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15 **Abstract:** To accelerate wine maturation, low frequency ultrasonic waves of 28 kHz
16 and 45 kHz were used to treat the steeped greengage wine. The contents of total acid,
17 total ester, fusel oil and the wine chromaticity were determined before and after the
18 ultrasonic treatment. The volatile compounds were analyzed by GC-MS method, and
19 the sensory quality was evaluated by panelist. The results indicated that ultrasonic
20 treatment of the steeped greengage wine at 45 kHz 360 W for 30 min was effective to
21 accelerate the aging process, where the fusel oil and alcohol compounds were
22 significantly reduced and acid and ester compounds were significantly increased.

23 **Keywords:** Steeped greengage wine; Low frequency ultrasonic wave; Maturation

24

25 **Introduction**

26 Greengage wine is a popular alcoholic beverage in Southeast Asia, especially
27 China, because of its unique fruit flavor and potential health benefits such as
28 antioxidant and anti-cancer properties (Jo et al., 2006; Chen, Wu, Liu, & Li, 2008;
29 Jeong, Moon, Park, & Shin, 2006; Adachi et al., 2007). The Chinese well-known
30 story of “Discussing the heroes of the country while drinking greengage wine”
31 happened more than 1,800 years ago in Three Kingdoms Period has granted it a
32 historical culture. Greengage wine can be made by two different processes:
33 fermentation and steeping (Li & Zhou, 2005). Several researchers have demonstrated
34 that greengage wine made by steeping greengage fruit in rice wine could be more
35 effective in maintaining the fruit flavor than that of the fermentation method (Yang,
36 Wu, Peng, & Wang, 2005; Gao, Zeng, & Xiao, 2009). The steeping process is also a
37 common operation in most industry practice. After the steeping process, the wine
38 forms the basic flavor and body, but it is widely recognized that freshly steeped wine
39 is undrinkable due to the harsh taste, pungent smell and too high concentration of
40 fusel oil. The fusel oils are one group of the main flavor components of greengage
41 wine, but a high concentration of fusel oils may cause dizziness, headache, thirst, and
42 other uncomfortable symptoms (Watson & Preedy, 2003; Hori, Fujii, Hatanaka, &
43 Suwa, 2003). Therefore, it is essential for the freshly steeped wine to be aged until its
44 sensory properties become pleasurable. Generally, fresh wine is aged by natural
45 maturation which requires a long time (more than half a year) and huge space, and
46 consequently, is a low efficiency method in wine industry (Tao et al., 2012). To solve

47 this problem, scientists have worked out a number of chemical and physical
48 accelerating aging methods, such as oak wood bucket storage, micro-oxygenation,
49 ultrasonic wave, and ultra-high pressure treatments (Chang & Chen, 2002; Nevares &
50 Alamo, 2008; Alamo, Nevares, Gallego, Simon, & Cadahia, 2010; Van Jaarsveld &
51 Hattingh, 2012; Madrera, Hevia, & Valles, 2013). However, there is little information
52 on accelerating of steeped fruit wines including steeped greengage wine.

53 Ultrasonic wave, especially low frequency ultrasonic wave, can significantly
54 accelerate some types of chemical reaction rates, and is reported to be a promising
55 technique in shortening the wine aging process (Leonhardt & Morabito, 2007; Chang,
56 2005). Saterlay and Compton (2000) proposed that ultrasonic wave can create an
57 acoustic cavitation of microbubbles. The violent implosion of these microbubbles
58 leads to energy accumulations in hot spots, and generates extreme temperatures and
59 pressures, which produce very high shear energy waves and turbulence (Hemwimol,
60 Pavasant, & Shotipruk, 2006; Luque de Castro & Priego-Capote, 2007). Under this
61 extreme micro-environment, chemical polymers are accelerated to be broken into
62 numerous particles and recombined as new polymers with good flavor and body. In a
63 recent critical review of ultrasonic wave on food properties and bioactivities, Soria
64 and Villamiel (2010) concluded that the ultrasonic wave in a frequency range of 16 to
65 60 kHz is able to accelerate oxidation, polymerization and condensation of alcohol,
66 aldehydes, esters and olefins in wines. A number of reports demonstrated that
67 ultrasonic wave below 100 kHz could shorten the aging process of wine maturation
68 (Leonhardt & Morabito, 2007; Chang, 2004; Chang, 2005). However, research on

69 accelerating the aging of steeped greengage wine is still lack of information.

