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Unveiling the improvement mechanisms of moist-heat and hot-air treatments on the flavor of *Panax quinquefolius*

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Abstract

China-grown American ginseng, namely *Panax quinquefolius* (PQ), faces significant limitations in food industry applications due to its undesirable flavor. Moist-heat and hot-air treatments (MHHA) are one of the main methods for processing PQ. However, its impact on both flavor and functional components of PQ remained unclear. To address this issue, we proposed a three-step strategy termed "HE+H+EH", comprising the integration of human sensory evaluation and electronic tongue (HE), HPLC-Q-TOF-MS (H), and the integration of electronic nose and HS-GC-IMS (EH). Human sensory evaluation and electronic tongue analysis demonstrated that MHHA effectively improved the taste of PQ by significantly reducing its bitterness while enhancing its umami taste. Using HPLC-Q-TOF-MS, we identified 75 saponin compounds in PQ and 90 in processed *Panax quinquefolius* (PPQ). Notably, the content of five bitter malonylginsenosides decreased significantly, which contributed to the reduction in PQ's bitterness. Meanwhile, five newly generated rare bioactive saponins were detected: vinaginsenoside R₇, ginsenosides Rk₁, Rg₅, Rg₆, and Rh₄. Electronic nose and HS-GC-IMS analyses revealed that MHHA reduced the levels of undesirable odorants. This study highlighted the role of MHHA in improving the flavor and generating functional ingredients in PQ. These findings provided a solid foundation for the application of PQ in food development.

Keywords: *Panax quinquefolius*; Human sensory evaluation; Electronic tongue; Electronic nose; HPLC-Q-TOF-MS; HS-GC-IMS

1. Introduction

Panax quinquefolius L. (PQ), also known as American ginseng, is an important functional food native to North America. It was successfully introduced and cultivated on a large scale in China in the 1980s¹. PQ is renowned for its rich bioactive components, with a complex and diverse chemical composition that includes saponins, volatile oils, amino acids, sugars, and polyacetylenic alcohols. Among these, saponins are the primary constituents². PQ possesses both medicinal and dietetic value and is widely used in the processing of various health foods³. However, the natural earthy flavor and bitterness of PQ severely limit its development and application in the food industry. Furthermore, traditional processing methods, such as sun-dried ginseng, present several drawbacks, including prolonged drying cycles, flavor defects, and poor process controllability. Ultimately, these issues lead to a decline in product quality and a waste of resources. In recent years, combined processing technologies have become a research focus for improving PQ quality through multi-stage synergistic effects. Moist-heat processing (MH) employs high temperature and humidity to soften the tissue structure and facilitate the formation of active components. Hot-air drying (HA) uses forced convection to accelerate moisture transfer, thus helping to enhance the sensory quality of the product. Studies have shown that MH can significantly increase the total saponin content of PQ to 95.63 mg/g⁴. Additionally, HA can shorten the drying time by more than 30%⁵. Both techniques show significant effects when applied individually. However, the combined impact of moist-heat and hot-air treatments (MHHA) on the flavor and composition of PQ remains unclear.

In food research, the innovative combination of multiple technologies enables efficient and precise analysis of food flavor and composition. In electronic sensory evaluation, electronic tongue

and electronic nose play indispensable roles. While conventional human sensory evaluation captures people's real opinions about food, the results are not always reliable. They can be skewed by an evaluator's personal experience, the conditions of the test, and inconsistent rating scales. Consequently, the evaluation outcomes exhibit a degree of inherent subjectivity and variability. In contrast, electronic sensory technologies effectively compensate for these shortcomings with their objectivity and reproducibility. For example, changes in the sensory characteristics of strawberries during five-day storage were evaluated by utilizing the relationship between human and electronic senses⁶. In another study, a systematic evaluation of Italian wines was conducted based on a combination of electronic tongue and human sensory perception⁷. Among volatile compound detection technologies, HS-GC-IMS is characterized by rapid response, high sensitivity, simple operation, and cost-effectiveness⁸. For instance, volatile flavor compounds in five dried fish samples were successfully distinguished using HS-GC-IMS⁹. By employing HS-GC-IMS, 35, 29, 8, and 12 key volatile components were respectively identified from four Baijiu samples¹⁰. The high sensitivity, high resolution, and strong qualitative and structural analysis capabilities of HPLC-Q-TOF-MS make it an ideal tool for the comprehensive analysis of non-volatile food components¹¹. For example, 117 compounds were identified from *Zanthoxylum nitidum* using HPLC-Q-TOF-MS¹². A total of 103 compounds were identified and categorized from *Magnolia officinalis* using HPLC-Q-TOF-MS¹³. The integrated application of these technologies in flavor evaluation has become an inevitable trend in the food industry.

This study aimed to elucidate the enhancement mechanisms of MHHA on the flavor and functional components of China-grown PQ, thereby providing a theoretical basis for the

development and quality enhancement of PQ products. To this end, we integrated five techniques, including human sensory evaluation (H), electronic tongue (E), HPLC-Q-TOF-MS (H), electronic nose (E), and HS-GC-IMS (H), into a three-step strategy termed "HE+H+EH". First, human sensory evaluation and electronic tongue (HE) were integrated to comprehensively and accurately characterize the taste enhancement of PQ by MHHA. Second, HPLC-Q-TOF-MS (H) was employed to investigate the alterations in taste and functional components of PQ induced by MHHA. Third, electronic nose and HS-GC-IMS (EH) were combined to comprehensively analyze the changes in odor components of PQ resulting from MHHA. The integration of the HE, H, and EH strategies enabled a systematic elucidation of the mechanism by which MHHA improves the flavor of PQ. This established a crucial foundation for the further development of China-grown American ginseng in the food industry.

2. Results

2.1 Three-step "HE+H+EH" strategy

To systematically decipher the multifaceted effects of MHHA treatment, we designed an integrated analytical strategy that progressed from sensory perception to molecular characterization (as illustrated in Fig. 1). This "HE+H+EH" strategy was intentionally structured to establish causal links between sensory attributes and their underlying chemical constituents. First, the combined human sensory evaluation and electronic tongue (HE) analysis quantified the holistic taste profile, thereby defining the key sensory outcomes produced by the treatment. Subsequently, HPLC-Q-TOF-MS (H) was employed to target the non-volatile compound pool, identifying the specific taste-active and functional components responsible for the sensory changes

measured in the first step. Finally, the electronic nose coupled with HS-GC-IMS (EH) mapped the volatile composition, thereby completing a comprehensive flavor assessment by linking aroma changes to the process. Therefore, the "HE+H+EH" strategy provided a clear roadmap for this investigation, constructing an evidence chain from sensory perception to chemical causation.

2.2 The enhancing effect of MHHA on the flavor of PQ

The results of human sensory evaluation are shown in Fig. 2A and Fig. 2B. PPQ showed reductions in earthy flavor, bitterness, and crispness, while its softness increased significantly. It should be noted that earthy flavor is essentially a retronasal olfactory sensation, which is fundamentally different from the basic taste attributes¹⁴. The retronasal olfaction does not directly alter the recognition of basic tastes, but the inherent earthy flavor of PQ can synergize with bitterness to further intensify negative sensory perception. The decrease in crispness was closely related to the reduction in moisture content of PQ from 63.08% to 7.11%. Compared with traditional sun-drying which takes approximately 14.7 days, the drying time of MHHA is 13 hours, representing a reduction of more than 90%⁵. The improved softness may result from the moist-heat treatment disrupting rigid cell walls and reducing tissue strength, combined with the hot-air drying preventing shrinkage and preserving the loose structure¹⁵⁻¹⁶. This resulted from the synergistic effect of MHHA. The treatment improved the softness of PQ while reducing its unpleasant taste, thus yielding a softer and more palatable mouthfeel. Subsequently, the electronic tongue analysis quantified eight sensory dimensions: sourness, bitterness, saltiness, astringency, umami, richness, and the aftertastes of bitterness and astringency. Radar charts for PQ and PPQ are shown in Fig. 2C and Fig. 2D, respectively. The quantitative results for the eight taste attributes

are presented in Fig. 2E. Compared with PQ, PPQ showed reduced bitterness (decreasing from 9.4375 to 7.2990) and significantly enhanced umami (increasing from 6.1710 to 11.3065). By combining human sensory evaluation with electronic tongue analysis, it was demonstrated that MHHA improved the taste quality of PQ.

To further validate these findings, orthogonal partial least squares discriminant analysis (OPLS-DA) was applied to visualize and classify the data. As shown in Fig. 2F, the OPLS-DA model effectively discriminated between PQ and PPQ. The model showed high stability ($R^2Y = 0.881$) and predictive capability ($Q^2 = 0.829$), confirming the reliability of the analysis. Permutation tests further validated the model's robustness, yielding R^2Y and Q^2Y intercepts of 0.0772 and -0.3110, respectively, both of which were well below the critical thresholds of 0.40 and 0.05 (Fig. 2G)¹⁷. The variable importance in projection (VIP) analysis revealed that bitterness and umami ($VIP > 1$) were the taste indicators that significantly contributed to distinguishing PQ from PPQ (Fig. 2H). This provided additional evidence that MHHA had a significant impact on the taste of PQ. In brief, using human sensory evaluation and an electronic tongue improved the taste of PQ by reducing bitterness and earthy flavor, while enhancing umami and softness.

2.3 Impact of MHHA on the composition of PQ

HPLC-Q-TOF-MS was used for qualitative analysis and comparative analysis of component levels in 40 batches each of PQ and PPQ. The total ion chromatograms (TICs) of PQ and PPQ in negative ion mode are shown in Fig. 3A and Fig. 3B, respectively. The positive ion mode TICs are shown in Fig. S1A and Fig. S1B. The identification was based on exact relative molecular mass, retention time, mass spectrometric fragments, literature data, and comparison with reference

substances. In addition, published data and specialized databases were also employed to identify ginsenosides¹⁸⁻¹⁹. As a result, a total of 98 saponins were identified from PQ and PPQ (Table 1). Of these, 75 and 90 saponin compounds were specifically identified from PQ and PPQ, respectively. Sixty-seven saponins were common components shared by both PQ and PPQ. PQ contained 8 unique saponin constituents, while PPQ contained 23 unique saponin constituents.

After MHHA, the relative content of five malonylginsenosides in PQ was reduced by more than 50%. These included malonylginsenoside Rb₁ (by 84.21%), Rb₃ (by 81.39%), Rc (by 77.65%), Rb₂ (by 76.78%), and malonylvinaginsenoside R₇ (by 76.89%). Their content changes and chemical structures are shown in Fig. 4A. Thus, malonylginsenosides exhibited high polarity and strong hydrophilicity due to the presence of carboxyl groups²⁰. Previous literature has indicated that this type of saponin is thermally unstable and readily undergoes hydrolysis, losing the malonyl group to yield neutral saponins²¹. This observation likely accounted for the decrease in content of these saponins. Additional literature indicated that the carboxyl group in the malonyl moiety could interact with positively charged regions of bitter taste receptors, thereby contributing to the bitterness²². Therefore, the reduction in bitterness in PPQ may be related to the decreased content of malonylginsenosides. Furthermore, the newly generated neutral saponins had reduced hydrophilicity. They were thus more readily absorbed by the body and could have had higher bioavailability. These results indicated that MHHA not only reduced the content of bitter compounds but also promoted the formation of saponins with improved bioavailability.

