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Ultrasonic treatment maintains the flavor of the melon juice

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ABSTRACT

Thermal treatment usually leads to the flavor deterioration of melon juice. This study was initiated to evaluate the retention effect of ultrasonic (US) and ultra-high pressure (UHP) on volatile components of melon juice by gas chromatography-mass spectrometer (GC–MS) and gas chromatography-ion mobility spectrometry (GC-IMS). The electronic nose, electronic tongue, and GC-IMS analysis showed that US was much better way to contain the flavor of melon juice than UHP was does. The correlation coefficient between the US and the control was as high as 0.99. The concentration of characteristic aroma components in melon juice after ultrasonic treatment was 2.77 times and 3.02 times higher than that in the control and UHP, respectively. Moreover, the US treatment gave no significant difference in the total soluble solids, pH, and color of the juice. And it dramatically enhanced the flavor profile of melon juice.

1. Introduction

Melons (*Cucumis melo* L.) are highly popular as its delicate and delightful flavor in the worldwide. However, the flavor of the melon juice was easily affected by thermal treatments and unpleasant cooking smell during production process, such as dimethyl sulfide, methional, and dimethyl trisulfide etc. [1,2] The unpleasant cooking smell hindered the melon juice further prevailing trend among market. Ultra-high pressure (UHP) and Ultrasonic (US) are non-thermal processing methods, which avoids the cooking smell led by the thermal treatments [3,4]. Ultra-high pressure (UHP) has achieved very excellent results in the deep processing of fruit juice [5]. It transmitted high hydrostatic pressure through liquid, thus reducing the damage to the food matrix structure [6]. Compared with thermal treatments, UHP reduced the negative impact on food nutrition and flavor by delicately controlling the temperature change of the food matrix during processing [7]. UHP kept the unique flavor of different juices, such as mango juice [8], cloudy pomegranate juice [9], and mulberry juice [10]. In our previous study, UHP had a good effect on enhancing the characteristic flavor of melon juice. When the pressure was 200 MPa and the holding time was 20 min, the total concentration of 8 aromatic components was enhanced to 1.49 and 6.99 times of the control and UHT, respectively [11].

The application of ultrasonic technology in the juice industry is increasing day by day. The US can improve the quality [12], microbial safety [13,14] and nutritional value [4] of fruit juice [15] due to the cavitation phenomenon which caused by the acoustic and hydrodynamic effects [16]. Most research in the US was focused on the stability [17], nutrients [18,19] and antioxidant capacity [20,21] of fruit juice, However, the influence on its flavor was often regarded as an accessory and has not been studied in depth. Limited research manuscripts showed some new nectar-profile volatile compounds in cranberry juice were produced by US processing and were superior to thermal group in sensory evaluation [22].

The aim of this study was to further analysis the effects of US and UHP on the flavor of melon juice. The qualities of the juice, such as the color and soluble solid content were well compared. The difference of the juice was distinguished by electronic nose and electronic tongue. Moreover, the volatile components of the juice were further identified by GC-IMS and GC–MS analysis.

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2. Materials and methods

2.1. Raw material and treatment

The melon (*Cucumis melo* L. var. Xizhoumi No. 25) was purchased from ordinary fruit supermarket in Beijing, China. Melons with homogeneous color, size and maturity were chosen for the experiment. After cleaning, peeling and slitting, they were smashed in a juicer (HR1861, Philips Ltd., Beijing, China). All melon juices were mixed at room temperature of 25 degrees Celsius for 2 min and subsequently packaged in aluminum foil bags per 200 mL.

2.2. Experiment design

Melon juice was treated with two different non-thermal processing methods, and three groups of samples were collected: control, US, and UHP. The detailed processing method was as follows:

Control: Melon juice was stored in the refrigerator (4 ℃) for further experiments after cleaning the foam from the juice top.

US: Melon juice was ultrasound-treated for 10 min at room temperature in a circulating water bath by using an ultrasonic sterilizer (KQ-300E, Kunshan, China). The US group was processed at a constant working frequency of 40 kHz, and the power output was 300 W.

UHP: Melon juice was filled into 200 mL aluminum foil bags and then treated at 200 MPa for 20 min by the ultra-high pressure unit (BDS200-FL, STANSTED FLUID POWER ltd, England) at room temperature [11].

2.3. Determinations of total soluble solids and pH

The total soluble solids (TSS) of samples were measured at room temperature by using a digital refractometer (PAL-, ATAGO company, Japan) and described as °Brix with water as a blank [23]. The pH values of the samples were measured at room temperature by a pH meter (SevenCompact-S210, METTLER TOLEDO, America). The measurement of TSS and pH was repeated 3 times on melon juice.

2.4. Color difference

The color difference of samples was determined by a desktop color difference meter (CM-3700d, Konica Minolta, Japan). Color was expressed with L*for lightness, a* for redness, b*for yellowness, and ΔE for total color difference. Five evenly distributed points of the juice sample were selected for color difference analysis, and the measurement was repeated 3 times for each point.

2.5. Flavor difference analysis

The flavor difference of the sample was analyzed by an electronic nose (PEN3, AIRSENSE, Germany). Nine mental oxide sensors made up the sensor array for the experiments. The names of the sensors have the following response characteristics: W1C (aromatic compounds); W3C (ammonia and aromatic compounds); W6S (hydrogen); W5C (olefin and aromatic compounds); W5S (hydrocarbons); W1S (broad-methane); W1W (hydrogen sulfide); W2S (alcohols and partially aromatic compounds); W2W (aromatic compounds and organic sulfides); and W3S (alkanes (methane, etc.) [24]. After each test, a calibration technique for the sensor probe by using zero gas (activated carbon filtered gas) can be used to reduce the impact of changes caused by external parameters like: air relative humidity, temperature changes, and sensor changes over time.

The samples (15 mL) were placed in headspace vials. The vial was incubated at room temperature for 30 min. The headspace gas in the vial was extracted using a pump from the E-nose system at a flow rate of 300 mL/min and evaluated with the MOS sensors. The measurement time and flush time were 100 and 100 s, respectively. A signal was recorded every second during the sample inspection.

