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Effect of osmotic dehydration combined with vacuum freeze-drying treatment on characteristic aroma components of peach slices

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ABSTRACT

Hot air drying (HD), vacuum freeze drying (FD), and pilot-scale freeze drying (PSFD) are extensively used to prepare peach slices. However, the aroma of hot air drying and vacuum freeze-drying is yet to be addressed. In this study, HS-SPME-GC–MS was used to characterize and quantify the volatile compounds in peach slices. First, 33, 36, and 46 volatile compounds were identified and quantified in the HD, FD, and PSFD groups, respectively. PSFD is preferable to HD and FD in terms of the volatile compound types, content, and aroma profiles. PSFD was selected for subsequent permeation and dehydration experiments. The key aroma compounds with an OAV $\geq$ 1 were found in the PSFD30 group. GC-O analysis was conducted on the PSFD30 group, leading to the preliminary identification of 2-methylbutanal, pentanal, hexanal, 2-hexenal, phenylacetaldehyde, ethyl acetate, 2-methylbutyl acetate, ethyl lactate, linalool, methyl heptenone, and γ-octalactone as distinctive aromas in dried peach slices.

1. Introduction

Peach (*Amygdalus persica* Linn) belongs to the Rosaceae family and genus Prunus. China is the country of origin with the highest peach production in the world. It holds a crucial position in global fruit consumption as one of the fruits with the highest global yields. Peaches contain abundant vitamins, minerals, soluble dietary fiber, carotenoids, and proteins, among various nutrients and functional components (Barreira, Arraibi, & Ferreira, 2019).Drying is a traditional method used to extend the shelf life of fruits and vegetables. It effectively addresses the challenges associated with the preservation and transportation of raw materials, facilitating product diversification and catering to the consumption requirements of diverse populations. Peach slices are important peach-processing products. Peach slices have emerged as a type of snack owing to their unique flavor and slicesy texture; therefore, they play a significant role in people's daily lives. They are highly popular among consumers (Zhu, Liu, Zhu, & Wei, 2022).

The components responsible for food's aroma are crucial in determining its quality and whether or not it will be accepted by customers (Yang et al., 2016). According to previous reports, drying has a significant effect on the aroma of fruits and vegetables, such as jujube (Song et al., 2020), mushroom (H. Zhang et al., 2018), garlic (Makarichian, Chayjan, Ahmadi, & Mohtasebi, 2021). In addition, the drying method is a crucial factor that affects the flavor of the product. The drying process is crucial for determining the ultimate flavor of a product. To date, numerous drying methods for fruits and vegetables, including hot air drying (HD), freeze drying (FD), and pilot-scale freeze drying (PSFD), have been utilized. HD is characterized by its technological maturity, low investment, easy operation, and large processing capacity, rendering it highly ideal for drying most agricultural products (Papoutsis et al., 2017). The Maillard reaction produces aldehydes, alcohols, ketones, and furfural, which are the primary volatile compounds in peach slices (L. Feng et al., 2021). Freeze drying (FD) results in low moisture content, good rehydration, better texture and color, and effective preservation of volatile compounds, all of which contribute to increasing the overall acceptability of the product. Therefore, FD is an effective way to obtain high-quality and high-value dried products. Drying after permeation and dehydration can provide protection and increase the stability of processed fruit and vegetables.

Aldehydes, ketones, alcohols, esters, lactones, hydrocarbons, and various other volatile compounds have been isolated from various peach varieties (Reis, Rocha, Barros, Delgadillo, & Coimbra, 2009). A few of these volatile compounds contribute significantly to the aroma and are involved in the perception of aroma. Ester volatiles have a fruity taste,

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mainly acetate esters, such as methyl acetate; aldehydes, such as hexanal (grassy flavor) and phenylacetaldehyde (almond flavor); and lactones, such as C_6–C_{10} γ-lactones and δ-decalactone, are the most abundant volatile compounds in peaches (Niu et al., 2019). Researchers have primarily concentrated on the qualitative and quantitative analysis of volatile compounds in fresh peaches, peach juice, and peach wine, elucidating the distinctive aromas based on compound content. Nevertheless, few reports have confirmed the unique aroma of peach slices. Consequently, it is necessary to confirm the characteristic aroma components of peach slices processed by different drying methods. As a theoretical foundation, this confirmation can aid in adjusting the drying process and enhancing product quality.