Five newly transformed compounds were detected in PPQ, including vinaginsenoside R₇, ginsenoside Rk₁, ginsenoside Rg₅, ginsenoside Rg₆, and ginsenoside Rh₄. Their content changes

and chemical structures are presented in Fig. 4B. Notably, vinaginsenoside R₇ was the product of malonylvinaginsenoside R₇ after the removal of the malonyl group. This further demonstrated that malonyl saponins were unstable at high temperatures. In addition, the other four ginsenosides were classified as rare ginsenosides. These newly generated saponins were shown to have had beneficial effects on the human body. For instance, vinaginsenoside R₇ exerted anti-inflammatory and antioxidant effects through the inhibition of the NF- κ B transcription factor activity²³. Ginsenoside Rk₁ improved endothelial dysfunction in diabetic vasculature via activation of the PPAR γ /eNOS pathway²⁴. It promoted endogenous apoptosis in cancer cells through targeted regulation of key genes associated with liver cancer²⁵. Ginsenoside Rg₅ exerted sedative-hypnotic effects by influencing the GABAergic and serotonergic nervous systems²⁶. Ginsenoside Rg₆ inhibited the proliferation of human lymphoma JK cells by influencing mitochondrial dysfunction²⁷. Ginsenoside Rh₄ exerted anti-metastatic effects on gastric cancer by inhibiting the SIX1-TGF- β /Smad2/3 signaling axis²⁸.

OPLS-DA was performed based on the ratios of the peak areas of the compounds to that of the internal standard in 40 batches of PQ and 40 batches of PPQ samples. (Fig. S2A). The samples from the two groups were completely separated. The values of R²X (0.734), R²Y (0.869), and Q² (0.827) demonstrated the validity of the model. Fig. S2B shows the results of the permutation test. The R²Y-intercept (0.0162) and Q²-intercept (-0.156) were both below their respective thresholds of 0.40 and 0.05. This result further verified the reliability of the model. Using a VIP > 1 threshold, malonylginsenosides Rb₁, Rb₃, Rc, and vinaginsenoside R₇ were identified as the major differential markers between PQ and PPQ (Fig. S2C). These compounds were all malonyl ginsenosides or

their degradation products, suggesting that MHHA exerted a significant influence on this class of saponins. This series of component transformations may be mainly driven by the MH step of MHHA. The high temperature and humidity environment likely disrupts the cell wall structure of PQ, triggering the hydrolysis of thermolabile malonylginsenosides. Meanwhile, the high-temperature condition may induce the structural rearrangement of ginsenosides, which could be the key reason for the generation of rare bioactive saponins²⁹.

2.4 Impact of MHHA on the volatile compounds of PQ

To investigate the impact of MHHA on the volatile components of PQ, an electronic nose was employed to analyze the volatile profile of PQ and PPQ. Fig. 5A presents the comparative results of PQ and PPQ on the MXT-5 column. Similarly, Fig. 5B presents their comparative results on the MXT-1701 column. Evidently, distinct differences were observed between the odor fingerprints of PQ and PPQ. Furthermore, the principal component analysis (PCA) result demonstrated a complete separation between the 11 PQ and 11 PPQ samples (Fig. 5C). The recognition index of PCA reached 60, indicating significant intergroup differences. The contribution rates of PC1 and PC2 were as high as 94.24%. Discriminant factor analysis (DFA) results showed that PQ and PPQ were completely separated, with a cumulative contribution rate of 100% from DF1 and DF2 (Fig. 5D). This further confirmed the odor characteristic differences between PQ and PPQ. The volatile compounds of PQ and PPQ were identified using the AroChemBase database within the electronic nose in combination with Kovats retention indices. With a correlation index greater than 50 as the criterion, 14 components were identified from PQ (Table 2), and 3 components were identified from PPQ (Table 3). Based on the data, the number of some undesirable odor compounds in PPQ

was observed to decrease. These substances, including beta-damascenone, 2-methylpropanal, butanoic acid, pentanoic acid, and decyl acetate, were characterized by burnt, spicy, and putrid odors. Concurrently, several pleasant aroma compounds increased in PPQ, such as 3-methylbutanal, methyl isobutyrate, and alpha-pinene. These compounds displayed a spectrum of pleasant aromas, encompassing sweet, fruity, malty, and cheesy notes.

The 3D plots of PQ and PPQ based on HS-GC-IMS are presented in Fig. 6A. Each peak in the plots represents a volatile compound. The higher the peak, the larger the volume, and the redder the color, the higher the concentration of the compound. To directly compare the differences in volatile components between the two, the spectrum of PQ was subtracted from that of PPQ. This operation yielded a 2D difference plot (Fig. 6B). If the content of volatile compounds was identical, the subtracted background appeared white. The blue color indicated that the peak volume of PQ was higher than that of PPQ, while the red color signified the opposite. Numerous blue regions in Fig. 6B indicate that the content of most volatile components decreased after MHHA. Based on the color variation in the corridor plot shown in Fig. 6C, it was divided into two distinct regions, I and II. Region I represented compounds with higher content in PQ, while Region II represented those with higher content in PPQ. The results indicated that 39 volatile compounds were present at higher levels in PQ (Table 4). These included acetophenone, ethyl 3-hydroxyhexanoate, 3-(methylthio)-1-propanol, delta-cadinene, 4-terpineol, 2-methylpyrazine, 2-pentylfuran, (Z)-beta-farnesene, 1-octanol, (E)-2-nonenal, *cis*-2-penten-1-ol, 1-octen-3-ol, 6-methyl-5-hepten-2-one, 2,3-dimethylpyrazine, alpha-terpinene, 3-carene, ammonia, and camphene, etc. Among these, components such as 3-(methylthio)-1-propanol, *cis*-2-penten-1-ol, ammonia, and camphene

contributed to undesirable odors such as onion, meaty, soy sauce, spicy, almond, plastic, and rubber. This demonstrated that MHHA effectively improved the odor quality of PQ by significantly reducing the content of certain undesirable odorants. In contrast, 13 volatile compounds were present at higher levels in PPQ, including propanoic acid, alpha-farnesene, nonanal, (*E*)-2-heptenal, benzaldehyde, methyl hexanoate, myrcene, (*E*)-2-pentenal, 2-methyl-1-propanol, dimethyl disulfide, 2-ethyl-1-hexanol, 1-hydroxy-2-propanone, and terpinolene (Table 4). Among them, 8 compounds including alpha-farnesene, methyl hexanoate, nonanal, myrcene, benzaldehyde, 2-methyl-1-propanol, 2-ethyl-1-hexanol, and terpinolene possessed pleasant aromas such as sweet, grape juice, pineapple, cherry, rosy, woody, lavender, citrus, neroli, and fresh. The content of these favorable aroma substances significantly increased after MHHA. Based on the peak volume data measured for various categories of compounds, a pie chart was plotted as shown in Fig. 6D and Fig. 6E. From this figure, it was clearly observed that the content of all compound categories in PQ showed a decreasing trend after MHHA. Furthermore, the proportions of each compound category in PQ and PPQ were calculated separately. In PQ, the proportions were 23.08% (aldehydes), 22.86% (alcohols), 21.20% (alkenes), 10.60% (acids), 8.45% (ketones), 7.20% (esters), and 6.60% (others). The corresponding proportions in PPQ were 24.50%, 24.07%, 19.53%, 10.93%, 7.50%, 11.10%, and 2.37%, respectively. Notably, the proportion of esters with pleasant aromas increased from 7.20% to 11.10%. This change is one of the reasons for the improved aroma of PPQ. The regulation of volatile compounds in PQ by MHHA may be dominated by the HA step. HA could accelerate moisture migration via forced convection, which efficiently removes a large number of undesirable volatile compounds in PQ³⁰.

3. Discussion

In this study, we proposed an "HE+H+EH" strategy to investigate the effect of MHHA on PQ by integrating human sensory evaluation (H), electronic tongue (E), HPLC-Q-TOF-MS (H), electronic nose (E), and HS-GC-IMS (H) techniques. Human sensory evaluation and electronic tongue showed that MHHA improved the softness and umami of PQ while reducing its bitterness and earthy flavor. A total of 98 components were identified in PQ and PPQ by HPLC-Q-TOF-MS. MHHA led to a decrease in the content of malonylginsenosides, which was the main reason for the reduction of bitterness in PQ. Simultaneously, MHHA promoted the generation of vinaginsenoside R₇, ginsenoside Rk₁, Rg₅, Rg₆, and Rh₄, which demonstrated significant bioactivities beneficial to human health. The combination of electronic nose and HS-GC-IMS enabled the identification of 68 odor compounds in PQ and PPQ. MHHA reduced undesirable odor compounds while increasing pleasant aroma compounds in PQ. These results systematically reveal that the synergistic effects of MH treatment and HA treatment play a crucial role in improving the flavor quality of PQ and promoting the formation of its functional components.

Despite these findings, several limitations still exist. First, the MHHA processing parameters adopted in this study were fixed at 100 °C moist-heat treatment for 3 h followed by 60 °C hot-air drying for 10 h. The absence of gradient experiments on parameters prevented us from revealing the dynamic transformation patterns of saponins and volatile compounds during the continuous process. Second, this study only focused on the changes in the chemical composition and sensory flavor of PPQ, and lacked *in vivo* experiments to further verify the variations in its bioactivity. Third, the current research provided only a short-term static analysis of the finished products after

MHHA processing. The lack of long-term storage experiments made it impossible to evaluate the stability of the flavor characteristics and functional components of PPQ during storage. Thus, these limitations indicate directions for subsequent research, including exploring the dynamic changes of components and flavor during MHHA processing, verifying the bioactivity of PPQ through *in vivo* experiments, and investigating the storage stability of PPQ.

4. Methods

4.1 Chemicals and reagents

The ginsenosides Rb₁, Rb₂, Rb₃, and Rc were purchased from Chengdu Mansite Biotechnology Co., Ltd. 20(*S*)-Ginsenoside Rg₃, 20(*R*)-Ginsenoside Rg₃, and polyphyllin VII were obtained from Chengdu Push Bio-technology Co., Ltd. 20(*S*)-Ginsenoside Rg₂, ginsenosides Rd, Re, and F₂ were supplied by Chengdu Refensi Biological Technology Co., Ltd. The purity of all reference standards is > 98%. The C₆-C₁₆ mixed alkanes reference standard was purchased from RESTEK Corporation (USA). Formic acid was purchased from Tianjin Damao Chemical Reagent Factory. Potassium chloride and tartaric acid were purchased from Tianjin Komio Chemical Reagent Co., Ltd. Purified water was obtained commercially from Hangzhou Wahaha Group. HPLC-grade methanol and acetonitrile were purchased from Oceanpak (Sweden) and Merck (Germany), respectively.

