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Changes of Amygdalin and Volatile Components of Apricot Kernels during the Ultrasonically-Accelerated Debitterizing

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ABSTRACT

Ultrasound has been regarded as an efficient novel technique for debitterizing of the apricot kernels, but its influence is severely concerned on the possible epimerization of D-amygdalin to the L-amygdalin, a more potentially toxigenic compound. Considering this, the experiments were conducted to investigate the epimerization of D-amygdalin and the volatile components in the debitterizing water, which were separated and identified by the high performance liquid chromatography (HPLC) and gas chromatography with a mass spectrometer (GC-MS), respectively. The results indicate that the ultrasonically-debitterizing did not cause the epimerization of D-amygdalin to the L-amygdalin, while the procedure can be greatly accelerated due to the rapid mass transfer and degradation of D-amygdalin induced by ultrasound irradiation. In addition, the water from the ultrasonically-debitterizing of apricot kernels exerted more aromas compared with that of the conventional debitterizing, which might have more applications about this kind of water. In a word, ultrasound can be safely applied in the debitterizing industry of apricot kernels.

KEYWORDS: apricot kernels; debitterizing; amygdalin; epimerization; volatile components

1 INTRODUCTION

Apricot, *Prunus armeniaca L.*, the genus *prunus* of the subfamily Prunoideae in the family Rosaceae [1], mainly distributes throughout the Central Asia, West Asia, Mediterranean region and Western China, which is an internationally popular crop, with the global production reaching 4.1 million tons [2]. As the nut seed, apricot kernels contain abundant compounds like carbohydrates, protein, polyphenols, flavonoids and amygdalin [3, 4]. Among them, the amygdalin is very distinctive and determines the healthy function of the apricot kernel to some extent, which has a content of 2-5 g/100g apricot kernels [4]. According to the chemical structure, the amygdalin, ever called vitamin B_{17} or Nitrilosides, is composed of two molecules of glucose, one benzaldehyde and one hydrogen cyanide [5]. Generally, the amygdalin itself is considered to be nontoxic, while its metabolic product like HCN has the potential toxicity, and its lethal dose for human is 0.5-3.5 mg/kg body weight [6]. Therefore, the amygdalin is widely regarded as a potentially toxigenic compound [7, 8], and its occurring has been as an obstacle to the utilization and commercialization of the apricot kernels for human or animal nutrition. Considering this situation, the detoxification has become an indispensable operation unit in the processing of apricot kernels, by which the amygdalin can be lowered to the safe content, simultaneously removing the bitterness and potential toxicity of the apricot kernels.

The commonly employed methods of detoxifying the apricot kernels include two categories: conventional and novel methods, the former comprises the cold water

debitterizing [9], hot water debitterizing [10, 11], acid solution debitterizing [12] and acid-base alternate debitterizing, while the latter contains the vacuum debitterizing [13], ultrasound debitterizing and microwave debitterizing [7], etc. To the conventional methods, the main disadvantages are high energy consumption (water and electricity), time waste (from 6-7 hours to 6-7 days), labour-intensive, high pollution and high loss of compounds in apricot kernels. The contents of protein, carbohydrates, phenols, flavanoids and amygdalin have been detected in the debitterizing water concentrate (DWC) from the conventionally industrial debitterizing. Among them, the amygdalin has the highest content of 23.89 ± 0.03 (g/100 g dry base weight) in the DWC, and the total loss of weight is about 17% of the apricot kernels after the debitterizing [14]. In comparison, the novel techniques are relatively low-cost, eco-friendly, rapid and easy-industrialization. As a non-thermal processing technology, ultrasound is regarded as the most promising technique for accelerating the debitterizing of apricot kernels. With this method, the debitterizing time can be reduced to about two hours and the water consumption can also be greatly decreased by ultrasound irradiation [11], while the safety is severely considered about the transformation of configuration (epimer) and the products available generated from the amygdalin during exposure to ultrasound irradiation.

Regarding the amygdalin, it has two epimers of L-amygdalin and D-amygdalin (Figure 1), the former does not exist in nature, but it can be epimerized from the D-amygdalin during the decoction, particularly under basic conditions, because of the weakly acidic character of the benzylic proton [15, 16]. That is to say, the amygdalin

coexisted in D- and L- amygdalin forms at neutral or basic conditions, while the D-isomer only exists under acid conditions. This phenomenon suggests that the dominant amygdalin epimer might be easily changed during the debitterizing or sample pretreatment. Furthermore, the D-amygdalin tastes bitter, while the L-amygdalin has no bitterness and different physiological properties, so special concerns should be focused on this case during the debitterizing of apricot kernels, since both D- and L- amygdalin can be degraded into the HCN causing toxicity available by the gastric acid or enzymes in the digestive tract of human body. In other words, if the bitter D-amygdalin only converted into the non-bitter L-amygdalin during the debitterizing of ultrasound irradiation, its danger will be greater for the consumers eating this kind of debitterized apricot kernels.

In a word, ultrasound irradiation does greatly shorten the debitterizing time of apricot kernels and has the promising application in the apricot kernels processing industry, while its influencing mechanism on the amygdalin should not be neglected. In the meantime, the debitterizing water, containing abundant components especially volatile compounds, can also be as the main ingredients of some oral liquid (cough syrup). In pharmaceutical industry, the water soaked with the apricot kernels (namely aqua armeniacae) is the dominant constitute for cough syrup to treat the symptom of asthma, bronchitis, emphysema and cough in China. So special interests were centered on the available utilization of the debitterizing water in pharmaceutical industry by our group. Before considering the re-utilization of the debitterizing water, some investigations should be conducted about the effect of ultrasound irradiation on

the compositions of the debitterizing water, especially the typical flavor compounds. However, to the best of our knowledge, little information is available in this field.