2.6. Taste difference analysis

The taste difference of samples was analyzed by an electronic tongue (SA402B, Insent Company, Japan). The electronic tongue consists of 6 test sensors and 3 reference sensors. The sensors were expressed as CA0, CT0, AAE, C00, AE1, and AL1 that represented the intensity of sour, salty, fresh, bitter, acerbity, and sweetness, individually.

The samples of 50 mL were mixed with 100 mL of water. The mixture was centrifuged at 5000 rpm for 10 min and filtered with three layers of gauze. Poured the filtered sample into the electronic tongue sample cup, and adjusted the operating parameters for measurement.

2.7. GC-IMS analysis

The flavor changes of melon juice with different treatment methods were detected by using gas chromatography-ion mobility spectrometry (GC-IMS) (FlavourSpec®, G.A.S., Dortmund, Germany) equipped with MXT-5 (15 m × 0.53 mm × 1 μm) [25]. A total of 2 mL liquid samples were put into headspace bottles (20 mL) and incubated for 15 min at 35 ℃. After incubation, 200 μL of headspace gas from the headspace bottle was automatically drawn into the heating injector by a heated syringe needle (45 ℃). The chromatographic column was kept at 40 degreesC and ran for 20 min. The carrier gas was high pure nitrogen (99.99 %) and its flow rate program was as follows: 2 mL/min for 2 min, 100 mL/min for 23 min, 100 mL/min for 5 min. The drift gas (nitrogen gas) flowrate in drift tube was 150 mL/min. The *n*-Ketones C4-C9 (Ruisi Taikang Technology Co., ltd. Beijing, China) were used to calculate the retention index (RI). The identification of volatile compounds relied on the comparison of drift time (i.e., the time in milliseconds taken for ions to reach the collector through the drift tube) and RI in the GC-IMS library (Gesellschaft für Analytische Sensorsysteme mbH, Dortmund, Germany). The intensity of volatile compounds was measured in light of the peak volume.

2.8. SPME and GC–MS analysis

The volatile compounds were detected by using a headspace solid-phase microextraction (HS-SPME) tandem gas chromatography-mass spectrometer (GC–MS) method as described by Luo et al. [1] with a few modifications. The sample (6.0 g) was transferred into 20 mL headspace glass vials containing 2.0 g of sodium chloride and 10 μL of octanol (30 μg/mL) as an inner standard. The sample was stirred at 100 rpm and its volatile compounds in the headspace were extracted and absorbed by a SPME fiber (57329-U PDMS/DVB/CAR, Sigma-Aldrich company, USA) at 50 ℃ for 30 min. After being absorbed, the absorbed compounds were thermally desorbed at 250 ℃ for 3 min in a splitless mode by a GC–MS system (6890 N/5977B, Agilent Technologies Company, USA). Volatile compounds were separated on a DB-5MS elastic capillary column (30 m × 0.25 mm × 0.25 μm; Agilent Technologies, USA). Helium was used as a carrier gas with a constant flow rate of 1.0 mL/min. The initial temperature in the oven was set at 35 ℃ for 5 min, and increased at a rate of 4 ℃/min to 150 ℃, held for 3 min, and increased at a rate of 8 ℃/min to 190 ℃, held for 1 min, and ramped up to 250 ℃ at 30 ℃/min, and held at 250 ℃ for an additional 5 min. The full scan mode was adopted to collect signals at a scan speed of 1562 u/s. The mass detector was operated in electron impact mode (70 eV). The temperature of the ion source was 230 ℃, the transmission line temperature was 250 ℃, and the quadrupole temperature was 150 ℃. Identification of the detected volatile compounds was performed by comparing the mass spectra with those in mass spectral libraries (NIST17). The concentration of each aromatic compound was calculated based on the peak area of 1-octanol, an internal standard with a known concentration (Eq. (1)).

$$m_x = \frac{C_i \times V_i \times A_x}{m_s \times A_i} \times 1000 \quad (1)$$

Where C_i was the mass concentration of the internal standard compound, and the unit was μg/mL; V_i was the added amount of internal standard in the sample, 10 μL; m_s was the sample mass of 6 g; A_x and A_i were the peak areas of the target compound and the internal standard compound, respectively; m_x was the concentration of the target compound, expressed in μg/kg fresh weight (FW).

2.9. Statistical analysis

All basic physical and chemical indexes (TSS, pH, color difference) and flavor indexes (electronic nose and electronic tongue) were measured and repeated three times. The SPSS statistical 26 (IBM Corporation, Armonk, NY) was used to perform one-way analysis of variance (ANOVA) on different groups (CK, US, and UHP) of melon juice to test for significant differences. The value of $P < 0.05$ represented statistical significance. PCA was performed by using the SIMCA-P$^+$ software (version 11.0; Umetrics, Umeå, Sweden). The Origin 2021 software (OriginLab Corporation, Northampton, MA, USA) was used for Venn diagram. The concentration analysis chart and correlation coefficient of melon juice was made with Excel (Microsoft Office excel, Microsoft, USA).

3. Results and discussion

3.1. Effects of US and UHP on TSS, pH, and color parameters of melon juice

The TSS, pH, and color difference of US and UHP processed melon juice are shown in Table 1, which shows a significant difference among all samples ($P < 0.05$). The US was relatively closer to control. The Maillard reaction caused by a variety of temperature was the main reason for the reduction of TSS [26]. The UHP had a slight effect on the temperature of the sample. The temperature difference (ΔT) per 100 MPa for foods with high water content fluctuates around 3 ℃ [7]. The US had little effect on the temperature of melon juice, so its TSS and pH values had no difference in statistics with fresh melon juice.

