
	地　址	重庆市北碚区西南大学图书馆	电　话	023-68253283
委托文献 目录	**Degradation behavior of polyphenols in model aqueous extraction system based on mechanical and sonochemical effects induced by ultrasound** **Wang, PX; Cheng, CX; (...); Jia, M** Sep 15 2020 ｜ SEPARATION AND PURIFICATION TECHNOLOGY 247 等 4 篇			
检索的数据库范围	1. Science Citation Index Expanded (SCIE) –1900 年至今 2. 中科院期刊分区数据在线平台升级版 3. 中科院期刊分区数据在线平台基础版			
检索要点	论文被 SCI 收录，影响因子,中科院分区情况			
检索结论	经检索，委托人提交的 4 篇论文被 SCI 收录，影响因子、分区等检索结果详细情况见附件 1 和附件 2。 　　检索人（签名）：周剑 　　　　　　　　　　　　　　　　　职称：研究馆员 　　　　　　　　　　　　　　教育部科技查新工作站 N08 　　　　　　　　　　　　　　　　2021 年 08 月 17 日			
备注	1、影响因子及分区为最新的影响因子和分区。			

附件 1：SCI 收录情况

序号	题名	检索号	影响因子	中科院类别　分区			出版时间	语种
1	Degradation behavior of polyphenols in model aqueous extraction system based on mechanical and sonochemical effects induced by ultrasound Wang, PX; Cheng, CX; (...); Jia, M Sep 15 2020 | SEPARATION AND PURIFICATION TECHNOLOGY 247	000536142200014	IF_{2020}=7.312	中科院类别升级版　　　分区 大类　工程技术　　　1 区 小类　ENGINEERING, CHEMICAL 工程：化工　1 区			2020	英文
2	Comparison of the effects of novel processing technologies and conventional thermal pasteurisation on the nutritional quality and aroma of Mandarin (Citrus unshiu) juice Cheng, CX; Jia, M; (...); Ma, YQ Aug 2020 | INNOVATIVE FOOD SCIENCE & EMERGING TECHNOLOGIES 64	000564512100007	IF_{2020}=5.916	中科院类别升级版　　　分区 大类　农林科学　　　1 区 小类　E FOOD SCIENCE & TECHNOLOGY 食品科技　2 区			2020	英文
3	Evaluation of the effect of ultrasonic variables at locally ultrasonic field on yield of hesperidin from penggan (Citrus reticulata) peels Ma, YQ; Ye, XQ; (...); Han, Z Mar 2015 | LWT-FOOD SCIENCE AND TECHNOLOGY 60 (2) , pp.1088-1094	000347740800004	IF_{2015}=2.711	中科院类别基础版　　　分区 大类　工程技术　　　2 区 小类　E FOOD SCIENCE & TECHNOLOGY 食品科技　2 区			2015	英文
4	Considering solubility disparity and acoustic-cavitation susceptivity of neoteric solvents to accurately predict sono-recovery yield of value-added compounds Wang, PX; Ma, YQ; (...); Jia, M Dec 1 2021 | SEPARATION AND PURIFICATION TECHNOLOGY 276	000681684300001	IF_{2020}=7.312	中科院类别升级版　　　分区 大类　工程技术　　　1 区 小类　ENGINEERING, CHEMICAL 工程：化工　1 区			2020	英文