The main purpose of this paper was to investigate the effects of ultrasound irradiation on the amygdalin of apricot kernels and the volatile components in debitterizing water during the accelerated debitterizing process, so as to evaluate the safety of the novel debitterizing technique and the re-utilization of the debitterizing water, finally reducing the pollution of environment and promoting the added-value in the processing industry of apricot kernels.

2 MATERIALS AND METHODS

2.1 Materials and Reagents

The apricot kernels (harvested in June 2017) were purchased from the Northwest Herb Market of Xi'an, Shaanxi province, China. The water content of the apricot kernels is about 4.84 g water/100 g seeds, and the single weight is about 0.53±0.05 g for each seed.

Standard of D-amygdalin was obtained from Chengdu Manst Biotechnology Co., Ltd. Amygdalin was purchased from the Chengdu Perferred Bio-Technology Co. Ltd (Sichuan Province, China). HPLC-grade methanol and acetonitrile were bought from the Fisher Scientific (USA). The dichloromethane (CH_2Cl_2), aether [$(C_2H_5)_2O$], n-hexane (C_6H_{14}), anhydrous sodium sulfate (Na_2SO_4), sodium hydroxide (NaOH), hydrochloric acid (HCl), phosphoric acid (H_3PO_4), sodium dihydrogen phosphate (NaH_2PO_4) were purchased from Tianjin Tianli Reagent Co., Ltd. All other chemicals were of analytical grade. Ultra-pure water was prepared using a Millipore Milli-Q

purification system.

2.2. Preparation of L-amygdalin

There is no commercial L-amygdalin available in the market, so it was made from the standard of D-amygdalin according to the literature [17, 18]. To be specific, the standard solution of D-amygdalin (0.5 mg/mL), prepared by accurately weighing the D-amygdalin and dissolving in the NaOH solution (pH=11), was set for 2 h in the dark to make the isomerization of D-amygdalin equilibrium. Then, the mixture solution with both D- and L- amygdalin was adjusted to pH=7 with HCl solution and stored at 4 °C before determination by HPLC.

2.3. Optimization of the simultaneous determination conditions of the D- and L-amygdalin by HPLC

Generally, it is difficult to detect the epimers with the common conditions of HPLC, so some different operation parameters were optimized to obtain a good separation and sensitivity of the D- and L- amygdalin by the HPLC, which was considered to be simple, rapid, accurate [19]. The HPLC system (Dalian Elite Analytical Instruments Co., Ltd., Liaoning, China) consists of two P230II pumps, a UV230II ultraviolet visible detector and a ZW230II column oven. The column type, mobile phase, oven temperature, flow rate and detection wavelength employed were listed in Table 1. For all the operations, the injection volume was 20 μL. The resolution, sensitivity and signal intensity of the peaks were used to evaluate the suitable conditions of HPLC for the simultaneous analysis of the D- and L- amygdalin.

2.4. Pretreatment of apricot kernels and effects of ultrasound irradiation on the

amygdalin during debitterizing

Apricot kernels with removing the impurities were immersed in water of 15 °C for 5 h to peel the skin. Afterwards, one part of the peeled apricot kernels was put in the boiling water for 10 min to inactivate the beta-glucosidase activity [20], and the remaining was as the sample of non-inactivated beta-glucosidase. Then the boiled water for inactivating the beta-glucosidase was collected and filtered through a 0.45 μm membrane to investigate the effect of inactivation pretreatment on the epimerization of D-amygdalin, which was detected by the HPLC according to the above-optimized conditions.

Additionally, in order to investigate the effects of ultrasound irradiation on the amygdalin of apricot kernels during the ultrasonically-accelerated debitterizing, the experiments were conducted in an ultrasonic bath (SB-500DTY, Ningbo Xinzhi Biotechnology Co. Ltd., Ningbo City, Zhejiang Province, China) in this study, which can work at the frequencies of 25, 28, 40 and 59 kHz and with the variable powers (≤900 W). According to the results obtained in our previous studies [7, 11, 14], the ultrasonically-accelerated debitterizing parameters were designed as follows: the peeled apricot kernels of the beta-glucosidase inactivated and non-inactivated were placed in a container with the sample-to-liquid of 1:12 (g/mL) which was fixed in a designated position of the ultrasound bath, and the ultrasound parameters were of 55 ^{o}C (temperature), 300 W (power), 59 kHz (frequency) and 2 h (irradiation time) [21, 22]. In order to avoid the temperature increasing caused by the ultrasound irradiation, an in-water pipe was added to the opposite of the ultrasonic cleaner's out-water pipe,

and the flux ratio between in-water and out-water was regulated to keep the solution temperature stable in this experiment. Once finishing the debitterizing, the water was collected for determining the changes of the amygdalin mediated by ultrasound, and the quantitative was calculated according to the constructed working curve of amygdalin standard, and the formula is y=8421.6x +210.06 (R^2=0.9996).