The UHP made the color of melon juice brighter and redder. There was no statistical difference between the color index of the US and control from Table 1. ΔE value was the major index to evaluate color change. It has been generally believed that a ΔE value greater than or equal to 3.0 could be a significant visual difference for normal consumers, and <1 makes almost no difference [27]. UHP and US did not seriously damage the color of melon juice, especially the US. Similar results were observed in diluted avocado puree [28] and soursop juice [29]. Further, either color stability or undetectable color variations were reported for juice processed with US. The reasons for this phenomenon were mentioned in the study of ultrasonic treatment of peach juice. Ultrasonic treatment led to changes in the size and number of particles in the juice which in turn led to changes in light reflection and the possibility of increased pigments (dissolved oxygen) [30].

In general, the performance of the US treated melon juice in TSS, pH, and color difference were closer to that of fresh melon juice, while the UHP has a slight impact on the physical and chemical indexes of juice.

3.2. Flavor and taste difference analysis

The electronic nose and electronic tongue utilize chemical sensor arrays to simulate the human olfactory and taste systems to identify and distinguish complex volatiles [31]. The response values of 10 electronic nose sensors were analyzed by PCA to distinguish the flavor differences among the 3 treatment groups (Fig. 1A). The position of the 3 treatment groups in the figure and the distance between them can clearly distinguish the flavor similarity. The closer the distance, the higher the flavor similarity. The variance of PC1 was 87.5 %, the variance of PC2 was 0.45 %, and the sum of the two variances was 100 %, indicating that PC1 and PC2 covered all the flavor information of the samples. PC1 contained the most of samples flavor information. In PC1, both US and UHP had significant differences with the control. The distance between US and UHP was the largest and the distance between US and the control was the smallest.

The similar results were showed in the PCA analysis of melon juice electronic tongue (Fig. 1B). The sum of variances of PC1 and PC2 was 100 %, of which the variance of PC1 was 90.5 %, covered the most flavor information of the samples. The distance between US and the control was the smallest. In other words, the US had a relatively good effect on retaining the taste and smell of melon juice. A similar conclusion was also proved in the case of cranberry juice [22]. It was speculated that the main reason was that the temperature change caused by US could not change the composition of aromatic components in melon juice [32,33].

3.3. Volatile compounds identified by GC-IMS

For visual observation and comparison, topographic plots were used to describe the components of melon juice with different treatment methods (Fig. 2A). The ordinate represents the retention time of gas chromatography. Most of the signals appeared at the retention time of 100 to 300 s. In Fig. 2A, different points represented different volatile compounds. The red spots indicated that the content of the volatile compounds was high. The spot position and brightness of the US and control were almost the same. This meant that the flavor composition of the US was exactly the same as that of the fresh melon juice. The spot in the yellow rectangle was reduced and some new compounds were generated compared with the other two groups. This meant that UHP made melon juice produce some new volatile compounds and reduce some original characteristic flavors of fresh melon juice.

According to the peak signal of the topographic plots, the fingerprint of melon juice was formed (Fig. 2B). Each row represented the samples of different treatment groups. Each column represented the signal peak of the same substance in different treatments. If two substances have the same name in the fingerprint results, they are the monomers and their dimers.

There were 53 signal peaks in Fig. 2B, and a total of 34 volatile compounds were identified (Table 2). The types and contents of volatile compounds in the US and control were similar. Most of them were C6-C9 esters and aldehydes with obvious fragrance and fruit flavor [34]. Such as (Z)-6-nonenal, nonanal, heptanal, hexanal, which was characteristic aroma profile of melon [35]. There was a significant difference in the fingerprint distribution between the UHP and control. Some compounds that did not exist in the fresh melon juice were added, and these newly added compounds played a key role in the flavor expression of the UHP. Such as (E)-2-Nonenal, (E,Z)-2,6-Nonadienal, 2-Methylbutanol acetate, which was also a characteristic aroma of melon [35]. That was to say, UHP would not produce bad volatile compounds. It was speculated that the production of newly added compounds was due to the molecular

Table 1
Total soluble solids, pH and color difference of different treatments.

Treatments	TSS/°Brix	pH	L*	a*	b*	ΔE
Control	8.53 ± 0.06^{b}	6.47 ± 0.02^{c}	41.20 ± 0.24^{b}	0.66 ± 0.02^{b}	5.16 ± 0.07^{a}	
US	8.47 ± 0.06^{b}	6.51 ± 0.01^{b}	41.22 ± 0.14^{b}	0.66 ± 0.03^{b}	5.17 ± 0.13^{a}	0.37 ± 0.08^{b}
UHP	9.60 ± 0.00^{a}	6.62 ± 0.01^{a}	41.60 ± 0.12^{a}	0.75 ± 0.01^{a}	3.76 ± 0.02^{b}	1.46 ± 0.05^{a}

Notes: There are significant differences between data with different superscripts in the same column ($P < 0.05$).

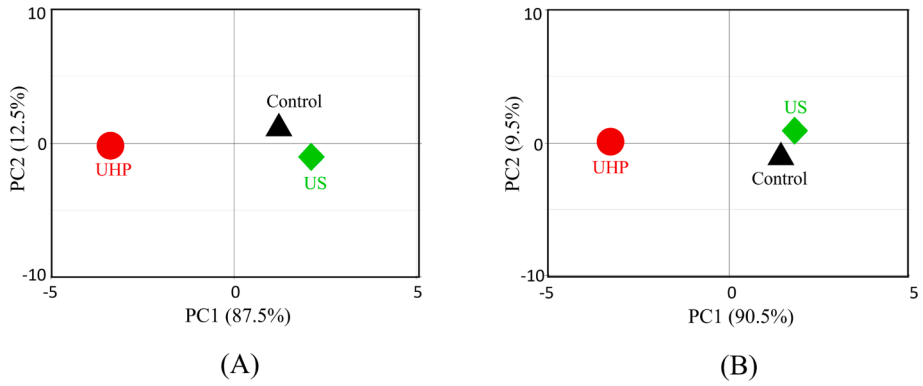

Fig. 1. PCA analysis of electronic nose (A) and electronic tongue (B) sensors.