70 The objective of this study was to develop an accelerating aging method on
71 steeped greengage wine by applying 28 kHz and 45 kHz ultrasonic treatment. The
72 changes of flavor components as well as other substances in wine affecting the
73 mouthfeel and quality, such as esters, acids and fusel oils, were evaluated after 15
74 days storage. This study may provide useful practical information to greengage wine
75 industry in application of ultrasonic treatment in accelerating the wine aging.

76

77 **2. Materials and Methods**

78 *2.1. Materials*

79 The fresh steeped greengage wine was kindly provided by Galore Food Co. Ltd,
80 Zhongshan city, China. The fresh wine was made by steeping fresh greengage fruit in
81 rice alcohols for one year. This is the conventional method of greengage wine
82 manufacturing in Asia. Most of un-dissolved particles were removed from the wine by
83 a series of filtering steps. The steeped greengage wine was filled in separate
84 polyethylene terephthalate (PET) containers (2 L/each), and kept in a dark and dry
85 environment (15°C). After arrival of our laboratory, the fresh wine was stored less
86 than 1 month before the experiment treatment. The alcohol concentration of the fresh
87 wine was 17.5% (v/v). All solvents and chemicals (Sinopharm Ltd., China) used in
88 this study were of analytical grade.

89 *2.2. Ultrasonic treatment*

90 The fresh greengage wine was treated by [an ultrasonic KQ-600VDV bath](#)

91 (Ultrasonic Instrument, Kunshan, China) with two separate frequencies: 28 kHz and
92 45 kHz. The ultrasonic power was adjusted at 240 W, 300 W and 360 W respectively.
93 The equipment was filled with water as a medium for ultrasonic vibration transmitting,
94 and the water was replaced after each treatment to keep the same ultrasonic heating
95 effect. About 300 mL of fresh steeped greengage wine was filled in a 500 mL
96 erlenmeyer flask with lid to reduce evaporation of volatile components. Then, the
97 flask was placed in the center of the ultrasonic bath to assure the consistent of
98 ultrasonic treatment. Samples were collected after 10, 20, 30, 40, and 50 min of
99 treatment and stored in sealed glass containers to prevent evaporation loss. Ultrasonic
100 untreated fresh greengage wine was also prepared in the same way as control. The
101 wines were analysed after 15 days of storage at a dark and dry environment (15 °C)
102 when the major flavor components in the wines were relatively stable after the
103 ultrasonic treatment.

104 *2.3 Total acid and ester determination*

105 According to China Food Industry Standard Collection (2000), the total acid of
106 steeped greengage wine was measured by the neutralization titration method and
107 expressed as citric acid (g/L), and the total ester content was measured by the
108 saponification reaction method and expressed as ethyl acetate (g/L).

109 *2.4 Chromaticity determination*

110 The chromaticity is one of the most typical sensory characteristics of fruit wines,
111 which reflects the shade and intensity of the wine products (Rentzsch, 2009).
112 According to Glories (1984), the chromaticity (I) of fruit wine was the sum of

113 absorbance at 420, 520, 620 nm ($I=A_{420}+A_{520}+A_{620}$). The chromaticity of wines were
114 determined on an UV2600 spectrophotometer (Techcomp, Shanghai, China), using
115 de-ionized water as reference.

116 2.5 Fusel alcohol determination

117 Fusel oils are by-products of wine-making industry, and are mainly composed of
118 n-propanol, n-butanol, isobutyl alcohol and isoamyl alcohol (Lachenmeier, Haupt, &
119 Schulz, 2008). In the present study, fusel oils refer to isobutyl alcohol and isoamyl
120 alcohol because they are the main fusel oil components in Chinese traditional rice
121 wine (Shen, 1998), which was used in the steeping of greengage fruit. Steeped
122 greengage wine was distilled to eliminate the effect of wine colour and the distillation
123 was used for the analysis. Total contents of fusel oils were determined by PDAB
124 (p-Dimethylaminobenzaldehyde) colorimetry on the UV2600 spectrophotometer at
125 520 nm against reagent blank as reference (AOAC, 1984). The concentrations of
126 individual fusel oils of isobutyl alcohol and isoamyl alcohol were determined by gas
127 chromatography (GC 2010, Shimadzu, Japan) using a DB-WAX column (60.0 m×250
128 μm I.D., 0.32 mm film thickness, Supelco, USA). Oven temperature program was:
129 from holding at 40°C for 5 min, to 180°C with an increase of 10 °C /min, keeping for
130 5 min. The injection temperature was 250 °C. Flow rate were: N₂, 1.2 mL/min; H₂, 47
131 mL/min; Air, 400 mL/min.