2.5. Effects of ultrasound irradiation on the volatile components in the debitterizing water of apricot kernels

2.5.1 Preparation of the volatile components from the debitterizing water

The debitterizing water mentioned in the section of 2.4 (the peeled apricot kernels were treated by the boiling water to inactivate the beta-glucosidase, then the apricot kernels were ultrasonically or non-ultrasonically debitterized and the waters were collected for the analysis) was also used for the analysis of volatile components by using a Shimadzu GC-MS QP-2010 Ultra gas chromatography coupled with a mass spectrometer (GC-MS). Regarding the sample pretreatment, the water (300 mL) was extracted 3 times with the solvent of diethyl ether (90 mL, 60 mL and 60 mL), and each extraction operation was for 8 h. Next, the collected extraction solutions were added with the nanhydrous sodium sulfate and placed at 4 ^{o}C overnight. Finally, the supernatant was condensed to 1 mL by a glass KD concentrator under the conditions of vacuum and 35 ^{o}C. Before use, it was diluted to 500 folds with the n-hexane. As the blank sample, the procedure was the same as the ultrasonically-accelerated debitterizing besides the ultrasound irradiation.

2.5.2 GC-MS determination of the volatile components

The volatile components were separated by GC-MS according to methods with a slight modification [23, 24], and were identified by retrieving the mass spectrometry data in a NIST14 library. The working parameters of GC were as follows: a Rtx-5MS-1 column (30 m×0.25 mm×0.25 μm, Restek), inlet temperature of 250 °C, injection volume of 1 μL and carrier gas of Helium. The programmed temperature was: maintaining 40 °C for 3 min, with an increase from 40 °C to 120 °C at the flow rate of 5 °C/min, then up to 230 °C with the flow rate of 10 °C/min and keeping for 5 min. The MS working parameters were as follow: Electron energy 70 eV; EI source; ion source temperature 200 °C; 40-550 amu scanning range; full spectrum scanning mode.

3 RESULTS AND DISCUSSION

3.1 Simultaneous determination of the D- and L- amygdalin by HPLC

Regarding the determination of D- and L- amygdalin, although some methods such as high-performance liquid chromatography (HPLC) [25], carbon-13 nuclear magnetic resonance (^{13}CNMR) spectroscopy [26], chemical ionization mass spectrometry [27] and gas chromatography with flame ionization detection (GC-FID) [28] have been employed for the identification and quantitative determination of the amygdalin epimers, yet these methods required some time-consuming complicated procedures to prepare the sample. In the meantime, considering the possible epimerization from D- to L- amygdalin, and the latter's potential safety, it is very necessary to have a simple, rapid and sensitive method which can simultaneously detect the epimers of D- and L- amygdalin during the processing of apricot kernels.

The results of simultaneously determining the D- and L- amygdalin by HPLC were shown in Fig. 2, which is corresponded to the conditions in Table 1. As shown in Fig. 2a, the D and L- amygdalin were not separated at the retention time of 17-20 min with the first working condition of HPLC, and the resolution of two peaks was very small. In comparison, the signal intensity of the peaks in Fig. 2b was stronger than that in Fig. 2a, when the detection wavelength was set at 210 nm, although the 214 nm was the optimal wavelength for determining the D-amygdalin. Therefore, the 210 nm was used as the optimum detection wavelength for the mixture of L-, D- amygdalin in the following studies, which is also in accordance with the results by Liu [29].

It could be seen from Fig. 2c that the changing of the column temperature still could not achieve a better separation between the D- and L- amygdalin. Generally, the mass transfer resistance decreases with the increase of temperature from the perspective of chromatographic thermodynamics, so the column efficiency increases and the peak shape becomes sharp, which is also favorable for the separation. The increase of temperature makes the retention factor and the solute's relative retention value smaller, which is not conducive to the separation [30]. Therefore, the detection was carried out using a column temperature of 8 ^{o}C.

Generally, the mobile phase composition has an important influence on the separation [31]. As shown in Fig. 2d and 2e, the resolution of the two peaks was significantly lowered, and the retention time was also shortened when the ratio of organic phase to acetonitrile was at 10%, while the retention time was increased to 25 min when the ratio of acetonitrile was reduced to the 7%. In Fig. 2f and Fig. 2g, the

compounds of D and L- amygdalin were well separated, but the signal was relative weak. Meanwhile, the mobile phase contained a high proportion of phosphate buffer not suitable for the equipment of the HPLC. In comparison, Fig. 2h demonstrated a good resolution and sensitivity about the separation of D- and L- amygdalin, which was therefore employed in this research.

3.2 Effect of ultrasonically-accelerated debitterizing on the epimerization of D-amygdalin

As shown in Fig. 3, the D-amygdalin could be epimerized into the L-amygdalin by the treatment of inactivating the beta-glucosidase in the peeled apricot kernels, which demonstrates that the processing does influence the existing form of the amygdalin. Furthermore, the epimerization rate of D-amygdalin was 34.29% with the peeled apricot kernels treated by the boiling water for 10 min. That is to say, high temperature treatment can cause the epimerization of the D-amygdalin, and the safety should be concerned about the water generated from inactivating the beta-glucosidase of apricot kernels.

Fig. 4 illustrated the chromatograms about the amygdalin transferred to the water from the apricot kernels during the ultrasonically-accelerated debitterizing. Obviously, no L-amygdalin was separated and detected using the same conditions of HPLC as in the above section of 3.1 (Fig. 2h). However, the D-amygdalin occurred in the debitterizing water, which suggests that the ultrasonically-accelerated debitterizing technique did not cause the epimerization of D-amygdalin under the employed conditions whether the beta-glucosidase of the apricot kernels inactivated or not. In

other words, the epimerization of D-amygdalin was not caused by the ultrasound irradiation and the beta-glucosidase, and the ultrasonic debitterizing can not induce the secondary problem of safety.