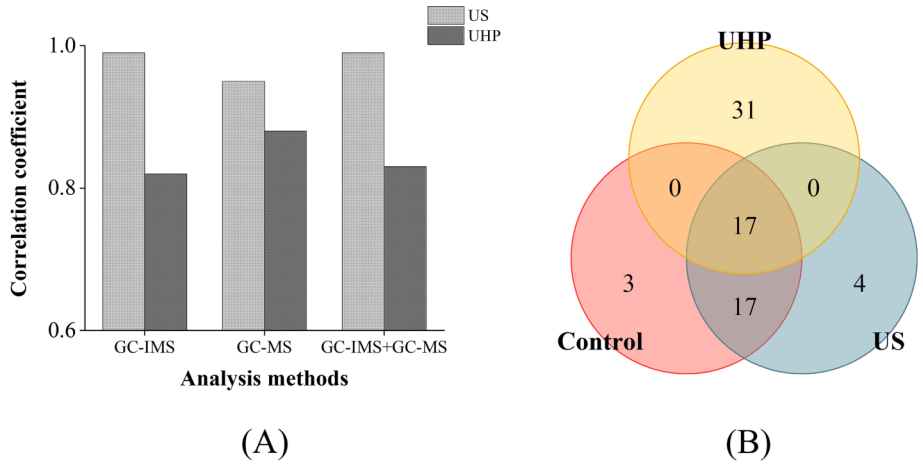

Fig. 2. (A) 2D-topographic plots of volatile compounds in melon juice at different treatments. (B) Fingerprint of volatile compounds in melon juice at different treatments.

aggregation caused by high pressure, thus reducing the C—C bond lengths [36–38]. In this process, the structure of volatile components changed, thus forming new characteristic aromatic components [39].

3.4. Volatile compounds identified by GC–MS

The flavor of melon juice treated by US and UHP was identified by GC–MS. Aldehydes, alcohols, esters, and ketones constituted the flavor display of melon juice. There were 59 volatile components, including 17 esters, 16 alcohols, 14 aldehydes, and 12 ketones, were detected (Table 3). The US made the concentration of each kind of volatile component reach its highest. This was consistent with the report on ultrasonic processing of mulberry juice [40]. The total concentration of volatile components in the US was 2.64 and 3.13 times that of the control and UHP, respectively. The results of GC–MS were similar to those of GC-IMS in the types of characteristic volatile component of melon juice, including many C6-C9 esters and aldehydes were detected. C6-C9 aldehydes and their corresponding alcohols or straight chain lipids were produced through fatty acid metabolism [41] and played an important role in melon flavor quality [35].

3.5. Correlation analysis of melon juice flavor detection among different treatments

The correlation analysis was used to explore the relationship between the volatile compounds of the control with the US and UHP, respectively (Fig. 3A). The correlation coefficients of the US with the control volatile compounds in different detection method reached 0.95 and more. And the correlation coefficient between UHP and control group was only about 0.83. This indicated that the volatile compounds of the US were the same as those of fresh melon juice. Similar results were demonstrated in cranberry juice, where the composition of the ultrasound-treated juice was more similar to that of fresh juice [22]. Therefore, US technology was better than UHP to maintain the composition of volatile components in fresh melon juice.

Although different treatments had great influence on the types of volatile components in melon juice (Fig. 3B). A total of 17 volatile components were the common flavor of the three groups, all of which were characteristic flavor profiles of melon juice. This indicated that both US and UHP have less effect on the natural flavor of melon juice. In addition, there were 4 volatile components that only existed in the US. For example, hexanal had the flavor of grass and apple [34]. There were up to 31 volatile components only present in the UHP. For example, (E)-2-nonenol, a characteristic flavor of melon juice, may be converted from (E)-2-nonenal by alcohol dehydrogenase (ADH) [42]. Besides, the other 17 kinds of volatile components only exist in the US and control. However, no similar volatile components were found both in the UHP and the control or in the US. This was consistent with the results observed in GC-IMS. The US was more similar to fresh melon juice in flavor composition, while the UHP produced new volatile components that are different from fresh melon juice.

3.6. Effects of different treatments on the concentration of characteristic aromatic components

Identification of volatile components in melon juice by GC–MS and

Table 2
GC-IMS integration parameters of volatile compounds in melon juices.