4.2 Preparation of PPQ

Six-year-old PQ samples were collected from Changbai Mountain. The samples were then standardized to ensure uniform size, with lengths of 22.70-24.00 cm and diameters of 1.50-1.70 cm. For the moist-heat treatment, PQ was steamed at 100 °C with a relative humidity of 95% for

3 h. Subsequently, hot-air drying was conducted in an electric thermostatic blast drying oven (Model 101-3BS, Shanghai Lichen Bangxi Instrument Technology Co., Ltd., China). The drying process was carried out at 60 °C with an average internal air velocity of 0.8-1.5 m/s for 10 h until the moisture content stabilized, yielding the final product PPQ. The moisture content was determined by the oven-drying method³¹⁻³².

4.3 Preparation of test solution

PQ and PPQ were ground separately, passed through a sieve with an aperture size of 355 µm, and prepared for experimental use. For HPLC-Q-TOF-MS analysis, 1.0 g of each type of powder was accurately weighed into a centrifuge tube. Then, 10 mL of 70% methanol was added. The mixture was sonicated at room temperature for 60 min and then centrifuged at 14,000 rpm for 10 min. The supernatant was collected for analysis. In addition, 1.5 g of each powder was accurately weighed separately, mixed with 45 mL of purified water, and ultrasonically treated at room temperature for 30 minutes for electronic tongue. The artificial saliva used in the electronic tongue was prepared by dissolving 2.237 g of potassium chloride and 0.045 g of tartaric acid in 1 L of water.

4.4 Human sensory evaluation

In this study, 57 volunteers (28 males and 29 females, aged 20-25 years) were recruited to conduct human sensory evaluation of sliced PQ and PPQ. All participants had normal taste and olfactory acuity, no habits of smoking or alcohol consumption, and no history of taste disorders. They signed informed consent forms before the experiment, agreeing to the use of their data for academic research and publication. The research process strictly adhered to ethical guidelines, and

all acquired data were anonymized. Participants had the right to withdraw from the experiment at any time. Prior to the formal experiment, systematic training was conducted in a sensory analysis laboratory. Theoretical instruction was provided to clarify the definition, perceptual characteristics, and rating criteria of related flavors. Geosmin was used as the reference compound to conduct practical training for earthy flavor recognition³³. To monitor the actual sensory experience, nose clips were not used during the sensory evaluation process. All evaluations were performed in individual sensory booths to minimize external interference. Sliced samples of PQ and PPQ were placed in disposable odorless trays and presented in coded numerical order using a blind method. The presentation sequence was randomized to avoid order effects. According to the evaluation protocol, participants were required to hold the sample in their mouth and chew for 15 s to ensure sufficient contact between taste receptors and the sample. After each sample, panelists rinsed their mouths thoroughly with purified water and rested for 1 h before testing the next sample to effectively avoid carry-over effects. The samples were evaluated using quantitative descriptive analysis with a 5-point intensity scale for four attributes including earthy flavor, bitterness, softness and crispness. These four attributes were selected because preliminary experiments indicated that they were significant factors affecting the flavor of PQ, and thus it was necessary to quantify them further. A score of 0 indicated no perception of the attribute, while a score of 5 represented the maximum perceived intensity. Graphs were generated using Origin 2022 and GraphPad Prism9.1.0 software^{6,34}.

4.5 Electronic tongue analysis

The taste characteristics were evaluated using an SA-402B taste analysis system (Intelligent

Sensor Technology Co., Ltd., Japan). The sensor array was composed of bitterness (C00), saltiness (CT0), astringency (AE1), sourness (CA0), and umami (AAE) sensors, along with two reference electrodes. Prior to the experiment, the taste sensors were activated in artificial saliva, and the reference electrodes were activated in a 3.3 M KCl solution. During measurement, each sensor was cleaned in artificial saliva. After the sensors were equilibrated for 30 s, the samples were tested for 30 s. Subsequently, the electronic tongue system converted the collected electronic signals into taste signals. All data were referenced against the artificial saliva¹⁷.

4.6 HPLC-Q-TOF-MS analysis

An Agilent 1290 HPLC system coupled with a 6550 Q-TOF mass spectrometer was used. The chemical components in PQ and PPQ were analyzed qualitatively and compared in terms of content. Polyphyllin VII (0.2 mg/mL), which shares structural similarity with ginsenosides, was used as the internal standard. The relative content was derived from the ratio of compound peak area to internal standard peak area. Given that MHHA might significantly affect the content of certain components, compounds with a peak area to internal standard peak area ratio >2 were selected to focus on substances with pronounced changes. A phenyl-hexyl column (4.6×50 mm, $3.5 \mu\text{m}$) was used for chromatographic separation. The mobile phase consisted of 0.1% formic acid in water (A) and acetonitrile (B). The elution gradient for both PQ and PPQ was as follows: 0-50 min, 5%-50% B; 50-55 min, 50%-100% B; 55-60 min, 100%-100% B. The flow rate was 0.5 mL/min, the column temperature was maintained at 30°C , and the injection volume was $10 \mu\text{L}$. The mass spectrometer parameters were set as follows: gas temperature, 200°C ; gas flow, 11 L/min; nebulizer gas pressure, 35 psig; sheath gas temperature, 350°C ; sheath gas flow, 8 L/min.

The fragmentor voltage was 75 V, and the nozzle voltage was 1000 V. The m/z range was set from 100 to 3000. Collision energies were 5, 10, and 15 eV in positive ion mode, and 40, 50, and 60 eV in negative ion mode³⁵.

4.7 Electronic nose analysis

Odor analysis of PQ and PPQ was performed using a Heracles Neo ultrafast electronic nose (Alpha MOS, France). The instrument was equipped with a headspace sampler, two flame ionization detectors (FID1 and FID2), and two capillary columns (MXT-5 and MXT-1701; both 10 m $\times$ 0.18 mm $\times$ 0.4 μ m). Briefly, all samples of PQ and PPQ were precisely weighed to 3.0 g and placed in 20 mL headspace vials for 24 h prior to analysis. The acquisition parameters were set as follows: injection volume, 5000 μ L; incubation temperature, 80 $^{\circ}$ C; incubation time, 22 min; injection time, 45 s; initial trap temperature, 20 $^{\circ}$ C. All other parameters were set to their default values. Furthermore, the temperature program was set as follows: the oven temperature was initially maintained at 50 $^{\circ}$ C. It was then ramped at a rate of 1.0 $^{\circ}$ C/s to 80 $^{\circ}$ C, followed by an increase at 3 $^{\circ}$ C/s to 250 $^{\circ}$ C. The final temperature of 250 $^{\circ}$ C was held for 21 s. A mixture of n-alkanes (C₆-C₁₆) was used as a reference to calibrate retention times. Odor components and their sensory descriptions were identified based on the AroChemBase database³⁶.

4.8 HS-GC-IMS analysis

A FlavourSpec HS-GC-IMS system (G.A.S., Germany) was employed. The system was coupled with a CTC-PAL3 static headspace autosampler (CTC Analytics AG, Switzerland) and equipped with an MXT-WAX capillary column (Restek, USA). Data processing was performed using the VOCal software. For analysis, 1.0 g of each sample was weighed into a 20 mL headspace

vial. After incubation at 80 °C for 20 min, each sample was analyzed in triplicate. The headspace conditions were: incubation at 80 °C for 20 min, a 500 µL injection in splitless mode, an agitator speed of 500 rpm, and a needle temperature of 85 °C. The chromatographic column temperature was maintained at 60 °C. High purity nitrogen was used as the carrier gas. The injector temperature was set to 80 °C. The ionization source was a tritium ($[^3\text{H}]$) source. The drift tube (length: 53 mm) was operated at 45 °C with an applied electric field strength of 500 V/cm. High purity nitrogen was used as the drift gas at a flow rate of 75 mL/min. The analysis was conducted in positive ion mode. A calibration curve was established using a mixture of six ketone standards, and qualitative identification of the target compounds was achieved by matching to the database of the Vocal software³⁷.

4.9 Statistical analysis

Data analysis and visualization were performed using multiple software platforms. Specifically, HPLC-Q-TOF-MS data were processed with Qualitative Analysis B.06.00 software. The electronic tongue data were modeled by OPLS-DA using SIMCA 14.1 software (Umetrics AB, Sweden) for visual representation of data characteristics. Electronic nose data were analyzed using AlphaSoft V2021 software (Alpha MOS, France) to generate PCA and DFA plots. Radar charts (electronic tongue), fingerprint spectra (electronic nose), and pie charts (HS-GC-IMS) were plotted using Origin 2022. Box plots and cluster heat maps were generated with GraphPad Prism 9.1.0. Molecular structure diagrams of the compounds were drawn using ChemDraw Professional 15.1.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Author Contributions

Hong-Juan Hou: Data curation, Investigation, Software, Writing-original draft; Wen-Han Pei: Methodology; Rui-Bo Sun: Methodology; Chao Wang: Methodology; Fang-Tong Liu: Validation; Tian-Qi Zhang: Validation; Gui-Zhong Xin: Validation; Cheng Qian: Data curation; Mu Zhang: Data curation; Xin-Ru Zhang: Data curation; Zi-Xuan Ding: Data curation; Hui Zhang: Investigation; Tian-Min Wang: Investigation; Ting-Guo Kang: Investigation, Funding acquisition; Hai-Bo Wang: Conceptualization, Methodology, Writing-review & editing; Yue-Hua Chen: Conceptualization, Methodology, Funding acquisition, Writing-review & editing; Hui-Peng Song: Conceptualization, Methodology, Funding acquisition, Writing-review & editing.

Competing Interests

The authors declare no competing financial or non-financial interests.

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Figure Legends

Fig. 1. Flowchart of the research strategy for PQ and PPQ. The workflow begins with the moist-heat and hot-air treatments. Step 1: Integration of human sensory evaluation and the electronic tongue for the analysis of taste characteristics; Step 2: Identification of potential taste and functional components using HPLC-Q-TOF-MS; Step 3: Combination of the electronic nose and HS-GC-IMS for the analysis of volatile aroma compounds.

Fig. 2. Differential flavor analysis of PQ and PPQ based on human sensory evaluation and electronic tongue. (A) Heatmap of taste attribute clustering based on human sensory evaluation scores of PQ and PPQ. Color scale: blue to red represents low to high intensity. (B) Box plots of earthy flavor, bitterness, softness and crispness distribution in PQ and PPQ. (C) Radar chart of PQ based on electronic tongue data. (D) Radar chart of PPQ based on electronic tongue data. Aftertaste-B refers to aftertaste-bitterness, while Aftertaste-A refers to aftertaste-astringency. (E) Box plots of quantitative scoring differences between PQ and PPQ across eight taste sensors. Statistical significance indicated as * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.0001$, and ns for not significant. (F) OPLS-DA plot of PQ (green) and PPQ (blue) samples based on electronic tongue data. (G) Permutation test ($n = 200$) for validation of the OPLS-DA model. (H) VIP score plot of taste attributes for discrimination between PQ and PPQ. Red represents taste attributes with $VIP > 1$.