132 2.6 Volatile compounds determination

133 The volatile compounds of steeped greengage wine were extracted by headspace
134 solid phase micro-extraction. The optimal ultrasonic-treated wine and untreated wine

135 (8 mL each) were placed in 15 mL vials with 2.4 g NaCl respectively. The vials was
136 sealed and preheated at 25°C for 10 min. A CAR-PDMS extraction fiber (Supelco,
137 USA) was inserted into the vials and fractionated from the sample matrix at 45°C in a
138 thermal block for 30 min until the equilibration of volatiles. Then, the fiber was
139 removed and inserted immediately into an injection port of a gas chromatograph (GC
140 6890, Agilent, USA) and desorbed for 3 min at 250 °C.

141 The qualitative analyses of volatile compounds were carried out on a gas
142 chromatography mass spectrophotometer (GC 6890/MS 5975, Agilent, USA) using a
143 DB-WAX column (30.0 m×250 µm I.D., 0.25 µm film thickness, Supelco, USA).
144 Nitrogen was used as carrier gas with a flow rate of 1.2 mL/min. Oven temperature
145 program was: from holding at 40°C for 4 min, to 60°C with an increase of 6 °C /min,
146 then increasing by 10 °C/min until oven temperature reached 230 °C (8 min) and the
147 injection temperature was 250 °C. The parameters of the mass spectrophotometer
148 were: interface temperature, 250 °C; ion source temperature, 200 °C; electron impact
149 (EI) spectra obtained at 70 eV; filament current, 200 uA; electrode stem source
150 temperature, 350 °C; scanning mass range of 33-450 m/z.

151 The identification of flavor compounds was achieved by comparing the Kovats
152 index (KI) of a series of n-alkane (C₇-C₂₁) with the mass spectra library of NIST98
153 (National Institute of Standards of Technology, Hewlett-Packard, MD, USA). The
154 integration reports were accepted if matching degree was above 800. The relative
155 contents of flavor compounds were determined by comparing the percentage of peak
156 areas.

157 2.7 Sensory evaluation

158 Ultrasonic treated and untreated wine samples were sensory evaluated by 10
159 qualified and experienced panelists in the School of Food Science and Technology,
160 Jiangnan University. Each panelist was in good health condition and has been trained
161 before the evaluation. The blind tasting and centesimal score system (O.I.V., 1990)
162 was applied to evaluate the wine's quality. Based on the distribution of appearance (20
163 scores), aroma (30 scores), taste (40 scores) and typicality (10 scores), all the samples
164 were presented to the panelists separately and randomly in a sensory evaluation room
165 at $21\pm 1^{\circ}\text{C}$. After consultation with sales representatives of the wine manufacturing
166 company of Galore Food Co. Ltd and from a market point of view, samples with a
167 total score of over 80 were considered as good and acceptable, over 85 were excellent,
168 between 70 and 80 were common, and below 70 were unacceptable.

169 2.8 Statistical analyses

170 Every determination was repeated three times and two replications of one
171 treatment were performed. All the data were statistically analyzed by the software of
172 SPSS 17.0 (SPSS Inc., Chicago, IL, USA). The significant differences were
173 determined at the 95% level.

174

175 3. Results and discussion

176 3.1 Total acid content

177 The contents of total acid in steeped greengage wine increased significantly after
178 ultrasound treatments (Table 1). Under the ultrasound frequency of 28 kHz and power

179 of 240 W, the highest concentration of total acid was 14.22 ± 0.07 g/L at 30 min,
180 whereas the highest level of 14.21 ± 0.07 g/L and 14.25 ± 0.09 g/L were achieved under
181 300 W and 360 W power at 40 min respectively. No significant differences were
182 observed for the total acid contents among the ultrasonic treated wines, which
183 suggested that the ultrasound may have quickly (about 10 min) promoted the
184 formation of acids in the greengage wine. In addition, the total acid under 45 kHz
185 treatment were higher than those of 28 kHz, with the highest concentration of
186 14.14 ± 0.07 g/L, 14.24 ± 0.04 g/L and 14.36 ± 0.07 g/L at 50 min for the three powers
187 respectively (Table 1).