Furthermore, the signal intensity of the D-amygdalin in the ultrasonically-debitterizing water with the beta-glucosidase inactivated of the apricot kernels was stronger than that of the beta-glucosidase non-inactivated (in Fig. 4A and 4B), indicating that the beta-glucosidase did promote the degradation of D-amygdalin during the debitterizing of apricot kernels. Moreover, the beta-glucosidase activity can also be activated with an increase of 34.67% by the ultrasound irradiation, which explains the reason why the time can be greatly shortened during the debitterizing of apricot kernels exposed to ultrasound irradiation [22]. Considering the potential application and recycling of the D-amygdalin, it is better to inactivate the beta-glucosidase of the apricot kernels when using the ultrasonically-accelerated debitterizing technique so as to reduce the degradation of amygdalin and make more amygdalins transferred into the debitterizing water.

3.3 Changes of D-amygdalin with different pretreatments on the beta-glucosidase of apricot kernels during debitterizing

Table 2 shows the changes of D-amygdalin with different pretreatments on the beta-glucosidase of apricot kernels during debitterizing. The content of D-amygdalin was 64.68 mg/g in the peeled apricot kernels (Untreated), and the residual content was 24.85 mg/g, when the peeled apricot kernels with the beta-glucosidase denatured were debitterized with the water of 55 ^{o}C for 2 h, and the leaching rate was 61.58%, which

means that the hot water can promote the transferring of D-amygdalin to the contacted water resulting in the removal of bitterness. In comparison, the ultrasonically-debitterizing could promote the leaching rates of the amygdalin from 61.58% to 85.42% and 95.70%, respectively. An increase of 23.84% was mainly attributed to the ultrasound when the beta-glucosidase was inactivated during ultrasonically-debitterizing, and the beta-glucosidase contributed an increase of 10.28% to the leaching rate of D-amygdalin. The reason that the beta-glucosidase promoted the removal of bitterness might be the synergistic action of temperature and ultrasound on the enzyme, i.e. the temperature of 55 ^{o}C is suitable for activating the beta-glucosidase, in the meantime, the activity of beta-glucosidase can also be triggered by the cavitation of ultrasound irradiation [22] which resulted in the degradation of of D-amygdalin, and then the rapid transferring from the apricot kernels. As a consequence, the residuals of D-amygdalin were decreased to 9.43 mg/g and 2.78 mg/g compared with the results of non-ultrasonically debitterizing, indicating that the ultrasound technology could improve the debitterizing efficiency of apricot kernels by accelerating the leaching rate of D-amygdalin. In a word, it is not necessary to inactivate the beta-glucosidase when the ultrasound was employed to rapidly remove the bitterness of apricot kernels.

3.4 Effects of ultrasonically-accelerated debitterizing on the volatile components in the debitterizing water of apricot kernels

In order to explore the re-utilization of the debitterizing water, the volatile components were analyzed and identified by the GC-MS according to the matching of

their recorded mass spectra with those of NIST14 (National Institute of Standards and Technology) libraries data provided by the software of GC-MS system, and the results were shown in Fig. 5, Table 3 and Table 4, respectively. Table 3 shows that a total of 44 kinds of volatile compounds were detected and identified in the debitterizing water of apricot kernels, including phenols, acids, aldehydes, esters, ketones and hydrocarbons. Among them, the benzaldehyde was the main compound with a relative content of 94.41%, followed by the benzyl alcohol and di-tert-butyl-p-methylphenol, and their contents were of 1.50% and 1.56%, respectively. To the main components of benzaldehyde and benzyl alcohol, they are considered to be originated from the degradation of the D-amygdalin due to contacting with the hot water during the debitterizing.

In comparison, 57 kinds of volatile compounds were detected and identified in the water from the ultrasonically-debitterized apricot kernels in Table 4, including aldehydes, ketones, esters, alcohols, acids, ethers and hydrocarbons, which was more than those in the debitterizing water without ultrasound irradiation on the apricot kernels during the debitterizing. Furthermore, the benzaldehyde was still the dominant volatile compound, accounting for 74.86%, followed by the benzyl alcohol with a relative content of 21.81%, which was much higher than that in the debitterizing water without ultrasound irradiation on the apricot kernels, and these results may be attributed to the degradation of amygdalin induced by the cavitation of ultrasound, which was also corresponded to the results of the amygdalin residual in the apricot kernels. In other words, ultrasound did have a great influence on the volatile

components in the debitterizing water of the apricot kernels. Furthermore, considering the preservative, flavor-adding and healthy function of the benzyl alcohol and benzaldehyde, it is necessary to recycle these compounds from the water or to develop some novel healthy drinks with this water as the main raw material. From the viewpoint of the flavor, the water from the ultrasonically-debitterized apricot kernels was better than that of the water from the non-ultrasonically debitterized apricot kernels. To some extent, the so-called wastewater from the debitterizing can not only be re-utilized, but also decrease the discharge and the environment pollution, consequently resulting in the added value of the apricot kernels in the industrial processing.

4 Conclusions

In summary, ultrasound irradiation can accelerate the debitterizing of apricot kernels by promoting the mass transfer and degradation of the D-amygdalin. Moreover, it can not cause the epimerization of the D-amygdalin to the L-amygdalin, which means that this novel ultrasonically-debitterizing technique has the same mechanism as the conventional debitterizing of hot water, i.e. there is no novel safety issue occurred in the ultrasonically-debitterizing based on the changes of D-amygdalin, while the procedure can be greatly accelerated due to the cavitation of ultrasound irradiation. In addition, the water from the ultrasonically-debitterizing of apricot kernels exerted more aromas compared with that of the conventional debitterizing, which suggests that there are more possible applications about this kind of water in the beverage drinks, cosmetics and pharmaceutical industry. However, the

specific forming mechanism should be further conducted about the volatile compounds induced by the ultrasound irradiation.