Fig. 3. Total ion chromatograms of PQ (A) and PPQ (B) under negative ion mode. Peak

numbers correspond to compounds listed in Table 1. Chromatographic conditions were consistent across both samples to enable direct component comparison.

Fig. 4. Relative content changes and chemical structural characteristics of ten differential saponins in PQ and PPQ. (A) Significant decrease in five malonylginsenosides in the PPQ group. (B) Significant increase in five newly formed saponins in the PPQ group. **** $p \leq 0.0001$.

Fig. 5. Comparative analysis of PQ and PPQ based on electronic nose and multivariate statistical analysis. (A) Odor profiles of PQ and PPQ on the MXT-5 column. (B) Odor profiles of PQ and PPQ on the MXT-1701 column. (C) PCA score plot of PQ and PPQ samples. (D) DFA score plot of PQ and PPQ samples.

Fig. 6. Comparative analysis of volatile components in PQ and PPQ based on HS-GC-IMS. (A) 3D topographic plots of PQ and PPQ. (B) 2D difference plots of PQ and PPQ. Red dots represent compounds with higher content in PPQ samples, blue dots represent those with higher content in PQ samples, and white areas indicate no significant difference between the two groups. (C) Comparison of volatile component contents in PQ and PPQ. Region I represents components with higher content in PQ, while Region II represents those with higher content in PPQ. (D) Proportional distribution of volatile compound classes in PQ. (E) Proportional distribution of volatile compound classes in PPQ.

Table Legends

Table 1. Chemical constituents identified in PQ and PPQ via HPLC-Q-TOF-MS.

Table 2. Volatile compounds in PQ were identified using an electronic nose.

Table 3. Volatile compounds in PPQ were identified using an electronic nose.

Table 4. Volatile compounds were identified from PQ and PPQ samples using HS-GC-IMS.

Fig. 1

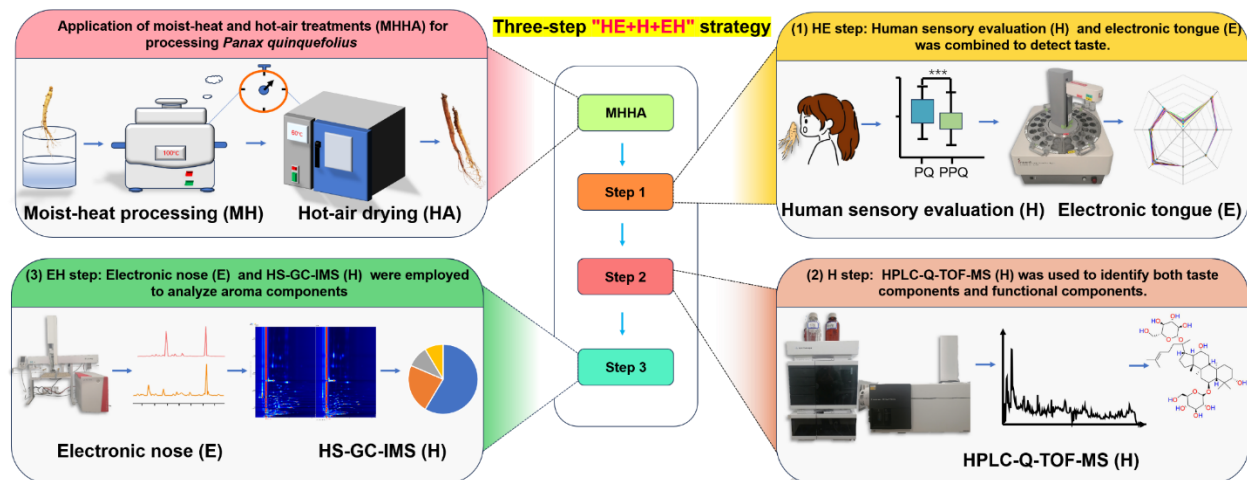


Fig. 2

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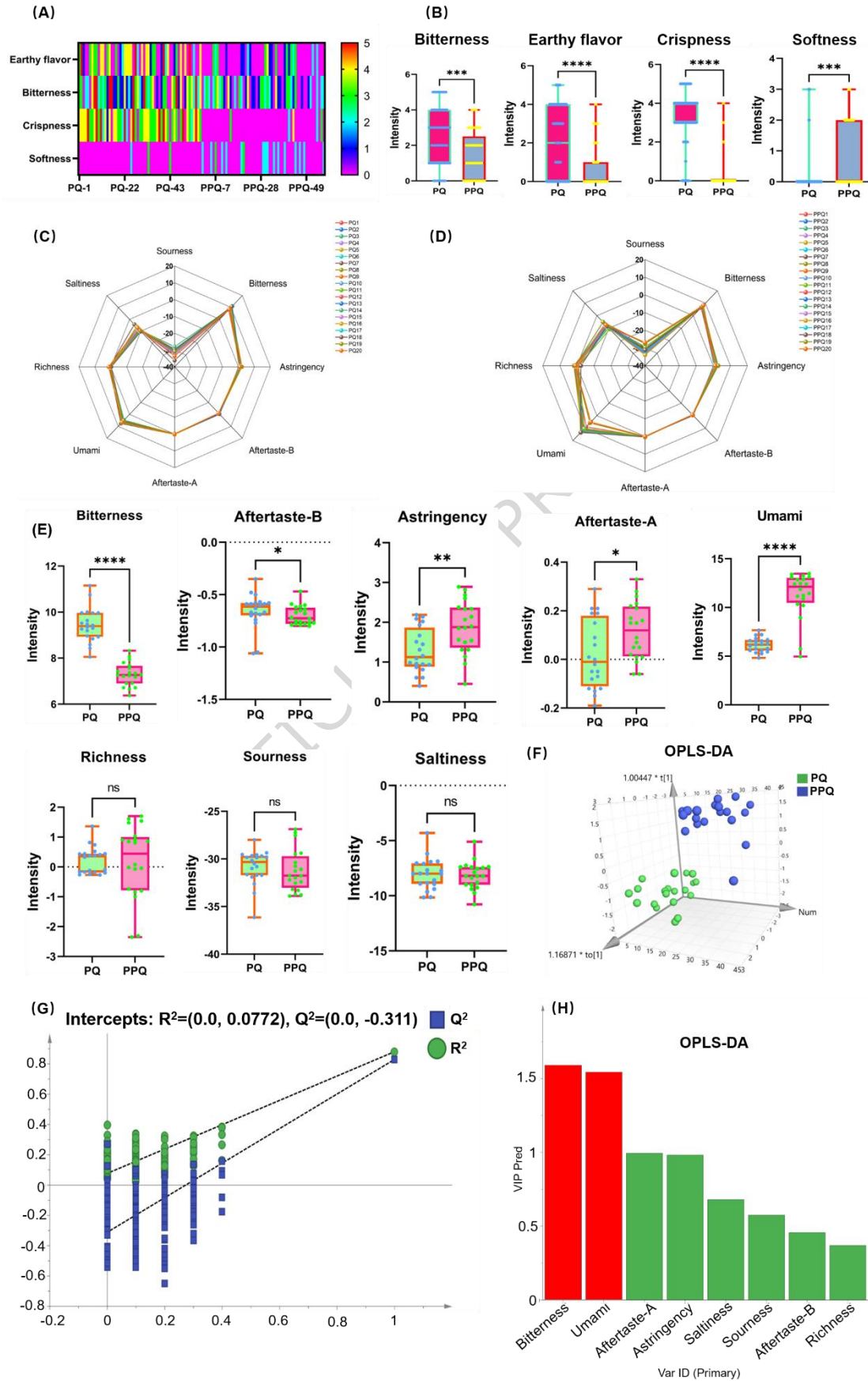
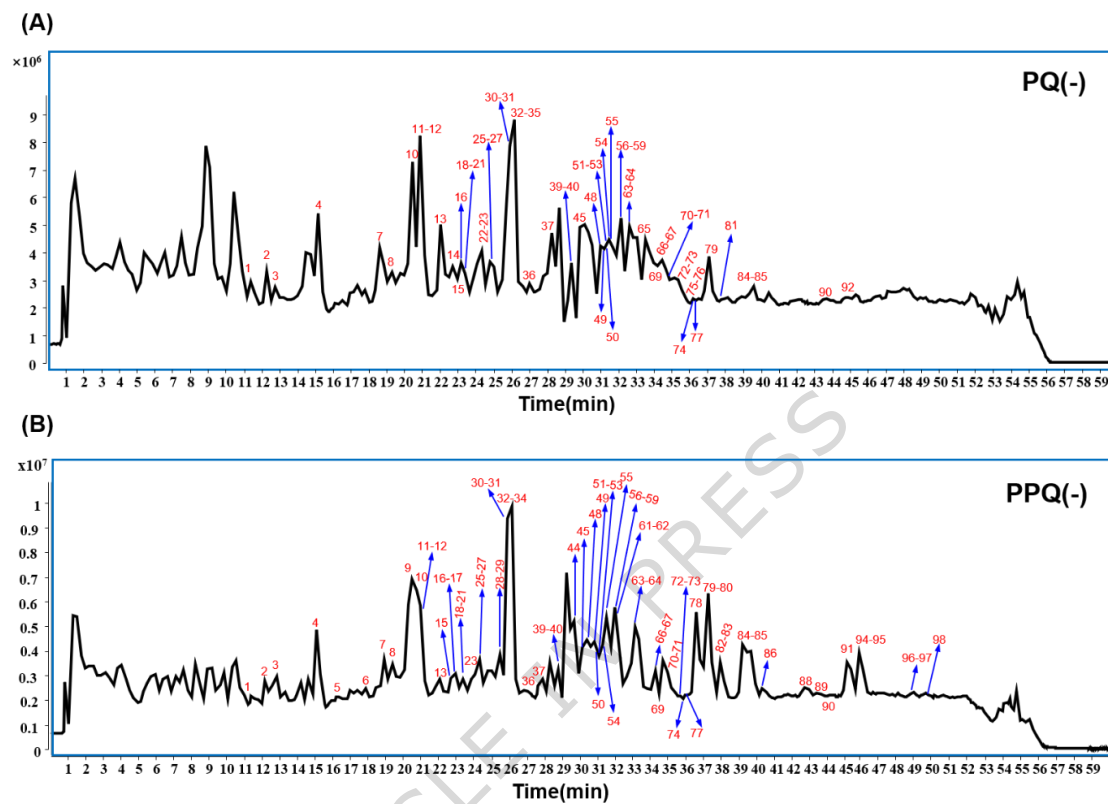