No.	Volatile compounds	CAS	Formula	MW	RI	Rt (*sec*)	Dt (RIP relative)	Control (a.u.)	US (a.u.)	UHP (a.u.)
1	(E)-2-Nonenal (M)	18829-56-6	$C_9H_{16}O$	140.2	1154.4	910.498	1.40748	377.5	673.52	1498.55
2	(E,Z)-2,6-Nonadienal (M)	557-48-2	$C_9H_{14}O$	138.2	1147.8	894.226	1.36547	268.58	564.77	1142.22
3	(Z)-6-Nonenal (M)	2277-19-2	$C_9H_{16}O$	140.2	1104.7	794.244	1.16961	584.23	901.33	328.33
4	(Z)-6-Nonenal (D)	2277-19-2	$C_9H_{16}O$	140.2	1103	790.575	1.76984	172.1	272.54	148.18
5	*n*-Nonanal (M)	124-19-6	$C_9H_{18}O$	142.2	1106.1	797.374	1.47813	3441.1	4231.45	2996.36
6	*n*-Nonanal (D)	124-19-6	$C_9H_{18}O$	142.2	1105.7	796.524	1.93787	779.86	1143.9	552.34
7	2-Ethyl-1-hexanol	104-76-7	$C_8H_{18}O$	130.2	1009.5	611.279	1.40196	530.05	589.47	486.78
8	6-Methyl-5-hepten-2-one	110-93-0	$C_8H_{14}O$	126.2	991.2	577.615	1.17036	39.61	53.79	48.26
9	Benzaldehyde (M)	100-52-7	C_7H_6O	106.1	969.4	530.384	1.14777	1609.69	1452.38	1851.02
10	Benzaldehyde (D)	100-52-7	C_7H_6O	106.1	969.4	530.384	1.46687	684.16	687.29	719.92
11	(E)-2-Heptenal	18829-55-5	$C_7H_{12}O$	112.2	957.6	506.473	1.25265	157.79	182.94	222.15
12	Heptanal (M)	111-71-7	$C_7H_{14}O$	114.2	899.6	403.656	1.33277	552.17	834.62	550.22
13	Heptanal (D)	111-71-7	$C_7H_{14}O$	114.2	899	402.71	1.69493	105.36	160.68	68.46
14	2-Methylbutanol acetate (M)	624-41-9	$C_7H_{14}O_2$	130.2	877	370.528	1.28704	1275.35	1151.39	2222.38
15	2-Methylbutanol acetate (D)	624-41-9	$C_7H_{14}O_2$	130.2	875.9	369.108	1.73334	345.53	258.66	1073.16
16	2-Hexenal (M)	505-57-7	$C_6H_{10}O$	98.1	851.8	337.399	1.1773	825.96	966.06	405.64
17	2-Hexenal (D)	505-57-7	$C_6H_{10}O$	98.1	849.5	334.56	1.51019	147.74	175.65	84.26
18	Hexanal (M)	66-25-1	$C_6H_{12}O$	100.2	791.9	270.007	1.25988	1306.66	1554.4	794.01
19	Hexanal (D)	66-25-1	$C_6H_{12}O$	100.2	790.6	268.643	1.55797	432.74	677.67	355.38
20	3-Methyl-2-butenal (M)	107-86-8	C_5H_8O	84.1	790.6	268.643	1.09576	221.69	210.31	816.99
21	3-Methyl-2-butenal (D)	107-86-8	C_5H_8O	84.1	793.3	271.371	1.35869	210.94	231.21	350.57
22	Isobutyl acetate	110-19-0	$C_6H_{12}O_2$	116.2	764.9	243.415	1.60989	1915.07	1710.96	6205
23	(E)-2-Pentenal	1576-87-0	C_5H_8O	84.1	751.6	231.142	1.10581	398.17	433.07	1307.59
24	Pyridine	110-86-1	C_5H_5N	79.1	736.8	218.184	1.24091	257.92	335.8	239.08
25	Propyl acetate	109-60-4	$C_5H_{10}O_2$	102.1	707.1	194.401	1.16153	632.74	502.78	1894.72
26	3-Pentanone	96-22-0	$C_5H_{10}O$	86.1	695.1	185.577	1.1087	426.18	400.28	1271.72
27	IsoPropyl acetate (M)	108-21-4	$C_5H_{10}O_2$	102.1	654.4	163.518	1.1693	3796	3852.41	1529.76
28	IsoPropyl acetate (D)	108-21-4	$C_5H_{10}O_2$	102.1	653.6	163.15	1.47384	3052.34	2767.19	2953.83
29	Ethyl acetate (M)	141-78-6	$C_4H_8O_2$	88.1	612.4	144.4	1.09316	4243.47	4246.47	489.34
30	Ethyl acetate (D)	141-78-6	$C_4H_8O_2$	88.1	609.8	143.297	1.33555	8201.53	8066.06	27493.6
31	Methyl acetate (M)	79-20-9	$C_3H_6O_2$	74.1	536.5	115.355	1.03101	12376.23	12132.01	16453.55
32	Methyl acetate (D)	79-20-9	$C_3H_6O_2$	74.1	529.9	113.15	1.19105	5282.64	4332.77	6984.08
33	(E) −2-Nonenal (D)	18829-56-6	$C_9H_{16}O$	140.2	1153.8	909.111	1.96247	70.45	101.55	182.18
34	(E,Z)-2,6-Nonadienal (D)	557-48-2	$C_9H_{14}O$	138.2	1149.4	898.11	1.89623	56.18	63.42	102.16
35	Area 7 *							435.00	494.17	456.82
36	Area 23 *							2783.02	2633.61	3610.45
37	Area 37 *							691.50	761.09	616.45
38	Area 38 *							445.17	398.13	1165.60
39	Area 39 *							349.73	390.70	1143.96
40	Area 40 *							50.86	52.80	371.74
41	Area 41 *							133.02	138.53	568.16
42	Area 42 *							2438.62	2803.11	4700.92
43	Area 43 *							2147.83	2250.70	4368.22
44	Area 44 *							121.31	125.55	2809.66
45	Area 45 *							120.76	146.42	1008.26
46	Area 46 *							222.68	245.59	1033.34
47	Area 47 *							10.25	9.12	16.70
48	Area 48 *							61.36	60.23	204.50
49	Area 49 *							398.70	593.04	448.35
50	Area 50 *							345.96	340.03	475.24
51	Area 51 *							160.69	154.46	1985.20
52	Area 52 *							777.95	770.31	1756.98
53	Area 53 *							1430.20	1997.55	2241.20

Notes: MW: Molecular weight, RI: the retention index, Rt: the retention time, Dt: the drift time. The peak area value is the mean of triplicate biological samples. "*" is means unidentified. "D" is the mean of dimer, "M" is the mean of monomer. In the same row with different letters differ significantly ($p < 0.05$).

GC-IMS, 10 volatile components were selected as the characteristic aromatic components of this study including 2-methyl-1-butyl acetate, ethyl acetate, (E,Z)-3,6-nonadien-1-ol, (Z)-3-nonen-1-ol, (E)-2-nonenal, (Z)-6-nonenal, acetal, nonanal, octanal and β-ionone. They were the key ingredients of melon's characteristic flavor and contributed to the perception of floral, sweet, and fruity fragrances [43,44].