The identification of aroma-active compounds utilizing the Olfactory Detection Port (ODP) coupled with Gas Chromatography-Olfactometry (GC-O) analysis is the prevailing approach for determining characteristic aromas (Zhao et al., 2020). The OAV is the concentration/threshold ratio of a volatile compound and is typically used to evaluate its contribution. An OAV ≥ 1 indicates a significant contribution to the overall aroma, whereas a lower value implies a lesser contribution (Liu et al., 2019). The higher the OAV, the greater the contribution to the overall aroma profile. GC-O analysis integrates human perception of odor with instrument sensitivity in the Beijing duck. It is commonly employed in the identification of aroma-active substances in food. Detection Frequency Analysis (DFA) is a recognized method based on GC-O analysis because it is simple to operate and time-efficient (Jiang et al., 2022).

Therefore, to ascertain the characteristic aroma of peach slices by osmotic dehydration combined with vacuum freeze-drying, the following operations were carried out: (1) The volatile compounds of peach slices with varying drying methods were determined using HS-SPME-GC–MS. Accurate quantification was achieved by employing an authentic standard; (2) Osmotic dehydration in conjunction with vacuum freeze drying was utilized to separate the aromatic active compounds of the peach slices, which were then identified using HS-SPME-GC–MS and OAV combined with the GC-O-based detection frequency analysis (DFA) method.

2. Materials and method

2.1. Reagents

Acetic acid (≥99%), 2-cyclopentene-1,4-dione (≥95%), sodium chloride were purchased from Sigma-aldrich Company in the US; the normal alkane mixture (C_7-C_{40}) was purchased from Anpel Laboratory Technologies (Shanghai) Inc., and 2-ethyl-1-hexanol (≥99%), 2-acetylpyrrole (≥99%), 2-methylpyrazine (≥98%), 2-ethylpyrazine (≥99%), hexyl acetate (≥99%), 2-hexenal (≥95%), hexenal (≥95%), γ-hexalactone (≥98%), and linalool (≥96%) were purchased from TCI (Shanghai) Development Co.,Ltd.; Trans-linalool oxide (≥95%) purchased from Beijing Bioneeds Biotechnology Co.,LTD. γ-heptalactone (≥98%), 6-Methyl-5-hepten-2-one (≥98%), furfural (≥99%), 1-hexanol (≥98%), (Z)-3-hexenyl acetate (≥98%), 1-pentanol (≥99.5%) were purchased from Shanghai Aladdin Biochemical Technology Co., Ltd.; benzyl alcohol (≥99%), pentanal (≥98%), γ-nonalactone (≥98%), γ-undecalactone (≥98%), undecane (≥99%), 4-oxoisophorone (≥99%), safranal (≥91%), 2-acetylfuran (≥99%), caprylic acid (≥98%), hexanoic acid (≥99%), ethyl acetate (≥99%), (E)-2-hexenyl acetate (≥99%), 3-furfural (≥99%), 3-hydroxy-2-butanone (≥99%), 2,3-octanedione (≥95%), ethanol (≥99%), dibutyl phthalate (≥98%), 2,5-octanedione (≥95%), (E)-2-hexen-1-ol (≥99%), (*Z*)-3-hexen-1-ol (≥98%), α-terpineol (≥98%), and 5-decanolide (≥99%) were all purchased from Beijing Tanmo Quality Inspection Technology Co., Ltd.; Nonanal (≥96%), γ-octalactone (≥99%) and γ-decalactone (≥98%) were purchased from Shanghai Macklin Biochemical Co.,Ltd.; Phenylacetaldehyde (≥98%), 1-octanol (≥99%), linalool oxide (≥98%), 2,4-dimethylbenzaldehyde (≥97%), (E)-3-nonen-2-one (≥95%), norfuraneo (≥97%), (Z)-Jasmin lactone (≥95%), 6-pentyl-2-pyrone (≥96%), 2-pentylfuran (≥99%), geranylacetone (≥98%), 2-phenyl-2-butenal (≥97%), 3-methylbutanoic acid (≥99%), 5-methyl-2(3H)-furanone (≥97%), 5-methyl-2-furfural (≥98%), tetradecane (≥99%), 2-decanone (≥98%), 2,4-di-tert-butylphenol (≥99%), and 2-formylpyrrole (≥98%) were all purchased from Shanghai Yuanye Bio-Technology Co., Ltd.; Methanol (≥95%) purchased from Thermo Fisher, USA. The above reagents are chromatographic grade.