Fig. 3



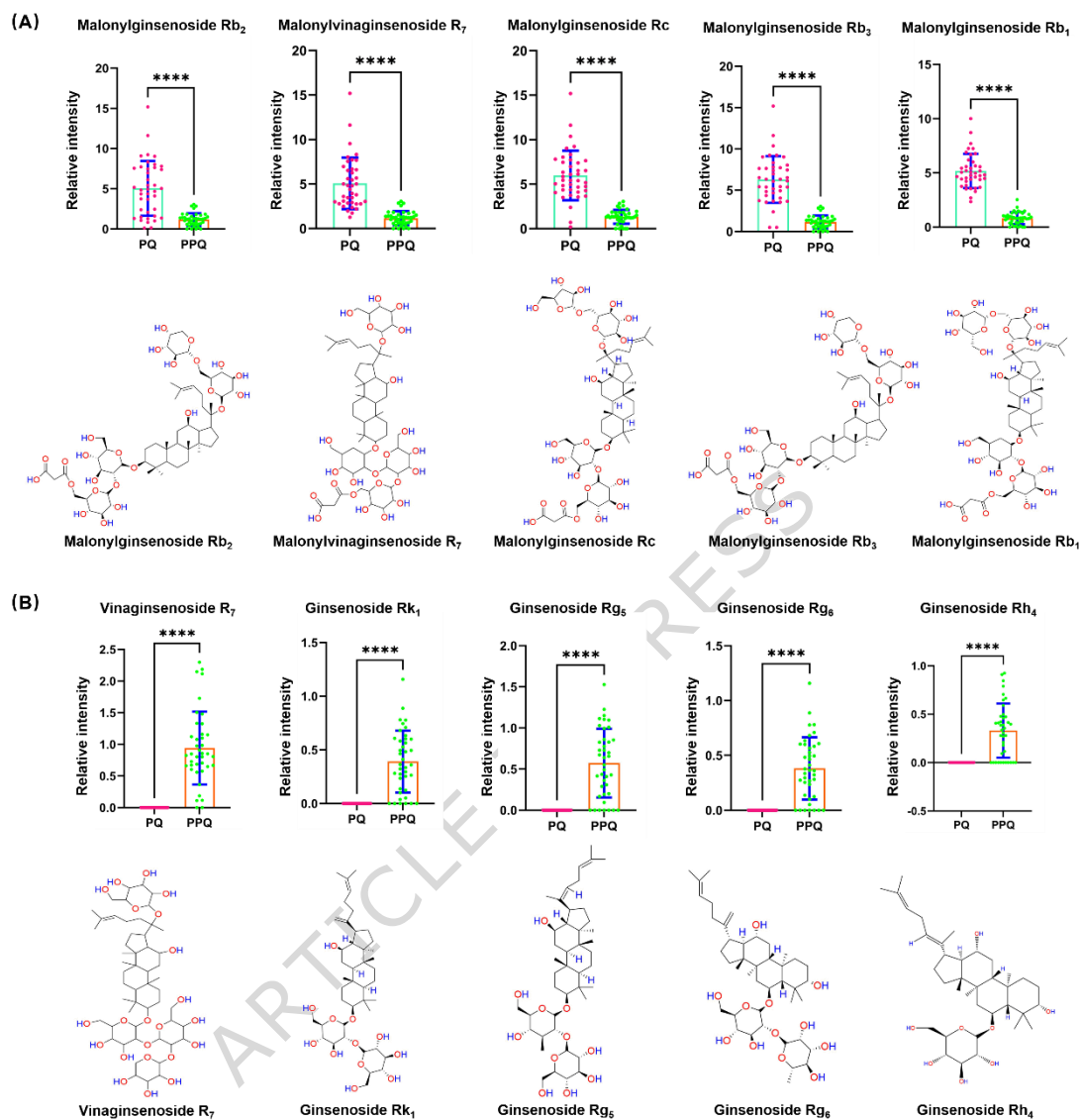


Fig. 4

Fig. 5

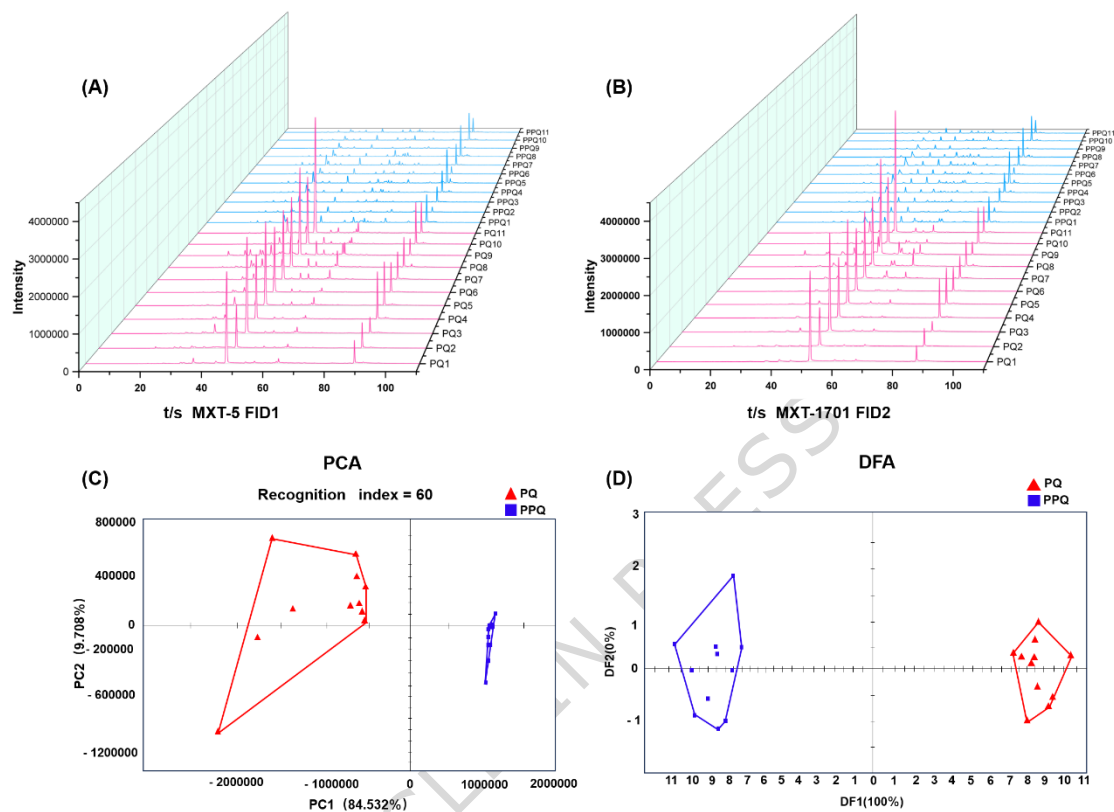


Fig. 6

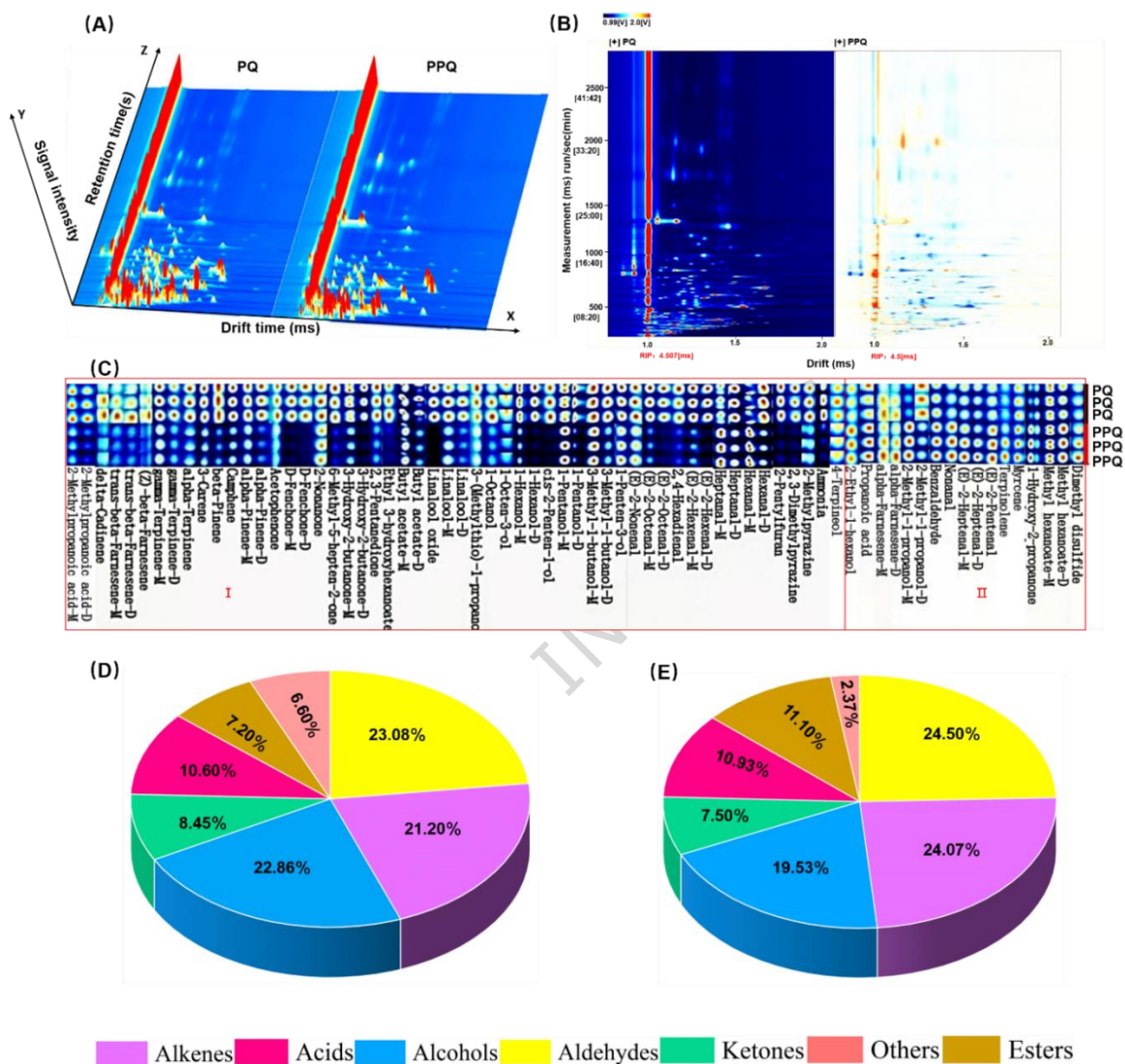


Table 1. Chemical constituents identified in PQ and PPQ via HPLC-Q-TOF-MS.