Fig. 4 showed the effect of different processing methods on the concentration of the characteristic aromatic components of melon juice. The effect of US on the concentration of aromatic components was much stronger than that of UHP. The US made the total concentration of the characteristic aromatic components 2.77 times higher than that of the control and 3.02 times higher than that of the UHP. This may be due to cavitation generated by the US [45]. Cavitation effects produced chemical and physical changes, promoted the release of fatty acids, and decomposed water molecules to generate H and OH radicals, which acted as initiators of lipid oxidation to form hydroperoxide (ROOH) [46]. And then it was converted into corresponding aldehydes and alcohols by oxidation, splitting decomposition, and dehydrogenation [47], and further formed esters. On the other hand, US would lead to the rupture of cells in fruit juice, caused the release of cellular components, thus increased the concentration of characteristic aromatic components [30]. (E)-2-Nonenal and (Z)-6-Nonenal gave melon juice a distinct aroma and other sensory qualities [48]. It is worth noticing that that the concentration of (E)-2-Nonenal and (Z)-6-Nonenal increased significantly in the US, but they were not detected in the UHP. These two aldehydes may have a very high sensitivity to temperature. The UHP caused a temperature change in the juice [7], and then caused the damage to the molecule structure of (E)-2-Nonenal and (Z)-6-Nonenal.

Table 3
Volatile compounds and their concentrations in melon juice identified by GC–MS.

ID	Volatile compounds[a]	CAS	Molecular formula	Concentration (μg/kg)[b]		
				Control	US	UHP
Ester						
1	1,2-Benzenedicarboxylic acid, butyl octyl ester	84–78-6	$C_{20}H_{30}O_4$	–	–	–
2	1-Adamantanecarboxylic acid, 3-phenylpropyl ester	1000282–39-7	$C_{20}H_{26}O_2$	–	–	–
3	1-Butanol, 2-methyl-, acetate	624–41-9	$C_7H_{14}O_2$	13.83 ± 1.12	24.79 ± 1.02	9.76 ± 0.14
4	1-Butanol, 3-methyl-, acetate	123–92-2	$C_7H_{14}O_2$	1.56 ± 0.25	2.75 ± 0.45	–
5	2,3-Butanediol, diacetate	1114–92-7	$C_8H_{14}O_4$	1.62 ± 0.16	4.47 ± 1.72	4.65 ± 1.48
6	(Z)-3-Hexen-1-ol, acetate	3681–71-8	$C_8H_{14}O_2$	–	–	–
7	Acetic acid, 2-ethylhexyl ester	103–09-3	$C_{10}H_{20}O_2$	3.20 ± 0.87	–	–
8	Acetic acid, 2-phenylethyl ester	103–45-7	$C_{10}H_{12}O_2$	–	–	–
9	Acetic acid, butyl ester	123–86-4	$C_6H_{12}O_2$	1.09 ± 0.03	–	2.40 ± 0.89
10	Acetic acid, non-3-enyl ester, cis-	13049–88-2	$C_{11}H_{20}O_2$	1.13 ± 0.67	–	–
11	Acetic acid, phenylmethyl ester	140–11-4	$C_9H_{10}O_2$	27.97 ± 3.52	54.30 ± 4.12	–
12	Benzoic acid, 2,4-dimethyl-, (2,4-dimethylphenyl)methyl ester	55000–43-6	$C_{18}H_{20}O_2$	–	–	–
13	Cyclohexanol, 1-methyl-4-(1-methylethenyl)-, acetate	10198–23-9	$C_{12}H_{20}O_2$	1.15 ± 0.64	–	–
14	Ethyl Acetate	141–78-6	$C_4H_8O_2$	8.70 ± 1.54	24.67 ± 3.61	21.59 ± 3.43
15	Isobutyl acetate	110–19-0	$C_6H_{12}O_2$	5.40 ± 2.14	10.88 ± 3.25	12.25 ± 3.65
16	Isopulegol acetate	57576–09-7	$C_{12}H_{20}O_2$	–	2.94 ± 0.85	–
17	Propanoic acid, 2-methyl-, 3-hydroxy-2,2,4-trimethylpentyl ester	77–68-9	$C_{12}H_{24}O_3$	–	–	–