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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FIGURE CAPTIONS:

Figure 1 Chemical structures of D- and L- amygdalin

Figure 2 Chromatograms of the D- and L- amygdalin with different conditions of HPLC

Figure 3 Chromatogram of the D- and L- amygdalin in the water from the inactivating of the beta-glucosidase in apricot kernels

Figure 4 Chromatograms of D-amygdalin in the debitterizing water with the beta-glucosidase of apricot kernels inactivated and non-inactivated

Figure 5 Total ion chromatograms of the volatile components in the debitterizing water and the ultrasonically-debitterized water of the apricot kernels by GC-MS

Tables

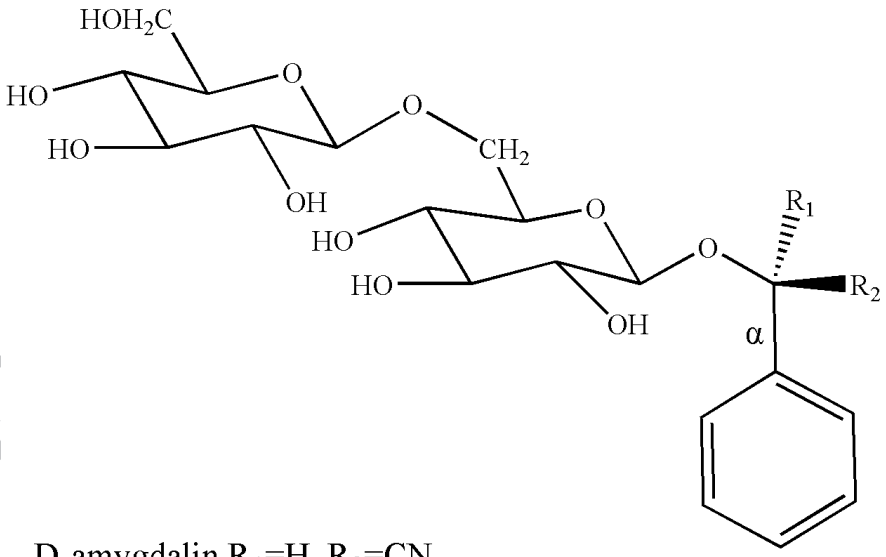
Table 1 Conditions for the separation of D- and L-amygdalin by high performance liquid chromatography

Table. 2 Changes of D-amygdalin with different pretreatments on the β-glucosidase of apricot kernels during debitterizing

Table 3 The volatile components in the non-ultrasonically debitterizing water of apricot kernels

Table 4 The volatile components in the ultrasonically debitterizing water of apricot kernels