No.	t _R (min)	m/z (Error, ppm)	Formula	Fragment ions (m/z)	Identification	Distribution
1	11.418	861.4864 (-1.32) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₅	391.2839、 491.3698、 553.3395、 653.4286、 655.3815、 815.4802	Momorcharassikde A	PQ、PPQ
2	12.334	1007.5436 (-0.38) ^{+HCOO}	C ₄₈ H ₈₂ O ₁₉	637.4221	Notoginsenoside R ₃	PQ、PPQ
3	12.535	1007.5433 (-0.07) ^{+HCOO}	C ₄₈ H ₈₂ O ₁₉	637.4273	Ginsenoside Re ₁	PQ、PPQ
4	14.768	861.4871 (-2.17) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₅	391.2851、 491.3724、 653.4281、 655.4353、 815.4706	Majonoside R ₁	PQ、PPQ
5	16.749	977.5332 (-0.57) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₈	931.5263	Ginsenoside Re ₄	PPQ
6	18.479	977.5329 (-0.25) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₈	475.3794、 637.4328、 931.5272	Quinquenoside L ₁₇	PPQ
7	19.071	1007.5429 (-0.35) ^{+HCOO}	C ₄₈ H ₈₂ O ₁₉	637.4331、 799.4692	Ginsenoside Re ₂	PQ、PPQ
8	19.328	977.5339 (-1.32) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₈	475.3775、 637.4323、 751.4701、 769.4755、 799.4853、 931.5279	Notoginsenoside R ₁	PQ、PPQ
9	20.091	991.5500 (-1.78) ^{+HCOO}	C ₄₈ H ₈₂ O ₁₈	475.3827、 619.4249、 637.4325、 765.4797、 783.4933、 799.4850、 945.5431	Ginsenoside Re*	PPQ
10	20.064	1025.5576 (-3.88) ^{+HCOO}	C ₄₈ H ₈₄ O ₂₀	655.4438、 817.4960	Vinaginsenoside R ₁₃	PQ、PPQ
11	20.343	845.4917 (-1.61) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₄	799.4263、 637.4303、 619.4169、 475.3765	Ginsenoside Rf	PQ、PPQ
12	20.505	845.4964 (-7.48) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₄	475.3793、 637.4318	Ginsenoside Ia	PQ、PPQ

13	21.046	845.4899 (0.64) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₄	475.3781、 799.4851	Ginsenoside Rg ₇	PQ、PPQ
14	22.074	885.4853 (0.03) ^{-H}	C ₄₅ H ₇₄ O ₁₇	475.3805、 781.4743	Ginsenoside mRf	PQ
15	22.532	1031.5446 (-1.32) ^{-H}	C ₅₁ H ₈₄ O ₂₁	637.4341、 783.4857、 945.5421、 987.5527	Malonylginsenoside Re	PQ、PPQ
16	22.682	1139.5860 (- 0.46) ^{+HCOO}	C ₅₃ H ₉₀ O ₂₃	1093.5803、 781.4745	Floranotoginsenoside A	PQ、PPQ
17	22.693	1139.5850 (0.45) ^{+HCOO}	C ₅₃ H ₉₀ O ₂₃	781.4732、 1093.5807	Yesanchinoside H	PPQ
18	22.715	1139.5859 (- 0.37) ^{+HCOO}	C ₅₃ H ₉₀ O ₂₃	619.4169、 781.4740	Floranotoginsenoside D	PQ、PPQ
19	22.733	1139.5866 (- 1.01) ^{+HCOO}	C ₅₃ H ₉₀ O ₂₃	475.3800、 637.4314、 781.4749、 961.5351、 1093.5798	Gypenoside LXIX	PQ、PPQ
20	22.828	1139.5870 (- 1.38) ^{+HCOO}	C ₅₃ H ₉₀ O ₂₃	637.4267、 1093.5795	Gypenoside LXXI	PQ、PPQ
21	22.861	961.5378 (-0.05) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	915.5330	Vinaginsenoside R ₁₆	PQ、PPQ
22	23.564	885.4864 (-1.21) ^{-H}	C ₄₅ H ₇₄ O ₁₇	475.3754、 619.4158	Malonylginsenoside Rg ₁	PQ
23	24.005	815.4798 (0.06) ^{+HCOO}	C ₄₁ H ₇₀ O ₁₃	769.4263、 637.4303、 619.4169、 475.3765	Notoginsenoside R ₂	PQ、PPQ
24	24.077	793.4696 (1.64) ^{+Na}	C ₄₁ H ₇₀ O ₁₃	793.4696	Ginsenoside F ₅	PQ、PPQ
25	24.107	961.5391 (-1.47) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	459.3506、 783.4882、 915.5314	Vinaginsenoside R ₁₇	PQ、PPQ
26	24.134	815.4832 (-4.35) ^{+HCOO}	C ₄₁ H ₇₀ O ₁₃	769.4710、 637.4325、 619.4142、 475.3782	Notoginsenoside F ₃	PQ、PPQ
27	24.151	815.4810 (-1.41) ^{-H}	C ₅₃ H ₉₀ O ₂₄	475.3802、 637.4327	Floralginsenoside C	PQ、PPQ
28	24.642	887.5024 (-1.69) ^{+HCOO}	C ₄₄ H ₇₄ O ₁₅	619.4246、 475.3778、 781.4760、 841.4939	Acetylginsenoside Rg ₁	PPQ
29	24.654	887.5019 (-1.10) ^{+HCOO}	C ₄₄ H ₇₄ O ₁₅	841.4889	YesanchinosideD(6'-O- acetyl-ginsenoside Rg ₁)	PPQ
30	24.793	1033.5589 (-0.02) ^{-H}	C ₅₁ H ₈₆ O ₂₁	621.4143、 765.4804、 783.4912、 927.5280、 945.5429	Quinquenoside III	PQ、PPQ

31	24.845	1033.5609 (-2.04) ^{+HCOO}	C ₅₀ H ₈₄ O ₁₉	475.3810、 637.4327、 799.4877	6''-O-acetylginsenoside Re	PQ、PPQ
32	25.022	1007.5449 (-1.73) ^{+HCOO}	C ₄₈ H ₈₂ O ₁₉	637.4313、 799.4858	Ginsenoside Re ₃	PQ、PPQ
33	25.379	831.4746 (0.20) ^{+HCOO}	C ₄₁ H ₇₀ O ₁₄	653.4277	Pseudoginsenoside RT ₂	PQ、PPQ
34	25.412	831.4742 (0.71) ^{+HCOO}	C ₄₁ H ₇₀ O ₁₄	653.4257、 785.4675	Majonoside R ₂	PQ、PPQ
35	25.737	699.4340 (-2.29) ^{+HCOO}	C ₃₆ H ₆₂ O ₁₀	491.3778	Pseudoginsenoside Rt	PQ
36	26.473	845.4922 (-2.24) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₄	491.3743、 637.4363	Ginsenoside La	PQ、PPQ
37	28.027	815.4809 (-1.37) ^{+HCOO}	C ₄₁ H ₇₀ O ₁₃	769.4695、 637.4313、 475.3791	Notoginsenoside F ₅	PQ、PPQ
38	28.264	793.4705 (0.47) ^{+Na}	C ₄₁ H ₇₀ O ₁₃	793.4695、 335.0951	Ginsenoside F ₃	PQ、PPQ
39	29.366	829.4963 (-1.03) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₃	475.3798、 619.4229、 637.4326	20(S)-Ginsenoside Rg ₂ *	PQ、PPQ
40	29.462	1193.5987 (-2.21) ^{-H}	C ₅₇ H ₉₄ O ₂₆	459.3874、 621.4375、 765.4775、 783.4895、 927.5297、 945.5435、 1089.5847、 1107.5955、 1149.6071	Malonylginsenoside Rb ₁	PQ、PPQ
41	29.626	1131.5919 (0.23) ^{+Na}	C ₅₄ H ₉₂ O ₂₃	1131.5892、 365.1041	Ginsenoside Rb ₁ *	PQ、PPQ
42	29.666	1101.5809 (0.64) ^{+Na}	C ₅₃ H ₉₀ O ₂₂	407.3681、 767.4951	Ginsenoside Rb ₂ *	PQ、PPQ
43	29.838	1101.5810 (0.55) ^{+Na}	C ₅₃ H ₉₀ O ₂₂	789.4761	Ginsenoside Rc*	PQ、PPQ
44	30.053	1123.5918 (-1.13) ^{+HCOO}	C ₅₃ H ₉₀ O ₂₂	945.5374	Vinaginsenoside R ₇	PPQ
45	30.265	1163.5871 (-1.38) ^{-H}	C ₅₆ H ₉₂ O ₂₅	459.3855、 621.4371、 783.4899、 945.5446、 1077.5855	Malonylvinaginsenoside R ₇	PQ、PPQ
46	30.731	1101.5814 (0.18) ^{+Na}	C ₅₃ H ₉₀ O ₂₂	789.4781	Ginsenoside Rb ₃ *	PQ、PPQ
47	30.811	979.4857 (1.67) ^{+Na}	C ₄₈ H ₇₆ O ₁₉	379.0813、 641.3976、 979.4855	Ginsenoside Ro	PQ、PPQ
48	31.031	955.4903 (0.53) ^{-H}	C ₄₈ H ₇₆ O ₁₉	793.4387	Hemsgiganoside B	PQ、PPQ
49	31.147	1163.5849 (0.51) ^{-H}	C ₅₆ H ₉₂ O ₂₅	621.4373、 783.4899、 1077.5853、 1119.5944	Malonylginsenoside Rc	PQ、PPQ

50	31.260	1163.5834 (1.80) ^{-H}	C ₅₆ H ₉₂ O ₂₅	459.3820、 621.4326、 783.4898、 945.5425、 1077.5850	Malonylginsenoside Rb ₃	PQ、PPQ
51	31.343	955.4917 (-0.94) ^{-H}	C ₄₈ H ₇₆ O ₁₉	793.4364	Tuberoside A	PQ、PPQ
52	31.443	1087.5374 (-3.98) ^{-H}	C ₅₃ H ₈₄ O ₂₃	955.4902	OA-28-Glc-Glc-3- GlurA-Xyl	PQ、PPQ
53	31.522	1163.5855 (-0.01) ^{-H}	C ₅₆ H ₉₂ O ₂₅	459.3838、 621.4378、 765.4820、 783.4925、 915.5330、 945.5425、 1059.5745、 1077.5852、 1119.5910	Malonylginsenoside Rb ₂	PQ、PPQ
54	31.606	1195.6131 (- 1.30) ^{+HCOO}	C ₅₆ H ₉₄ O ₂₄	459.3791、 621.4360、 765.4809、 783.4886、 927.5330、 945.5417、 1089.5857、 1107.5961、 1149.6045	Acetylginsenoside Rb ₁	PQ、PPQ
55	31.690	925.4797 (0.58) ^{-H}	C ₄₇ H ₇₄ O ₁₈	569.3858	Chikusetsusaponin Ib	PQ、PPQ
56	31.718	925.4823 (-2.22) ^{-H}	C ₄₇ H ₇₄ O ₁₈	569.3858、 613.3754、 763.4294	Pseudoginsenoside RT ₁	PQ、PPQ
57	31.734	925.4790 (1.34) ^{-H}	C ₄₇ H ₇₄ O ₁₈	613.3746、 569.3857	Chikusetsusaponin IV	PQ、PPQ
58	31.751	925.4802 (0.04) ^{-H}	C ₄₇ H ₇₄ O ₁₈	455.3518、 497.3628、 523.3777、 569.3854、 583.4036、 587.3964、 613.3751、 719.4379、 763.4277	Stipuleanoside R ₁	PQ、PPQ
59	31.755	1149.6075 (-1.11) ^{-H}	C ₅₆ H ₉₄ O ₂₄	621.4383、 765.4791、 783.4908、 927.5124、 945.5465、 1089.5862、 1107.5966	Quinquenoside R ₁	PQ、PPQ