2.2. Preparation of peach slices

Jintong 7 yellow peaches were purchased from an orchard in the Pinggu District, Beijing. After harvest, they were immediately transported to the laboratory and stored at 4 °C. Preprocessing method: Select ripe peaches that are free from diseases, pests, and rot. Clean the peaches, peel them, remove the pits, and slice them into 8 mm thick slices.

(1) Preparation of hot air dried peach slices.

Pre-pre-treated peach slices (500 g) were uniformly spread on a stainless steel mesh tray, ensuring that there was no overlap between the peach slices. The tray was placed in a hot-air oven at 80 °C and dried for 480 min. The ultimate moisture content was 6.33%, as determined by hot-air drying (HD).

(2) Preparation of vacuum freeze dried peach slices.

Peach slices weighing 500 g were pre-frozen at −80 °C for 12 h and then placed in the freeze-drying chamber of a lyophilizer. The temperature of the cold trap was set at −53 °C, and the vacuum level was approximately 1 mbar. The drying process lasted for 72 h, resulting in a final moisture content of 6.47% (FD).

(3) Preparation of pilot-scale vacuum freeze-dried peach slices

Pretreat 500 g of peach slices by flash freezing them at −80 °C for 12 h. The items were then placed in the drying chamber of a freeze dryer. The cold trap was maintained at a constant −30 °C, with a vacuum pressure of 60 Pa. Over the course of 45 min, the heating plate was raised to 80 °C from room temperature and then held at that temperature for the subsequent 8 h to facilitate drying. PSFD (freeze drying) quantifies the ultimate moisture content to 6.45%.

Preparation of pilot-scale vacuum freeze-dried peach slices using osmotic dehydration.

Prepare sugar solutions with concentrations of 10, 20, and 30°Brix as osmotic solutions (calibrated using a digital refractometer). The peach slices stored in a − 40 °C cold room were transferred to room temperature (25 °C) and allowed to thaw for 24 h. After removing surface moisture from the peach slices, they were immersed in an osmotic solution at a temperature of 25 °C. A 1:5 (m/V) solution to peach slice ratio was established. The solution was stirred every 30 min to counteract the mass-transfer resistance generated by the osmotic process. After osmotic processing, the peach slices were removed from the osmotic solution. Absorbent paper was used to rinse any remaining osmotic solution from the surface with distilled water to remove surface moisture. The peach slices at −80 °C for 12 h. Prepretreated peach slices (500 g) were placed in the drying chamber of a freeze dryer. The cold trap was configured to operate at −30 °C, while the vacuum pressure was consistently maintained at 60 Pa. The drying temperature of the heating plate was increased from room temperature to 80 °C and maintained constant for 8 h. PSFD10, PSFD20, and PSFD30 resulted in final moisture contents of 6.43%, 6.46%, and 6.47%, respectively. The dried peach slices were ground into a powder and stored at −80 °C. Fresh peaches were used as controls for the aroma analysis.

2.3. Study on extraction of volatile compounds from peach slices by HS-SPME

The extraction of volatile compounds was based on preliminary laboratory research and was modified accordingly. In summary, accurately weigh 2.0 g of the chopped sample and place in a 20 mL headspace vial. Then, 25 μL of the internal standard (2-methylpyrazine, 0.025 μg/mL dissolved in methanol) was added, and the vial was sealed with a PTFE silicone cap. Prior to extraction, the SPME fiber (DVB/CAR/PDMS, 0.25 μm, Supelco, Inc., Bellefonte, PA, USA) was pre-treated at 250 °C for 30 min to avoid any residual. The PAL RTC automatic sampler (Inlab & Co.) was used for incubation at 45 °C for 40 min. Volatile compounds were extracted at 45 °C for 30 min. Following the extraction process, the SPME fiber was promptly inserted into the GC injector and desorbed at 250 °C for 3 min.