188 Citric acid, malic acid, and tannic acid are the main organic acids in steeped
189 greengage wine that contribute to the wine's quality (Gao, Zeng, Xiao, 2009). The
190 increase of total acid could be explained by the oxidation of unsaturated alcohols and
191 aldehydes under ultrasonic conditions. The cavitation and mechanical effect of
192 ultrasound is able to create an extreme micro-environment of high temperature and
193 pressure, which in turn facilitate the activity of reactive molecules. Moreover, it was
194 favorable to the formation of acids in wines because of the dissociation of oxygen that
195 caused by cavitation bubble collapse (Petrier, Combet, & Mason, 2007).

196

197 *3.2 Total ester content*

198 The concentration of total ester also increased in the ultrasonic treated samples
199 (Table 2). At the ultrasonic frequency of 28 kHz, the highest concentrations were
200 1.45 ± 0.04 g/L, 1.66 ± 0.04 g/L, and 1.63 ± 0.06 g/L at 10 min under the three powers

201 respectively, which also suggested a very quick ultrasonic effect on esterification. At
202 the 45 kHz ultrasound and 240 W power, the highest concentration of total ester was
203 1.55 ± 0.03 g/L at 20 min. Both the 300 W and 360 W power treatments had the highest
204 level of 1.71 ± 0.02 g/L at 10 min and 30 min, respectively (Table 2). It showed that the
205 frequency of 45 kHz was more effective than 28 kHz in promoting the esterification
206 in the wines, which may be caused by the more intense interaction between alcohols
207 and acids under the higher frequency. The enhanced esterification effect between
208 alcohols and acids under ultrasonic treatment has also been observed by Ince,
209 Tezcanli, Belen, & Apikyan (2001). However, in the present study, ultrasonic
210 treatment of longer than 30 min was not favorable to the greengage wine maturation
211 as the total ester contents were decreased (Table 2), possibly because the heating
212 effect of ultrasonic energy would have accelerated the evaporation of esters. Therefore,
213 10-30 min ultrasonic treatment might be appropriate for a significant esterification of
214 the steeped greengage wine.

215 3.3 Chromaticity

216 The chromaticity of steeped greengage wine after ultrasonic treatments changed
217 slightly as shown in Table 3. Although there had some differences among the
218 ultrasonic treated and untreated samples, the chromaticity values were in a small
219 variation range of 1.18-1.25, which suggested that the ultrasonic treatment has no
220 negative effect on the color of the wines. It was reported that the mechanical effect of
221 ultrasonic treatment accelerated the condensation of pigment compounds and
222 increased the chromaticity, and ultrasound processing was able to affect the

223 anthocyanins degradation and the color of grape juice (Tiwari, Patras, Brunton, Cullen,
224 & O'Donnell, 2009; Tiwari, Patras, Brunton, Cullen, & O'Donnell, 2010). However,
225 the effect of ultrasonic wave on wine chromaticity was not extensively investigated
226 and the mechanism is not fully understood.

227 *3.4 Fusel oil content*

228 The results indicated that ultrasonic wave was able to reduce the concentration of
229 fusel oil in steeped greengage wine significantly when compared with untreated
230 sample (Table 4). At the frequency of 28 kHz, the lowest concentrations of fusel oil
231 were determined in 10-30 min under all the three powers, with the values of
232 394.33 ± 7.54 mg/L, 374.33 ± 14.71 mg/L, 392.00 ± 5.51 mg/L, respectively. However,
233 after 30 min, the concentration of fusel oil increased slightly. This might be caused by
234 the release of fusel oils from the degradation of associated-alcohols in the wine (Lin,
235 Zeng, & Yu, 2013).

236 For the 45 kHz treatment, the variations of fusel oil content were different for the
237 three powers. Under the 240 W power, the lowest concentration of fusel oil was
238 377.00 ± 5.29 mg/L at 10 min, whereas for the 300 W and 360 W was 400.67 ± 2.03
239 mg/L and 358.00 ± 2.00 mg/L at 30 min, respectively (Table 4). Generally, the
240 ultrasonic of 28 kHz, 300 W and 45 kHz, 360 W were suitable for reducing the
241 concentration of fusel oils. The concentration of individual fusel oil component was
242 analyzed by GC and the results in the treatment of 45 kHz and 360 W sample were
243 showed in Table 5. It indicated that the lowest concentration of isobutyl alcohol and
244 isoamyl alcohol was 117.77 mg/L and 224.62 mg/L under 45 kHz, 360 W and 30 min

245 ultrasonic treatment, which was consistent with the lowest total fusel oil content using
246 colorimetry determination, although the sum of isobutyl alcohol and isoamyl alcohol
247 was 4.36% lower than that of the total fusel oils, suggesting some other minor fusel
248 oil components may also exist in the wine. The sonochemical effect on reducing fusel
249 oils in greengage wine could be related to advanced oxidative processes with the
250 production of hydroxyl radical (Mason, 2003). The ultrasound activates the surface
251 hydroxyl of fusel oil to free radical which is in favour of oxidation and esterification,
252 and therefore increases the acids and esters with the sacrifice of fusel oils, as
253 discussed in sections 3.1 and 3.2.