60	32.205	969.5385 (0.88) ^{+Na}	C ₄₈ H ₈₂ O ₁₈	789.4769、 365.1076	Ginsenoside Rd*	PQ、PPQ
61	32.460	1165.6016 (- 0.41) ^{+HCOO}	C ₅₅ H ₉₂ O ₂₃	621.4355、 783.4945、 945.5440、 1059.5752、 1077.5830	Ginsenoside Rs ₁	PPQ
62	32.571	1165.6017 (- 0.50) ^{+HCOO}	C ₅₅ H ₉₂ O ₂₃	459.3823、 621.4375、 783.4913、 945.5420、 1059.5734、 1077.5827	Ginsenoside Rs ₂	PPQ
63	32.912	793.4392 (-1.54) ^{-H}	C ₄₂ H ₆₆ O ₁₄	455.3529、 587.3950、 613.3755	Zingibroside R ₁	PQ、PPQ
64	32.929	793.4399 (4.98) ^{-H}	C ₃₅ H ₇₀ O ₁₉	455.3538、 497.3657、 569.3861、 587.3962、 613.3761、 631.3858、 673.3945	Spinasaponin A	PQ、PPQ
65	33.961	1117.5439 (-0.24) ^{-H}	C ₅₄ H ₈₆ O ₂₄	987.5533、 945.5419、 783.4927、 459.3845	Dimalonylginsenoside Rd	PQ
66	34.208	961.5394 (-1.80) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	621.4376、 459.3818	Notoginsenoside Fd	PQ、PPQ
67	34.236	961.5405 (-3.00) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	459.3838、 621.4369	Notoginsenoside Fe	PQ、PPQ
68	34.245	939.5287 (0.08) ^{+Na}	C ₄₇ H ₈₀ O ₁₇	335.0938、 939.5286	Ginsenoside Rd ₂	PQ、PPQ
69	34.252	961.5370 (0.82) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	621.4377、 783.4874、 915.5279	Compound O	PQ、PPQ
70	34.693	961.5381 (-0.38) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	915.5323、 783.4901、 621.4376、 459.3818	Gynosaponin I	PQ、PPQ
71	34.710	961.5390 (-1.36) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	915.5327、 783.4903、 621.4384、 459.3839	Vinaginsenoside R ₁₈	PQ、PPQ
72	35.008	1033.5591 (-0.21) ^{-H}	C ₅₁ H ₈₆ O ₂₁	459.3842、 603.4288、 621.4275、 765.4734、	Pseudoginsenoside Rc ₁	PQ、PPQ

				783.4828、 927.5298、 945.5447		
73	35.088	1033.5583 (0.59) ^{+HCOO}	C ₅₀ H ₈₄ O ₁₉	783.4828、 161.0463	Quinquefolium III	PQ、PPQ
74	35.352	961.5361 (1.80) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	621.4387、 783.4878、 915.5327	Gypenoside IX	PQ、PPQ
75	35.380	1001.5342 (-1.53) ^{-H}	C ₅₀ H ₈₂ O ₂₀	915.5324、 621.4368、 459.3831	Malonylvinaginsenoside R ₁₈	PQ
76	35.413	1001.5329 (-0.23) ^{-H}	C ₅₀ H ₈₂ O ₂₀	459.3847、 621.4378、 783.4913、 915.5305	Malonylnotoginsenoside Fe	PQ
77	35.496	961.5399 (-2.34) ^{+HCOO}	C ₄₇ H ₈₀ O ₁₇	459.3846、 621.4367	Notoginsenoside Ft ₁	PQ、PPQ
78	36.827	811.4867 (-2.31) ^{+HCOO}	C ₄₂ H ₇₀ O ₁₂	161.0464	Ginsenoside Rg ₄	PPQ
79	37.134	829.4967 (-1.54) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₃	113.0246、 143.0450、 161.0456、 621.4365、 783.4903	Ginsenoside F ₂ [*]	PQ、PPQ
80	37.346	811.4849 (0.04) ^{+HCOO}	C ₄₂ H ₇₀ O ₁₂	101.0251、 113.0250、 125.0251、 143.0352、 161.0462、 205.0725、 457.3671、 601.4065、 619.4225、 765.4775	Ginsenoside Rg ₆	PPQ
81	37.446	1059.5748 (- 0.26) ^{+HCOO}	C ₅₂ H ₈₆ O ₁₉	161.0431、 783.4905	Quinquefolium I	PQ
82	37.972	665.4290 (-3.19) ^{+HCOO}	C ₃₆ H ₆₀ O ₈	113.0253、 161.0446	Ginsenoside Rh ₄	PPQ
83	38.050	665.4286 (-2.54) ^{+HCOO}	C ₃₆ H ₆₀ O ₈	161.0446	Ginsenoside Rk ₃	PPQ
84	39.473	829.4955 (-0.01) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₃	101.0243、 113.0244、 143.0359、 161.0458、 459.3850、 621.4370、	20(<i>S</i>)-Ginsenoside Rg ₃ [*]	PQ、PPQ
85	39.941	829.4961 (-0.77) ^{+HCOO}	C ₄₂ H ₇₂ O ₁₃	101.0253、 113.0246、 143.0357、 161.0459、	20(<i>R</i>)-Ginsenoside Rg ₃ [*]	PQ、PPQ

				459.3855、 621.4387、 783.4907		
86	40.527	871.5059 (0.19) ^{+HCOO}	C ₄₄ H ₇₄ O ₁₄	783.4860、 621.4357、 459.3794	Ginsenoside R _{S3}	PPQ
87	40.603	777.4749 (1.39) ^{+Na}	C ₄₁ H ₇₀ O ₁₂	335.0968、 777.4755	Ginsenoside C-Y	PPQ
88	42.083	763.4282 (-1.03) ^{-H}	C ₄₁ H ₆₄ O ₁₃	569.3825	Pseudoginsenoside R _{p1}	PPQ
89	42.875	871.5076 (-1.86) ^{+HCOO}	C ₄₄ H ₇₄ O ₁₄	459.3852、 621.4376、 783.4919	Acetylginsenoside R _{g3}	PPQ
90	43.572	631.3862 (-1.65) ^{-H}	C ₃₆ H ₅₆ O ₉	631.3858、 455.3533	Calenduloside E	PQ、PPQ
91	44.132	667.4434 (-1.17) ^{+HCOO}	C ₃₆ H ₆₂ O ₈	459.3874	Compound K	PPQ
92	44.834	723.3809 (-0.06) ^{+HCOO}	C ₃₃ H ₅₈ O ₁₄	415.1484、 397.1347、 379.1245、 305.0898、 279.2340、 235.0812、 179.0553、 125.0238	Pseudoginsenoside R _{T5}	PQ
93	45.199	789.4754 (0.72) ^{+Na}	C ₄₂ H ₇₀ O ₁₂	365.1018、 789.4749	Ginsenoside R _{k1}	PQ、PPQ
94	45.388	811.4862 (-1.66) ^{+HCOO}	C ₄₂ H ₇₀ O ₁₂	101.0251、 113.0248、 125.0253、 143.0356、 161.0456	Ginsenoside F ₄	PPQ
95	45.549	811.4864 (-1.92) ^{+HCOO}	C ₄₂ H ₇₀ O ₁₂	161.0450、 765.4796	Ginsenoside R _{g5}	PPQ
96	48.816	853.4958 (-0.38) ^{+HCOO}	C ₄₄ H ₇₂ O ₁₃	441.0785、 603.4286、 747.4677、 765.4780、 807.4908	Acetylginsenoside R _{g5}	PPQ
97	48.849	853.4986 (-3.84) ^{+HCOO}	C ₄₄ H ₇₂ O ₁₃	603.4264、 765.4802	Ginsenoside R _{s4}	PPQ
98	49.062	853.4991 (-4.46) ^{+HCOO}	C ₄₄ H ₇₂ O ₁₃	441.3752、 603.4284	Ginsenoside R _{s5}	PPQ

+Na: [M+Na]⁺; -H: [M-H]⁻; +HCOO: [M+HCOO]⁻

* The compounds were identified by comparing with reference substances.

Table 2. Volatile compounds in PQ were identified using an electronic nose.

No.	RI (MXT-5)	RI (MXT-1701)	Molecular formula	Possible volatile compounds	Index of correlation	Sensory descriptions
1	938	934	C ₁₀ H ₁₆	alpha-Pinene	62.46	camphor, orange, earthy, fresh, fruity, freshly cut grass, lime flavor, pine, sweet, terpenic, turpentine, woody
2	1381	1500	C ₁₃ H ₁₈ O	beta-Damascenone	69.65	apple, rose apple, canned peach, fruity, honey, rosy, sweet, tobacco
3	534	616	C ₄ H ₈ O	2-Methylpropanal	63.61	aldehydic, baked potato, burnt, floral, fresh, fruity, freshly cut grass, malty, spicy, lavender, citrus, neroli
4	818	934	C ₇ H ₁₆ O	1-Pentanol, 2,3- dimethyl-	68.48	/
5	818	972	C ₄ H ₈ O ₂	Butanoic acid	79.74	buttery, cheesy, penetrating, rotten, sharp, sweet
6	714	848	C ₄ H ₈ O ₂	Acetoin	82.66	buttery, coffee, creamy, dairy, fatty, milky, sweet, woody
7	908	1096	C ₅ H ₁₀ O ₂	Pentanoic acid	63.99	acidic, beefy, chee sy, penetrating, spi cy, putrid, rotten, s our, sweet
8	908	1035	C ₄ H ₄ O ₂	2-(5H)-Furanone	95.70	buttery
9	938	1052	C ₇ H ₁₂ O	3-Hepten-2-one	91.77	coriander, grassy, freshly cut grass
10	938	1071	C ₇ H ₁₆ O	4-Methylhexan-1- ol	76.02	grassy, sweet
11	1419	1479	C ₉ H ₁₈ O ₂	Decyl acetate	73.15	fresh, fruity, fatty, orange, soapy, waxy
12	2098	2197	C ₁₉ H ₃₈ O	2-Nonadecanone	84.28	/

13	1113	1176	$C_9H_{18}O_2$	Heptyl acetate	51.72	apricot, fresh, freshly cut grass,
14	1442	1479	$C_{15}H_{24}$	alpha- Himachalene	90.17	pear, rum, woody /

Table 3. Volatile compounds in PPQ were identified using an electronic nose.