2.4. GC–MS analysis

The extraction of volatile compounds was modified based on previous laboratory research. The QP-2020NX gas chromatography–mass spectrometry system (SHIMADZU, Japan) was used for the analysis of volatile compounds. The instrument was equipped with a DB-WAX fused quartz capillary column (30 m × 250 μm, 0.25 μm, Agilent Technologies, Santa Clara, CA). The carrier gas was helium (purity ≥99.999%, Beijing Qianxi Jingcheng Gas Co., Ltd., China) with a flow rate of 1.0 mL/min. There was no separation of the injector mode. The oven temperature was initially 30 °C, then increased from 4 °C /min to 150 °C, then increased from 5 °C /min to 240 °C, and kept warm for 5 min. The electron ionization (EI) was set to 70 eV and the scanning range was 35–350 *m/z*. The detector voltage was 0.2 kV, the mass spectrum interface temperature was 250 °C, the ion source temperature was 200 °C, and the solvent delay was 3 min.

2.5. GC-O analysis

GC-O analysis was performed using a TSQ 9000 gas chromatograph-mass spectrometer (Thermo Fisher Scientific Co., Ltd., Shanghai, China). It was equipped with a smell detection port (OP275 ProII, Zhida Laboratory Technology Co., Ltd., Guangzhou). The GC conditions employed in this study were consistent with those outlined in Section 2.4. Following the separation of volatile compounds using gas chromatography, the effluent was split in a 1:3 ratio between the mass spectrometer (MS) and sniffing port. To ensure that the panel members were as comfortable as possible, the transfer line temperature was adjusted to 120 °C and humidified nitrogen gas was injected into the sniffer port at a rate of 50 mL/min. Detection frequency analysis (DFA) was performed according to the method of with minor modifications, which was performed by three training sensory evaluators (two males and one females aged 25–35)(W. Zhang et al., 2021). The precise procedure was as follows: each participant took two inhalations, and after inhalation, the retention time, odor intensity, and number of inhalations were calculated for the volatile compounds. If the odor dilution factor (DF) is greater than or equal to 2 (reported at least once by each person), it can be considered that the volatile compounds contribute significantly to the aroma profile of the peach slices and are considered odor-active compounds.

2.6. Identification of volatile compounds

Volatile compounds were identified by comparing them with mass spectrum libraries, retention indices (RI), odor quality, and authentic standard compounds (Ma et al., 2022). The mass spectra of the compounds were compared those with of the NIST 17 library placed in the GC–MS instrument. A similarity score of 80 or above was used to preliminarily identify volatile compounds. The retention indices (RI) of the volatile compounds were calculated based on the retention times of a mixture of C_7-C_{40} n-alkanes under identical gas chromatographic conditions. The calculation formula for RIs is RI = 100n + 100(tx-tn)/(tn + 1-tn), where tx is the retention time of compound x, tn and tn + 1 are the retention times of alkane n and alkane n + 1(tn < tx < tn + 1), respectively, and n and n + 1 are the closed retention times of compound x. Finally, the discrepancy between the calculated RI and reported RI (reduced to <20) was considered. The aroma grade was determined using gas chromatography-olfactometry (GC-O). Observations of experienced panelists were recorded, and odor descriptors were compared to aroma descriptors of standard compounds (Aprea et al., 2012). Retention time of volatiles in the standard mixed solution and peach slices under the same GC–MS detection conditions.

2.7. Quantitative analysis of volatile compounds

Calibration curves were applied to measure the volatiles (Tan, Wang, Zhan, & Tian, 2022). First, a rough estimate of the volatile component content of the peach slices was made using the peak area to the internal standard concentration ratio. Second, we established a calibration curve for the real aroma compounds. Methanol was used as the solvent, with a final concentration of 1.0 and 1000 mg/g for the vaporized compounds (Yao et al., 2021). The mixed solution was added to an odorless matrix prepared as a reference, with slight modifications, and 25 μL of the internal standard was added. The analysis was performed under the same GC–MS conditions as those used for the peach slices. The calibration curve was plotted with the ratio of the peak area to the internal standard on the y-axis, and the ratio of the compound concentration to the internal standard on the x-axis. Table S1 lists the volatile calibration curves. R2 > 0.99 for all the calibration curves. The aroma compound concentration (d. b.) on a drying basis was then estimated using a calibration curve.