254 3.5 Flavor content

255 According to our preliminary determination, the optimal ultrasonic-accelerated
256 wine was the sample that was treated by 45 kHz, 360 W ultrasonic for 30 min, and
257 therefore was used for volatile compound analysis. The GC-MS total ion
258 chromatogram of aroma components in treated wine and untreated wines were shown
259 in Fig. 1 and the contents were present in Table 6. About 38 and 39 volatile
260 compounds were determined in the treated and untreated wine respectively, which
261 included esters, alcohols, aldehydes, ketones and other compounds. Compared with
262 the untreated wine, 3 more esters (ethyl isovalerate, isoamyl acetate and ethyl
263 heptanoate) were determined and 1 ester (ethyl furoate), 1 aldehydes (decanal), 1
264 ketone (3-hydroxy-2-butanone) were not determined (Fig. 1 and Table 6) in the
265 ultrasonic treated sample.

266 The results showed that the esters in steeped greengage wine increased by 7.74%

267 after ultrasonic irradiation, which represented a significant flavor variation ($p<0.05$).
268 Esters are one of the main flavor contributors in alcoholic beverages. The content of
269 ethyl acetate and ethyl benzoate was increased by 1.57% and 2.42% in treated wine,
270 suggesting the acceleration of esterification. However, another major flavor
271 contributor to the greengage wine, alcohols decreased 6.75% after the ultrasonic
272 treatment, especially with the decrease of ethyl alcohol by 7.40%. It was suggested
273 that the increase of ester compounds in greengage wine could be the conversion of
274 alcoholic compounds, as discussed by Ince, Tezcanli, Belen, & Apikyan (2001), and
275 above sections of 3.2 and 3.4. It was reported that benzaldehyde was a characteristic
276 volatile compound in steeped greengage wine (Yang, Wu, Peng, & Wang, 2005), but
277 no significant change was detected for benzaldehyde in the present work. The content
278 of benzaldehyde decreased from 19.41% to 19.21% after ultrasonic treatment.
279 Meanwhile, other volatile compounds changes slightly without significant variation.

280 *3.6 Sensory evaluation*

281 Steeped greengage wine has its characteristic taste and flavor which are
282 contributed from several compounds such as organic acids and volatile materials.
283 Sensory evaluation is a very important tool to assess its quality and consumer
284 acceptability. Evaluated by the 10 panelists, the sensory scores of wine samples were
285 presented in Table 7. Sensory scores of the 28 kHz treated wines increased as the
286 ultrasonic power and time increasing. The highest scores of 28 kHz under three
287 powers were 82.10 ± 3.64 , 83.03 ± 3.59 , 83.40 ± 2.77 at 50 min, 40 min and 40 min,
288 respectively. In the first 30 min of 45 kHz, the score changes were similar to those of

289 28 kHz treatments, but the increase was more remarkable. However, for the 50 min
290 treated wine at both 28 and 45 kHz frequencies and powers, their scores declined
291 when compared to 30 and 40 min treated ones. The sensory evaluation was relevant to
292 the chemical indices such as total esters. For example, the highest sensory evaluation
293 score was 84.40 ± 2.85 which suggested an excellent wine quality after ultrasonic
294 treatment at the frequency of 45 kHz, 360 W for 30min (Table 7), and the
295 concentration of total esters of this sample was 1.71 ± 0.02 g/L, also the highest in the
296 treated wines (Table 2). However, after 30 min treatment, the sensory scores of the
297 greengage wines decreased as the ultrasonic power increased (Table 7). Generally, the
298 results of sensory evaluation were highly in agreement with the results of chemical
299 analysis. Suitable ultrasonic frequency and power treatments were able to accelerate
300 the aging process by reducing the fusel oil and alcohol compounds and increasing acid
301 and ester compounds, and therefore, improve the sensory quality.