Figure 1



D-amygdalin R_1=H, R_2=CN
L-amygdalin R_1=CN, R_2=H

Figure 2

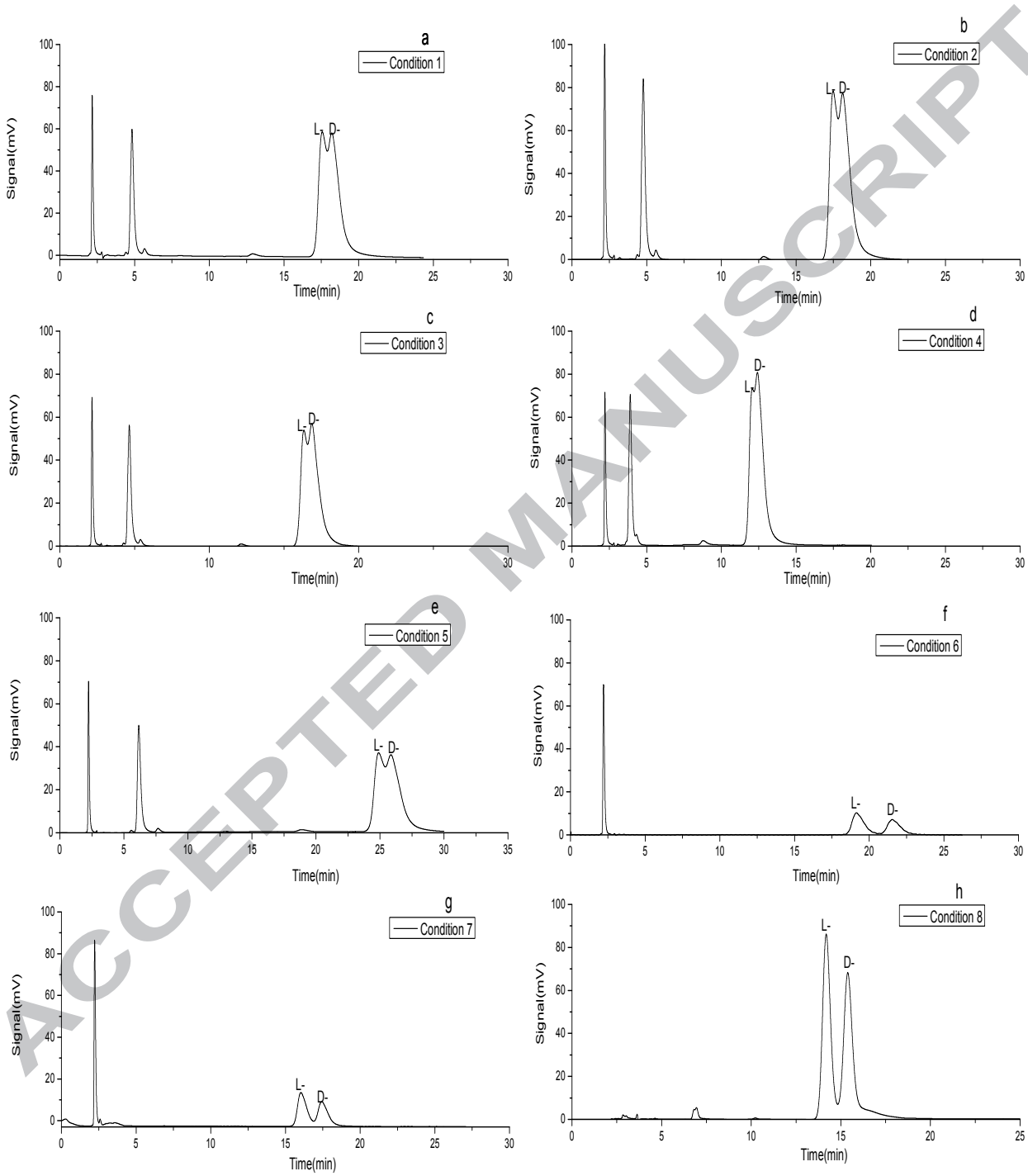


Figure 3

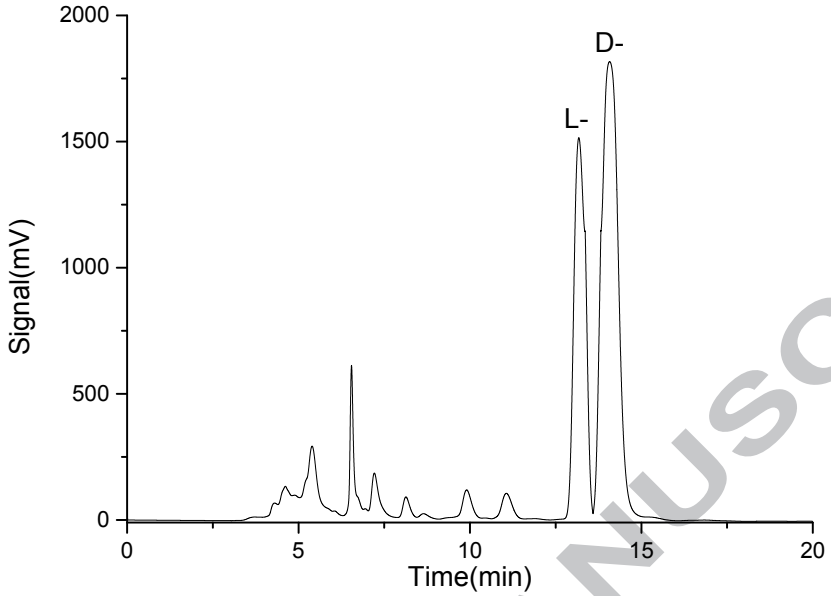


Figure 4

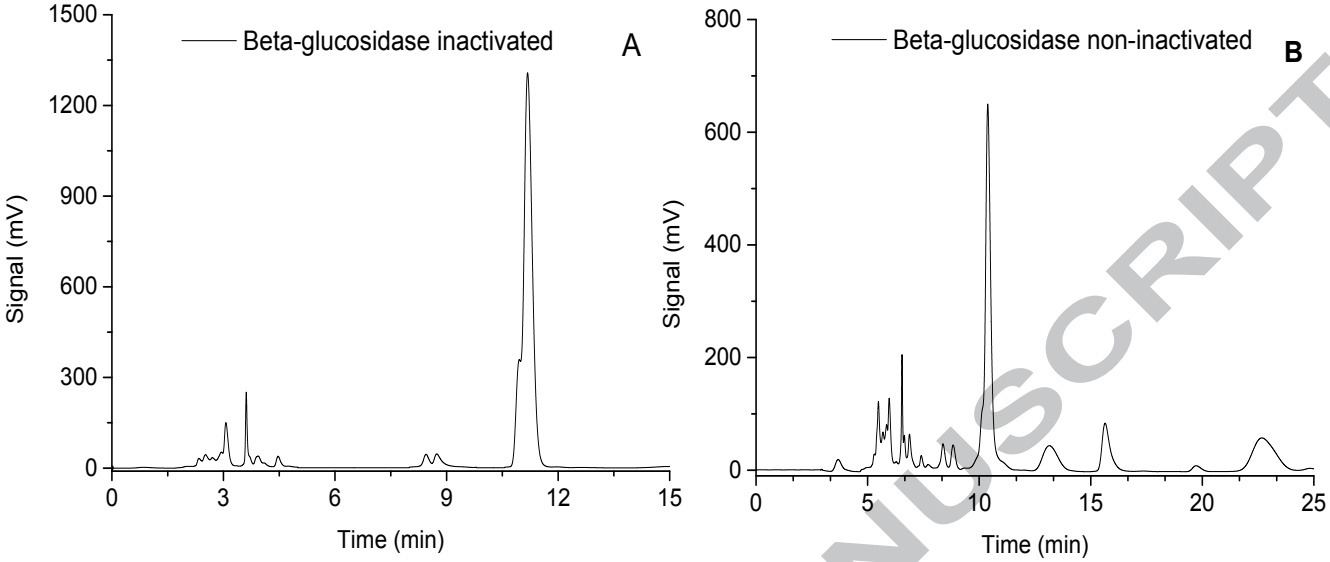


Figure 5

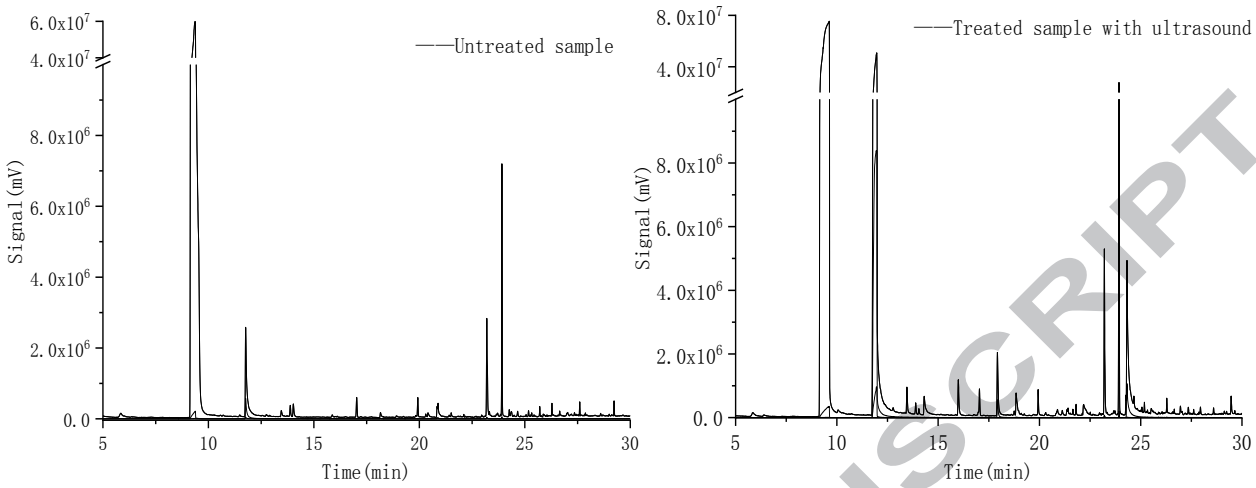


Table 1 Conditions for the separation of D- and L-amygdalin by high performance liquid chromatography

Conditions number	Column type	Detection wavelength (nm)	Mobile phase (mL: mL)	Flow rate (mL/min)	Column Temperature (°C)
1	Eclipse Plus C_{18}	214	Acetonitrile: Phosphate buffer (pH 3.1) = 8.5: 91.5	1.2	8
2	Eclipse Plus C_{18}	210	Acetonitrile: Phosphate buffer (pH 3.1) = 8.5: 91.5	1.2	8
3	Eclipse Plus C_{18}	210	Acetonitrile: Phosphate buffer (pH 3.1) = 8.5: 91.5	1.2	35
4	Eclipse Plus C_{18}	210	Acetonitrile: Phosphate buffer (pH 3.1) = 10:90	1.2	8
5	Eclipse Plus C_{18}	210	Acetonitrile: Phosphate buffer (pH 3.1) = 7:93	1.2	8
6	Eclipse Plus C_{18}	210	Acetonitrile: Phosphate buffer (pH 3.1) = 5:95	1.2	8
7	Eclipse Plus C_{18}	210	Acetonitrile: Phosphate buffer (pH 3.1) =4:96	1.2	8

8	Cosmosil C_{18}-AR-II	210	Acetonitrile: 0.1% Phosphate buffer=7:93	1.0	25

Table. 2 Changes of D-amygdalin with different pretreatments on the β-glucosidase of apricot kernels during debitterizing

	Untreated apricot kernels	55 °C water for 2 h with the β-glucosidase denatured	Ultrasonic debitterizing with the β-glucosidase denatured[a]	Ultrasonic debitterizing with the β-glucosidase non-denatured
Residual of amygdalin (mg/g)	64.68±0.69	24.85±0.11	9.43±1.08	2.78±0.18