Alcohol						
1	(6Z)-Nonen-1-ol	35854–86-5	$C_9H_{18}O$	–	–	–
2	2-ethyl-1-Hexanol	104–76-7	$C_8H_{18}O$	13.64 ± 3.69	45.13 ± 5.96	13.55 ± 4.42
3	1-Nonanol	143–08-8	$C_9H_{20}O$	68.92 ± 10.23	103.49 ± 15.28	25.14 ± 5.52
4	1-Octanol	111–87-5	$C_8H_{18}O$	50.00 ± 0.00	50.00 ± 0.00	50.00 ± 0.00
5	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	6846–50-0	$C_{16}H_{30}O_4$	–	5.72 ± 1.12	–
6	2,4-Di-*tert*-butylphenol	96–76-4	$C_{14}H_{22}O$	77.71 ± 4.69	314.45 ± 23.68	2.79 ± 0.12
7	2-Nonen-1-ol	22104–79-6	C9H18O	–	–	2.52 ± 0.58
8	(E,Z)-3,6-Nonadien-1-ol	56805–23-3	$C_9H_{16}O$	54.49 ± 3.89	153.90 ± 8.39	51.68 ± 8.28
9	(E)-3-Hepten-1-ol	2108–05-6	C7H14O	–	–	1.24 ± 0.62
10	(Z)-3-Nonen-1-ol	10340–23-5	$C_9H_{18}O$	175.85 ± 13.65	496.50 ± 26.54	183.21 ± 13.48
11	4-[5-(2,4,6-trimethylbenzylthio)-1-tetrazolyl]-Benzamide	309735–33-9	$C_{18}H_{19}N_5OS$	–	–	–
12	Butylated Hydroxytoluene	128–37-0	$C_{15}H_{24}O$	–	–	4.82 ± 1.52
13	Eucalyptol	470–82-6	$C_{10}H_{18}O$	–	–	–
14	Phenylethyl Alcohol	60–12-8	$C_8H_{10}O$	–	–	–
15	dimethyl-Silanediol	1066–42-8	$C_2H_8O_2Si$	3.66 ± 0.52	8.77 ± 1.45	2.91 ± 0.61
16	(E)-Isoeugenol	5932–68-3	$C_{10}H_{12}O_2$	–	–	–
Aldehyde						
1	2,6,6-trimethyl-1-Cyclohexene-1-acetaldehyde	472–66-2	$C_{11}H_{18}O$	–	–	–
2	2,6,6-trimethyl-1-Cyclohexene-1-carboxaldehyde	432–25-7	$C_{10}H_{16}O$	2.24 ± 0.54	6.41 ± 1.03	2.55 ± 0.12
3	(E,E)-2,4-Decadienal	25152–84-5	$C_{10}H_{16}O$	–	–	–
4	(E)-2-Nonenal	18829–56-6	$C_9H_{16}O$	11.42 ± 1.30	47.05 ± 4.29	–
5	(E)-6-Nonenal	2277–20-5	$C_9H_{16}O$	–	–	18.69 ± 3.20
6	(Z)-6-Nonenal	2277–19-2	$C_9H_{16}O$	46.99 ± 5.29	127.13 ± 5.57	–
7	(Z)-7-Tetradecenal	65128–96-3	$C_{14}H_{26}O$	–	–	–
8	Benzaldehyde	100–52-7	C_7H_6O	1.56 ± 0.21	3.60 ± 0.01	–
9	Benzeneacetaldehyde	122–78-1	C_8H_8O	–	–	–
10	Decanal	112–31-2	$C_{10}H_{20}O$	1.20 ± 0.06	3.43 ± 0.57	–
11	Hexanal	66–25-1	$C_6H_{12}O$	–	3.22 ± 0.26	–
12	Nonanal	124–19-6	$C_9H_{18}O$	63.72 ± 4.25	210.11 ± 10.62	42.17 ± 2.13
13	Octanal	124–13-0	$C_8H_{16}O$	72.70 ± 7.57	157.53 ± 10.12	96.87 ± 8.23
14	(E)-2-Nonenal	18829–56-6	$C_9H_{16}O$	–	–	21.72 ± 3.62
Ketone						
1	2-ethylidene-1-Cyclododecanone	1138–01-8	$C_{14}H_{24}O$	2.14 ± 0.68	5.08 ± 1.69	–
2	2,6-bis(1,1-dimethylethyl)-2,5-Cyclohexadiene-1,4-dione	719–22-2	$C_{14}H_{20}O_2$	–	–	1.96 ± 0.54
3	1-(benzoyloxy)-2,5-Pyrrolidinedione	23405–15-4	$C_{11}H_9NO_4$	–	–	2.31 ± 0.78
4	1-(benzoyloxy)-2,5-Pyrrolidinedione	23405–15-4	$C_{11}H_9NO_4$	–	–	2.31 ± 0.95
5	2,6-Di-*tert*-butyl-4-hydroxy-4-methylcyclohexa-2,5-dien-1-one	10396–80-2	$C_{15}H_{24}O_2$	–	–	15.12 ± 4.62
6	(E)-2,6-Naphthalenedione, octahydro-1,1,8a-trimethyl-	57289–17-5	$C_{13}H_{20}O_2$	–	–	1.08 ± 0.16
7	4-Hydroxy-3-methylacetophenone	876–02-8	$C_9H_{10}O_2$	–	–	–
8	6,10-dimethyl-5,9-Undecadien-2-one	689–67-8	$C_{13}H_{22}O$	9.55 ± 2.01	–	–
9	(E)-6,10-dimethyl-,5,9-Undecadien-2-one	3796–70-1	$C_{13}H_{22}O$	–	38.63 ± 2.91	15.45 ± 1.19
10	6-methyl-5-Hepten-2-one	110–93-0	$C_8H_{14}O$	–	–	–
11	Isophorone	78–59-1	$C_9H_{14}O$	–	–	–
12	β-Ionone	79–77-6	$C_{13}H_{20}O$	3.25 ± 0.54	10.76 ± 2.65	4.12 ± 1.12
All esters			65.63 ± 10.94	124.80 ± 15.02	50.65 ± 9.59	