302

303 **4. Conclusion**

304 In the present work, changes in total acid, total ester, fusel oil, chromaticity,
305 volatile compounds and sensory quality of steeped greengage wine by ultrasonic
306 treatment were investigated. The results showed that low frequency ultrasonic
307 treatment had a positive effect on the aging process of steeped greengage wine
308 according to the chemical analysis and sensory evaluation. After ultrasonic treatment,
309 the concentrations of total acids and esters were increased which was the accelerated
310 oxidation reactions of fusel oils and alcohols. The optimal ultrasonic treatment

311 conditions for accelerating the aging of steeped greengage wine were 45 kHz
312 frequency, 360 W and 30 min.

313

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318

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Table 1 Changes of total acid (g/L) in steeped greengage wine after 28 kHz and 45 kHz ultrasonic treatment

Frequency (kHz)	Power (W)	Treating time (min)					
		0	10	20	30	40	50
28	240	^a 12.82±0.03a	13.93±0.18b	13.98±0.05bc	14.22±0.07d	14.10±0.04cd	14.17±0.04d
	300	12.82±0.03a	14.06±0.06b	14.09±0.04b	14.14±0.04bc	14.21±0.07c	14.14±0.07bc
	360	12.82±0.03a	14.16±0.05bc	14.15±0.09bc	14.06±0.07b	14.25±0.09c	14.11±0.05b
45	240	12.82±0.03a	14.07±0.07b	14.11±0.04b	14.08±0.07b	14.08±0.09b	14.14±0.07b
	300	12.82±0.03a	14.13±0.07b	14.17±0.04bc	14.22±0.06bc	14.13±0.07b	14.24±0.04c
	360	12.82±0.03a	14.17±0.05b	14.16±0.04b	14.19±0.09b	14.22±0.09b	14.36±0.07c

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^a Different letters in the same row indicate significant different ($p \leq 0.05$).

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Table 2 Changes of total ester (g/L) in steeped greengage wine after 28 kHz and 45 kHz ultrasonic treatment

Frequency (kHz)	Power (W)	Treating time (min)					
		0	10	20	30	40	50
28	240	^a 1.22±0.03a	1.45±0.04d	1.42±0.04cd	1.30±0.06ab	1.26±0.03a	1.36±0.05bc
	300	1.22±0.03a	1.66±0.04d	1.56±0.04c	1.56±0.02c	1.26±0.06a	1.45±0.05b
	360	1.22±0.03a	1.63±0.06d	1.48±0.04c	1.37±0.07b	1.48±0.02c	1.52±0.07c
45	240	1.22±0.03a	1.54±0.03c	1.55±0.03c	1.50±0.05c	1.43±0.04b	1.55±0.03c
	300	1.22±0.03a	1.71±0.02e	1.63±0.03de	1.56±0.02cd	1.47±0.03b	1.53±0.04bc
	360	1.22±0.03a	1.55±0.03d	1.47±0.05bc	1.71±0.02e	1.41±0.06b	1.52±0.03cd

^aDifferent letters in the same row indicate significant different ($p \leq 0.05$).

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Table 3 Changes of chromaticity in steeped greengage wine after 28 kHz and 45 kHz ultrasonic treatment

Frequency (kHz)	Power (W)	Treating time (min)					
		0	10	20	30	40	50
28	240	^a 1.21±0.00b	1.18±0.00a	1.19±0.01a	1.20±0.01b	1.19±0.01a	1.20±0.02b
	300	1.21±0.00a	1.21±0.01a	1.20±0.01a	1.22±0.01b	1.23±0.01c	1.24±0.01c
	360	1.21±0.00a	1.21±0.01a	1.22±0.01a	1.23±0.01ab	1.25±0.02b	1.25±0.01b
45	240	1.21±0.00b	1.22±0.01b	1.21±0.01b	1.22±0.01b	1.21±0.01b	1.19±0.01a
	300	1.21±0.00ab	1.20±0.01a	1.22±0.01bc	1.23±0.01c	1.23±0.01c	1.22±0.01bc
	360	1.21±0.00a	1.22±0.01ab	1.23±0.01b	1.24±0.01c	1.22±0.01ab	1.22±0.02ab

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^a Different letters in the same row indicate significant different ($p \leq 0.05$).