Leaching rate of amygdalin (%)		61.58±0.25	85.42±1.79	95.70±0.35

a: Ultrasound conditions as power of 300 W, time of 2 h, frequency of 59 kHz, temperature of 55 °C and sample-to-liquid of 1:12 (g/mL).

Table 3 The volatile components in the non-ultrasonically debitterizing water of apricot kernels

n	Retention time (min)	Component	Relative content (%)
1	5.85	Ethylbenzene	0.0654
2	9.38	Benzaldehyde	94.4064
3	10.56	Decane	0.0084
4	11.48	D-Limonene	0.0168
5	11.77	Benzyl alcohol	1.5007
6	12.90	Diethyl malonate	0.0118
7	13.46	Benzeneacetonitrile, alpha.-oxo-	0.0716
8	13.88	Undecane	0.1087
9	14.03	Nonanal	0.1424
10	15.87	Acetic acid, phenylmethyl ester	0.0211
11	16.11	Benzoic acid, ethyl ester	0.0072
12	17.03	Dodecane	0.1799
13	18.16	2,3-Dimethoxytoluene	0.0527
14	19.93	Tridecane	0.1538
15	20.30	Phenylpropanamide	0.0291
16	20.84	1,3-Dioxolane, 2-(1-phenylethyl)-	0.2534
17	21.42	2-Dodecenal, (E)-	0.0122
18	21.95	1-Tetradecene	0.0088
19	22.11	Tetradecane	0.0214
20	22.32	1-tert-butyl-2-(1-methyl-2-nitroethyl) cyclohexanone	0.0067
21	22.38	1-Tetradecene	0.0139
22	22.96	2-Butanone, 1-bromo-3,3-dimethyl-	0.0129
23	23.01	1-Hexadecanol	0.0057
24	23.20	3-tert-Butyl-4-hydroxyanisole	0.9315
25	23.49	Butane, 1,1'-sulfonylbis-	0.0035
26	23.66	Heptadecane	0.0246
27	23.71	Pyrimido[1,2-a]azepine, 2,3,4,6,7,8,9,10-octahydro-	0.0389
28	23.92	Di-tert-butyl-p-methylphenol	1.5648
29	24.36	2-Butanone, 1-chloro-3,3-dimethyl-	0.0705
30	24.49	Spiro[4.5]decan-7-one, 1,8-dimethyl-4-(1-methylethyl)-	0.0150
31	24.81	Tetradecane, 1-chloro-	0.0001
33	25.33	Tetradecane	0.0223
34	25.78	Benzene, (1-butyloctyl)-	0.0078