No.	RI (MXT- 5)	RI (MXT- 1701)	Molecular formula	Possible volatile compounds	Index of correlation	Sensory descriptions
1	654	740	C ₃ H ₈ O	3-Methylbutanal	75.38	aldehydic, almond, apple, cheesy, chocolate, fatty, fruity, freshly cut grass, herbal, malty, peach, roasted
2	688	735	C ₃ H ₈ O	Methyl isobutyrate	78.43	apple, floral, green, fruit, pineapple, sweet
3	952	922	C ₁₀ H ₁₆	alpha-Pinene	84.36	camphor, orange, earthy, fresh, fruity, freshly cut grass, lime flavor, pine, sweet, terpenic, turpentine, woody

Table 4. Volatile compounds were identified from PQ and PPQ samples using HS-GC-IMS.

No.	Compound	Formula	Rt(s)	Dt (RIPrel)	Odor characteristics description
1 ^a	alpha-Farnesene-M	C ₁₅ H ₂₄	2730.476	1.43903	citrus, herbal, lavender, neroli
2 ^a	alpha-Farnesene-D	C ₁₅ H ₂₄	2733.951	1.48721	citrus, herbal, lavender, neroli
3 ^b	delta-Cadinene	C ₁₅ H ₂₄	2537.643	1.44041	thyme, herbal, woody
4 ^b	Acetophenone	C ₈ H ₈ O	2489.001	1.17749	sweet, spicy, almond
5 ^b	Ethyl 3-hydroxyhexanoate	C ₈ H ₁₆ O ₃	2455.993	1.29036	fruity, wood
6 ^b	3-(Methylthio)-1-propanol	C ₄ H ₁₀ OS	2410.825	1.10040	pungent onion, meaty, soy sauce
7 ^b	<i>trans</i> -beta-Farnesene-M	C ₁₅ H ₂₄	2247.525	1.43628	woody, citrus, sweet, green
8 ^b	<i>trans</i> -beta-Farnesene-D	C ₁₅ H ₂₄	2245.788	1.49134	woody, citrus, sweet, green
9 ^b	(<i>Z</i>)-beta-Farnesene	C ₁₅ H ₂₄	2077.276	1.44178	green, floral
10 ^b	4-Terpineol	C ₁₀ H ₁₈ O	1931.349	1.22154	pepper, woody, earthy musty
11 ^a	Propanoic acid	C ₃ H ₆ O ₂	1703.771	1.11692	yogurt, vinegar
12 ^b	2-Methylpropanoic acid-M	C ₄ H ₈ O ₂	1681.187	1.14996	yogurt, rancid cream
13 ^b	2-Methylpropanoic acid-D	C ₄ H ₈ O ₂	1679.450	1.36883	yogurt, rancid cream
14 ^b	Linalool-M	C ₁₀ H ₁₈ O	1686.399	1.22291	citrus, rose, woody, blueberry
15 ^b	Linalool-D	C ₁₀ H ₁₈ O	1686.399	1.78317	citrus, rose, woody, blueberry
16 ^b	1-Octanol	C ₈ H ₁₈ O	1656.866	1.47344	citrus, sweet, herbs, waxy, rose, mushroom
17 ^b	(<i>E</i>)-2-Nonenal	C ₉ H ₁₆ O	1494.111	1.41275	fatty, green, waxy, cucumber, melon
18 ^a	Benzaldehyde	C ₇ H ₆ O	1416.541	1.15560	bitter almond, cherry, nutty
19 ^a	2-Ethyl-1-hexanol	C ₈ H ₁₈ O	1382.926	1.42648	citrus, fresh floral, fatty
20 ^b	1-Octen-3-ol	C ₈ H ₁₆ O	1221.320	1.16309	mushroom, lavender, rose, hay
21 ^b	Linalool oxide	C ₁₀ H ₁₈ O ₂	1139.757	1.25551	floral
22 ^b	(<i>E</i>)-2-Octenal-M	C ₈ H ₁₄ O	1110.127	1.33410	fresh cucumber, fatty, green
23 ^b	(<i>E</i>)-2-Octenal-D	C ₈ H ₁₄ O	1112.530	1.81807	herbal, banana, green leaf
24 ^b	D-Fenchone-M	C ₁₀ H ₁₆ O	1061.278	1.29963	fresh cucumber, fatty, green
					herbal, banana, green leaf
					mint, camphor, cool

25 ^b	D-Fenchone-D	C ₁₀ H ₁₆ O	1062.079	1.78636	mint, camphor, cool
26 ^a	Nonanal	C ₉ H ₁₈ O	1030.047	1.49267	rose, citrus, strong oily
27 ^b	2-Nonanone	C ₉ H ₁₈ O	1016.434	1.40856	fresh, sweet, green, herb
28 ^b	2,4-Hexadienal	C ₆ H ₈ O	988.110	1.11242	sweet, green, floral, citrus
29 ^b	1-Hexanol-M	C ₆ H ₁₄ O	955.814	1.33685	fresh, fruity, wine, sweet, green
30 ^b	1-Hexanol-D	C ₆ H ₁₄ O	955.045	1.64263	fresh, fruity, wine, sweet, green
31 ^b	6-Methyl-5-hepten-2-one	C ₈ H ₁₄ O	931.208	1.16713	citrus, fruity, musty, ketonic
32 ^b	2,3-Dimethylpyrazine	C ₆ H ₈ N ₂	918.135	1.11663	nutty
33 ^b	<i>cis</i> -2-Penten-1-ol	C ₅ H ₁₀ O	898.912	1.44205	green, plastic, rubber
34 ^a	(<i>E</i>)-2-Heptenal-M	C ₇ H ₁₂ O	879.688	1.25970	spicy, green vegetables, fresh, fatty
35 ^a	(<i>E</i>)-2-Heptenal-D	C ₇ H ₁₂ O	879.688	1.67069	spicy, green vegetables, fresh, fatty
36 ^a	1-Hydroxy-2-propanone	C ₃ H ₆ O ₂	846.623	1.08016	pungent, caramel, fresh
37 ^b	3-Hydroxy-2-butanone-M	C ₄ H ₈ O ₂	819.183	1.07637	buttery, creamy
38 ^b	3-Hydroxy-2-butanone-D	C ₄ H ₈ O ₂	819.183	1.33142	buttery, creamy
39 ^b	Ammonia	NH ₃	780.947	0.85702	ammoniacal
40 ^a	Terpinolene	C ₁₀ H ₁₆	802.259	1.22047	woody, sweet, citrus
41 ^b	2-Methylpyrazine	C ₅ H ₆ N ₂	782.201	1.09039	nutty, musty, roasted, earthy
42 ^b	1-Pentanol-M	C ₅ H ₁₂ O	763.396	1.25746	balsamic
43 ^b	1-Pentanol-D	C ₅ H ₁₂ O	763.396	1.51124	balsamic
44 ^b	gamma-Terpinene-M	C ₁₀ H ₁₆	745.846	1.21665	oil, woody, terpenic, lemon, lime, herbal
45 ^b	gamma-Terpinene-D	C ₁₀ H ₁₆	745.846	1.70253	oil, woody, terpenic, lemon, lime, herbal
46 ^b	2-Pentylfuran	C ₉ H ₁₄ O	731.429	1.25108	beany, fruity, earthy, green, vegetal
47 ^b	(<i>E</i>)-2-Hexenal-M	C ₆ H ₁₀ O	714.505	1.18221	green, banana, fatty
48 ^b	(<i>E</i>)-2-Hexenal-D	C ₆ H ₁₀ O	715.758	1.52144	green, banana, fatty
49 ^b	3-Methyl-1-butanol-M	C ₅ H ₁₂ O	699.461	1.24598	whisky, banana
50 ^b	3-Methyl-1-butanol-D	C ₅ H ₁₂ O	698.834	1.49338	whisky, banana
51 ^b	Heptanal-M	C ₇ H ₁₄ O	664.323	1.35164	fresh, aldehydic, fatty, green herbal, wine, fruity
52 ^b	Heptanal-D	C ₇ H ₁₄ O	665.282	1.69392	fresh, aldehydic, fatty, green herbal, wine, fruity
53 ^a	Methyl hexanoate-M	C ₇ H ₁₄ O ₂	651.389	1.26083	pineapple, apricot

54 ^a	Methyl hexanoate-D	C ₇ H ₁₄ O ₂	650.431	1.68927	pineapple, apricot
55 ^b	alpha-Terpinene	C ₁₀ H ₁₆	647.078	1.21426	woody, terpenic, lemon, citrus
56 ^b	1-Penten-3-ol	C ₅ H ₁₀ O	626.958	0.94183	ethereal, green, tropical fruits
57 ^a	Myrcene	C ₁₀ H ₁₆	625.520	1.21426	grape juice, spicy, plastic
58 ^a	(E)-2-Pentenal	C ₅ H ₈ O	574.741	1.10715	potato, pea
59 ^b	3-Carene	C ₁₀ H ₁₆	539.770	1.21426	citrus, lemon, woody
60 ^b	beta-Pinene	C ₁₀ H ₁₆	539.770	1.21426	resinous, grassy green
61 ^a	2-Methyl-1-propanol-M	C ₄ H ₁₀ O	500.488	1.17468	fresh, alcoholic, leathery
62 ^a	2-Methyl-1-propanol-D	C ₄ H ₁₀ O	500.488	1.37143	fresh, alcoholic, leathery
63 ^b	Hexanal-M	C ₆ H ₁₂ O	485.159	1.27829	fresh, green, fatty, fruity
64 ^b	Hexanal-D	C ₆ H ₁₂ O	484.680	1.56353	fresh, green, fatty, fruity
65 ^b	Butyl acetate-M	C ₆ H ₁₂ O ₂	465.997	1.25268	fruity
66 ^b	Butyl acetate-D	C ₆ H ₁₂ O ₂	466.955	1.61825	fruity
67 ^a	Dimethyl disulfide	C ₂ H ₆ S ₂	461.206	1.15023	sulfurous, cabbage, onion
68 ^b	2,3-Pentanedione	C ₅ H ₈ O ₂	449.709	1.21310	sweet, buttery-creamy, caramel, nutty, cheesy
69 ^b	Camphene	C ₁₀ H ₁₆	435.771	1.20102	woody, camphor
70 ^b	alpha-Pinene-M	C ₁₀ H ₁₆	401.925	1.21556	fresh, camphor, sweet, pine
71 ^b	alpha-Pinene-D	C ₁₀ H ₁₆	402.201	1.66406	fresh, camphor, sweet, pine

a: indicates a higher content in PPQ.

b: indicates a higher content in PQ.

M and D represent monomer and dimer of the same compounds, respectively.