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Table 4 Changes of fusel oil (mg/L) in steeped greengage wine after 28 kHz and 45 kHz ultrasonic treatment

Frequency (kHz)	Power (W)	Treating time (min)					
		0	10	20	30	40	50
28	240	^a 445.45±3.32c	394.33±7.54a	425.67±4.06b	397.67±7.22a	405.00±5.69a	419.33±3.96b
	300	445.45±3.32e	390.00±4.04b	412.33±5.04d	374.33±14.71a	412.33±5.78d	400.02±7.57c
	360	445.45±3.32b	403.67±9.95a	393.67±8.41a	392.00±5.51a	400.56±3.93a	393.33±3.53a
45	240	445.45±3.32d	377.00±5.29a	422.33±5.04c	397.33±7.36b	403.00±1.53b	409.00±4.58bc
	300	445.45±3.32c	410.67±0.89ab	423.33±4.33b	400.67±2.03a	411.33±2.03ab	422.33±4.70b
	360	445.45±3.32e	400.67±5.54cd	380.67±5.69b	358.00±2.00a	411.00±5.77d	391.67±4.98bc

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^a Different letters in the same row indicate significant different ($p \leq 0.05$).

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Table 5 Changes of individual fusel oil components (mg/L) after 45 kHz, 360 W ultrasonic treatment.

Component	Treating time (min)					
	0	10	20	30	40	50
Isobutyl alcohol	141.21	126.94	123.32	117.77	121.65	119.74
Isoamyl alcohol	296.59	262.14	243.51	224.62	267.05	244.98

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Table 6 Volatile compounds in steeped greengage wine with and without 45 kHz ultrasonic treatment

R.T/min	Compounds	Normalized content/%	
		Untreated	treated
Esters		8.94	16.68
3.44	Ethyl acetate	6.31	7.88
6.82	Ethyl butyrate	0.03	0.06
7.27	Ethyl 2-methylbutyrate	0.02	0.12
7.71	Ethyl isovalerate	-	0.05
9.13	Isoamyl acetate	-	0.19
14.05	Ethyl heptanoate	-	0.06
14.41	Ethyl lactate	0.05	0.06
15.75	Ethyl caprylate	0.21	2.99
18.39	Ethyl furoate	0.02	-

18.57	Ethyl caprate	0.02	0.48
19.02	Ethyl benzoate	1.79	4.21
20.38	Ethyl phenylacetate	0.06	0.15
20.72	Ethyl salicylate	0.14	0.13
24.77	Methyl hexadecanoate	0.03	0.05
26.27	Diethyl phthalate	0.15	0.13
27.16	Triethyl citrate	0.08	0.07
Alcohols		67.42	60.67
5.07	Ethyl alcohol	56.56	49.16
8.93	Isobutyl alcohol	1.90	1.67
10.60	n-Butyl alcohol	0.02	0.05
12.02	Isoamyl alcohol	6.01	7.09
14.58	Hexyl alcohol	0.15	0.21

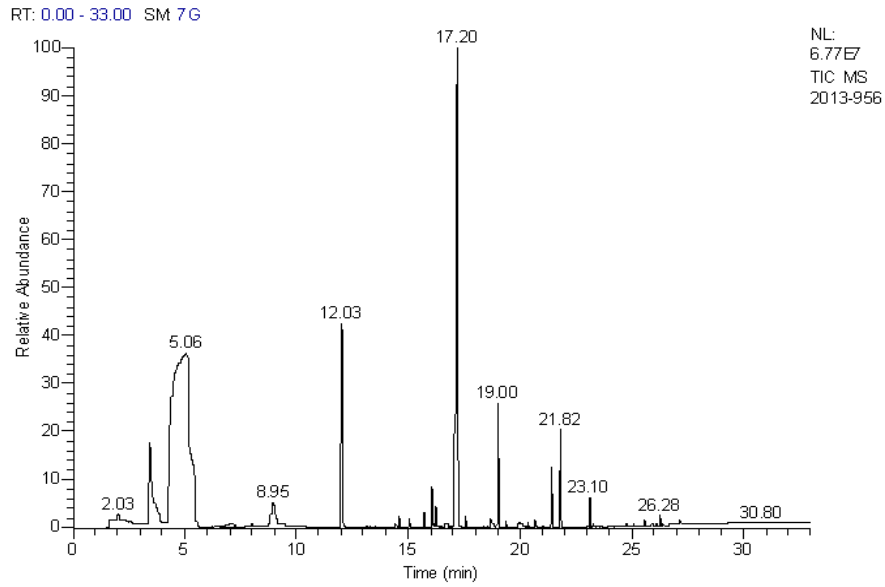
16.17	n-heptanol	0.05	0.05
17.56	1-Octanol	0.15	0.30
19.36	alpha-Terpineol	0.07	0.12
21.41	Benzyl alcohol	0.89	0.71
21.82	Phenethyl alcohol	1.62	1.31
Aldehydes&Ketones		20.39	20.38
8.00	Hexanal	0.07	0.07
13.26	Octanal	0.03	0.11
15.09	Nonanal	0.16	0.14
16.25	Furfural	0.32	0.35
16.67	Decanal	0.06	-
16.75	trans ,trans-2, 4- Heptadienal	0.08	0.16
17.21	Benzaldehyde	19.41	19.21