35	25.87	Naphthalene, decahydro-1,6-dimethyl-4-(1-methylethyl)-	0.0174
36	26.58	Tetratetracontane	0.0078
37	26.65	Heptadecane	0.0314
38	27.36	3-Heptanol, 3,6-dimethyl-	0.0235
39	27.53	Isobutyl tetradecyl carbonate	0.0159
40	27.67	Benzyl Benzoate	0.0166
41	27.82	1,2-Benzenediol, 3,5-bis(1,1-dimethylethyl)-	0.0058
42	28.60	1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester	0.0228
43	29.00	Nonadecane	0.0147
44	29.65	Dibutyl phthalate	0.0089

Table 4 The volatile components in the ultrasonically debitterizing water of apricot kernels

n	Retention time (min)	Component	Relative content (%)
1	5.85	Ethylbenzene	0.0315
2	9.59	Benzaldehyde	74.8550
3	10.73	Octanal	0.0022
4	11.97	Benzyl alcohol	21.8143
5	12.35	1,2-Ethylene glycol	0.0004
6	12.40	Heptane, 2,4-dimethyl-	0.0025
7	13.46	Benzeneacetonitrile, .alpha.-oxo-	0.1111
8	13.89	Undecane	0.0447
9	14.05	Nonanal	0.0223
10	15.87	Acetic acid, phenylmethyl ester	0.0030
11	15.99	1,2-Propanedione, 1-phenyl-	0.1635
12	17.04	Dodecane	0.0925
13	17.93	Benzenepropanenitrile, .beta.-hydroxy-	0.3022
14	18.85	Vinyl benzoate	0.1765
15	19.10	Benzenemethanamine, N-(1-methylethyl)-	0.0044
16	19.94	Tridecane	0.0811
17	20.31	Benzoic acid, 4-(1-methylethyl)-	0.0174
18	20.85	1,3-Dioxolane, 2-(phenylmethyl)-	0.0142
19	21.41	2-Dodecenal, (E)-	0.0284
20	22.12	Tetradecane	0.0051
21	22.31	Decane, 1-chloro-	0.0269
22	22.65	3,5-di-tert-Butyl-4-hydroxyanisole	0.0064
23	22.70	2,5-Cyclohexadiene-1,4-dione, 2,6-bis(1,1-dimethylethyl)-	0.0026
24	22.96	2-Butanone, 1-bromo-3,3-dimethyl-	0.0076
25	23.02	1-Hexadecanol	0.0040
26	23.13	2,4,4-Trimethyl-3-(3-oxobutyl)cyclohex-2-enone	0.0027
27	23.20	3-tert-Butyl-4-hydroxyanisole	0.5346
28	23.73	Octadecanal	0.0174
29	23.86	Pentadecane	0.0035
30	24.27	.alpha.-Ionone	0.0469
31	24.32	Mandelic acid	1.2995
32	24.83	Heptane, 2,2,3,3,5,6,6-heptamethyl-	0.0460
33	24.92	Tetradecane, 1-iodo-	0.0154
34	25.34	Octadecane	0.0167
35	25.44	1-Decanol, 2-hexyl-	0.0070

36	25.62	3-Heptene, 2,2,3,5,5,6,6-heptamethyl-	0.0120
37	26.12	Cyclopentane, decyl-	0.0030
38	26.22	Hexadecane, 2-methyl-	0.0086
39	26.29	4a,7a-Epoxy-5H-cyclopenta[a]cyclopropa[f]cycloundecen-4(1H)-one, 2,7,10,11-tetrakis(acetyloxy)decahydro-8,9-dihydroxy-1,1,3,6,9	0.0443
40	26.38	3-Octanol, 3,7-dimethyl-	0.0031
41	26.52	Propanoic acid, 2-methyl-, nonyl ester	0.0018
42	26.59	Octadecanoic acid, 2-oxo-, methyl ester	0.0071
43	26.96	1,4-Benzenediol, 2,5-bis(1,1-dimethylethyl)-	0.0315
44	27.62	Benzyl Benzoate	0.0155
45	27.72	Octadecane, 1-bromo-	0.0020
46	27.82	1,4-Benzenediol, 2,5-bis(1,1-dimethylethyl)-	0.0035
47	28.19	Benzenemethanamine, N-nitroso-N-(phenylmethyl)-	0.0020
48	28.60	1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester	0.0199
49	28.70	Octadecyl methacrylate	0.0013
50	28.88	Dodecane, 1-chloro-	0.0031
51	28.94	1-Decanol, 2-hexyl-	0.0027
52	29.04	3-Ethyl-3-methylheptane	0.0019
53	29.28	Heptacosanoic acid, methyl ester	0.0021
54	29.37	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester	0.0043
55	29.65	Dibutyl phthalate	0.0155
56	29.78	Octadecane, 1-iodo-	0.0029
57	29.82	n-Heptadecylcyclohexane	0.0021

Highlights:

- Ultrasonically-debitterizing did not cause the epimerization of D-amygdalin.
- Ultrasound rapidly debitterized the apricot kernels by degrading the amygdalin.
- Ultrasound can make the debitterizing water more safe and flavors.
- Ultrasound can be used to accelerate the removal of bitterness from apricot kernels.