(*continued on next page*)

Table 3 (*continued*)

ID	Volatile compounds[a]	CAS	Molecular formula	Concentration (μg/kg)[b]		
				Control	US	UHP
All alcohols			444.27 ± 36.67	1177.97 ± 82.42	337.86 ± 35.15	
All aldehydes			199.83 ± 19.22	558.47 ± 32.47	182.01 ± 17.30	
All ketones			14.94 ± 3.23	54.47 ± 7.25	42.34 ± 9.36	
Total			724.67 ± 70.06	1915.70 ± 137.16	612.86 ± 71.40	

[a] Volatile compounds detected by the GC–MS compared with the standard mass spectrum in the NIST 17 library (an MS match index ≥80 % were listed).
[b] Each value is the mean of triplicate biological samples. "–" is not detected.

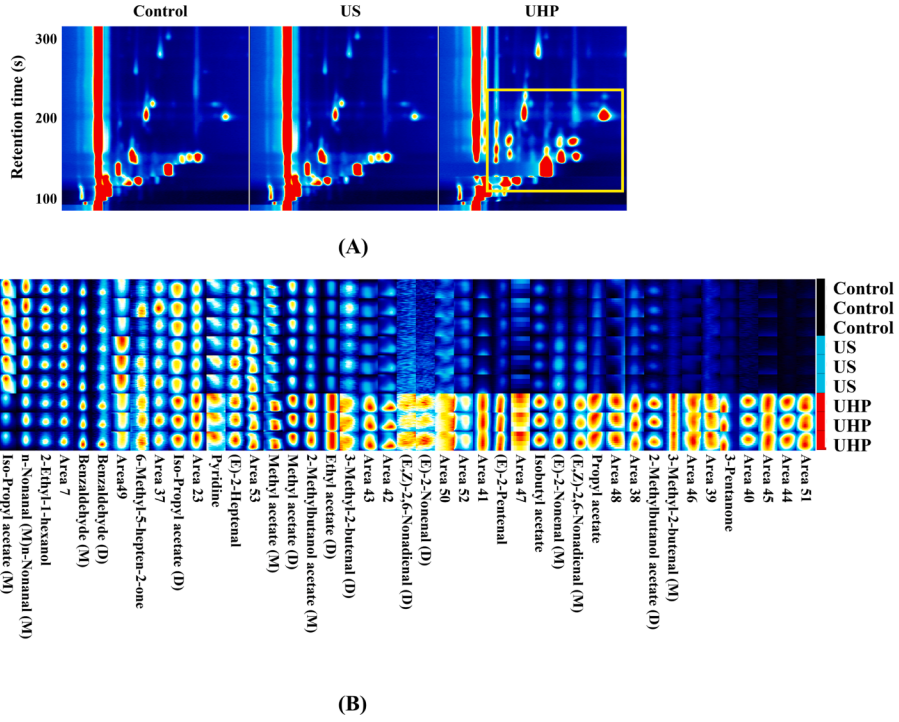

Fig. 3. (A) Correlation coefficient between control with US and UHP in different analysis methods. (B) Venn diagram of volatile components in melon juice in the control, US and UHP.

It can be seen that the UHP also had a weak enhancement effect on the concentration of individual aromatic components, for example, ethyl acetate, (Z)-3-Nonen-1-ol, octanal, acetal, β-Ionone. The possible reason for this phenomenon was the action mechanism of the UHP itself, which triggered the evolution of volatile compounds by changing the force between volatile components and the matrix and its reaction kinetics [39,49]. In general, the US was better than UHP in maintaining and enhancing the flavor of melon juice.

4. Conclusions

The US and UHP processing methods had no significant effect on the TSS, pH, and color of melon juice. In particular, the US had no effect on the basic sensory aspects of melon juice. The results of the electronic tongue and electronic nose showed that the flavor of the US was more similar to that of fresh melon juice. This result was further confirmed by GC-IMS. In the fingerprint, a total of 34 volatile compounds were identified, and the composition of volatile components in the US and control was consistent. A lot of volatile components were newly generated in the UHP but were not detected in the control. The volatile components demonstrated its characteristic attribute by GC–MS. There were 59 volatile components. Among them, the total concentration of the 10 characteristic aromatic components in the US was 2.77 and 3.02 times higher than that of the control and UHP, respectively. In conclusion, in terms of the types of natural aromatic components in melon juice, ultrasound had a good retention effect, and the enhancement effect of ultrasonic on the flavor of melon juice was better than that of ultra-high pressure. This provided more useful information for melon juice flavor enhancement technology and non-thermal processing methods.

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CRediT authorship contribution statement

Xiao Liu: Conceptualization, Methodology, Data curation, Formal analysis, Software, Writing – original draft. **Chao Zhang:** Conceptualization, Resources, Supervision, Writing – review & editing. **Hui Wang:** Methodology, Software, Visualization, Investigation. **Yubin Wang:** Software, Investigation. **Danshi Zhu:** Supervision, Funding acquisition. **He Liu:** Conceptualization, Resources, Supervision, Writing – review & editing.

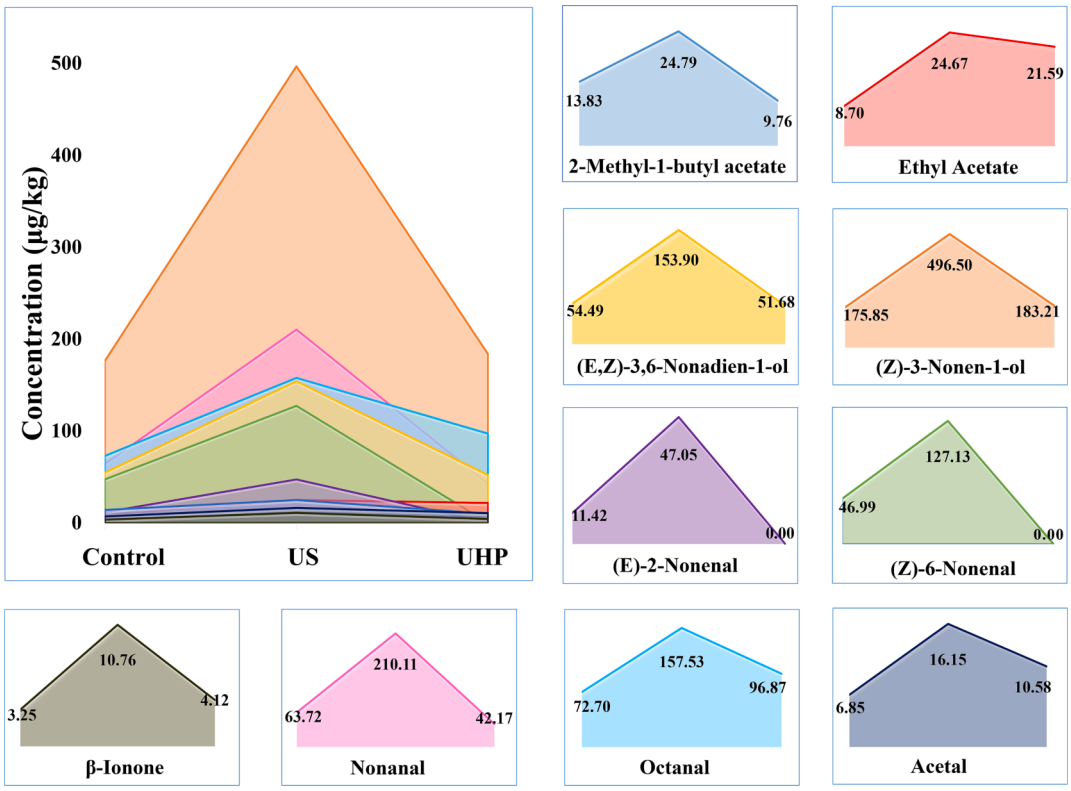

Fig. 4. Concentration of characteristic aromatic components in melon juice in the control, US and UHP. Notes: Each value is the mean of triplicate biological samples.

Declaration of Competing Interest

The authors declare that they 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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