13.52	3-Hydroxy-2-butanone	0.02	-
18.82	Acetophenone	0.10	0.19
20.68	2-Hydroxyacetophenone	0.14	0.15
Others		0.92	0.96
16.03	Acetic acid	0.71	0.64
21.01	Caproic acid	0.02	-
23.02	4-ethyl-2-methoxyphenol	0.02	-
23.24	Octanoic acid	0.06	0.10
25.29	Decanoic acid	-	0.05
25.59	2,4-Di-tert-butylphenol	0.08	0.12
25.89	tert-Butylhydroquinone	0.03	0.05

Table 7 Sensory evaluation scores of steeped greengage wine after 28 kHz and 45 kHz ultrasonic treatment

Frequency (kHz)	Power (W)	Treating time (min)					
		0	10	20	30	40	50
28	240	76.93±7.56a	79.58±5.82ab	80.95±3.85ab	81.20±4.54b	81.45±4.57b	82.10±3.64b
	300	76.93±7.56a	80.73±3.96ab	81.55±3.89b	82.45±3.88b	83.03±3.59b	82.95±3.34b
	360	76.93±7.56a	81.28±3.87b	81.90±3.59b	83.05±3.52b	83.40±2.77b	81.95±3.49b
45	240	76.93±7.56a	80.48±5.06ab	81.45±4.66ab	82.50±3.68b	83.05±3.42b	82.18±3.28b
	300	76.93±7.56a	80.90±4.57ab	82.23±3.75b	83.28±2.99b	81.88±4.23b	80.93±4.78ab
	360	76.93±7.56a	81.48±4.06b	83.35±2.82bc	84.40±2.85c	81.00±4.84b	79.15±5.86ab

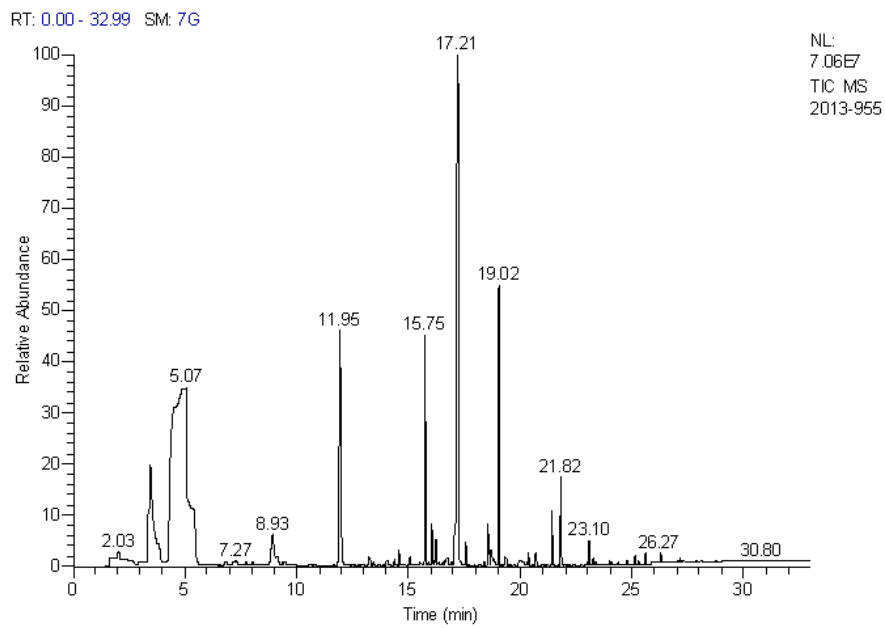
^a Different letters in the same row indicate significant different ($p \leq 0.05$).



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(a)



450

451

(b)

452 Fig. 1 Total ion chromatogram of aroma components in steeped greengage wines

453 analysed by GC-MS: (a) untreated, and (b) 45 kHz 360 w ultrasonic wave treatment

454 for 30 min. Peak identification refers to Table 6.