2.8. Calculation of odor activity value (OAV)

The OAV for each aroma compound was calculated as the ratio of the concentration of the compound (C_i) to its threshold (OT_i) in water, namely, $OAV=C_i/OT_i$. The threshold were got from literature and referenced from a book named “odor thresholds complication of odor threshold values, in air, water and other media (Cliff, Stanich, Trujillo, Toivonen, & Forney, 2011).

2.9. Statistical analysis

Significant differences between the samples were analyzed using SPSS 24.0. Statistical significance was set at $p < 0.05$. Origin 2021 software was used for the drawing. The testing of each sample was repeated thrice.

3. Results and discussion

3.1. Impact of drying methods on the volatile compounds in peach slices

This experiment used HS-SPME-GC–MS technology to analyze volatile compounds in fresh peaches, hot air-dried peach slices (HD), experimental vacuum freeze-dried peach slices (FD), and pilot-scale vacuum freeze-dried peach slices (PSFD). Fig. 1 displays the total ion chromatogram and Table 1 presents the corresponding data. Based on the data shown in Table 1, it is evident that a collective count of 59 volatile compounds were identified in both fresh and dried peaches. These compounds encompassed a range of chemical courses, including 10 alcohols, 8 aldehydes, 4 esters, 8 ketones, 10 lactones, 13 heterocyclic compounds, 4 acids, and 2 alkanes. PSFD had the highest concentration of volatile compounds (346.831 mg/kg). In comparison, FD contains 84.272 mg/kg volatile compounds, whereas HD contains 29.901 mg/kg volatile compounds (Bonneau, Boulanger, Lebrun, Maraval, & Gunata, 2016). The quantity of volatile compounds increased

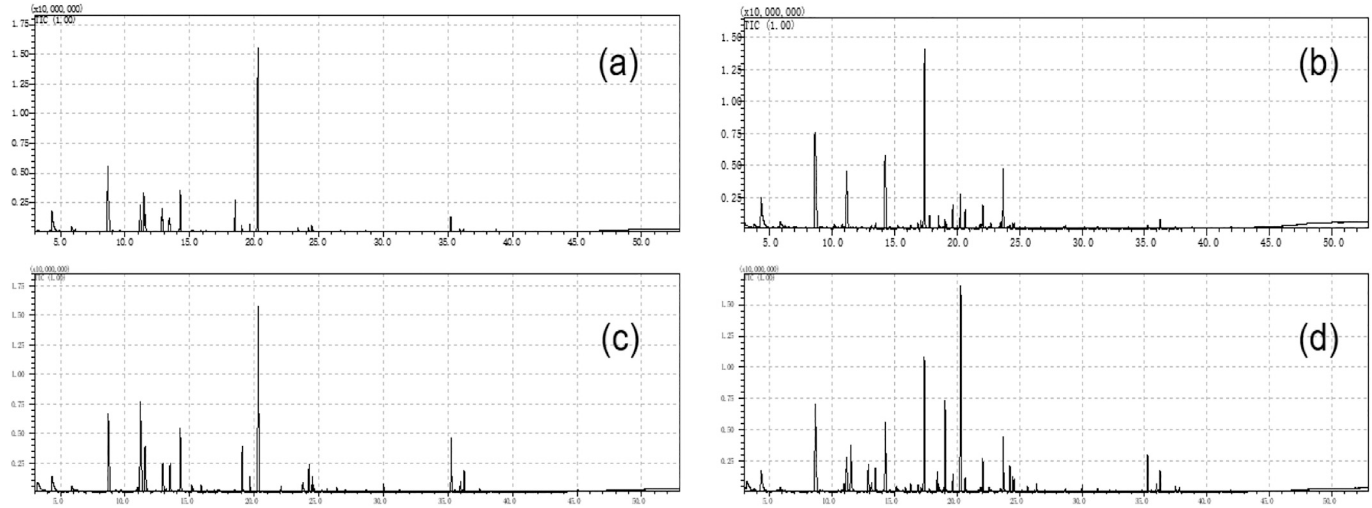

Fig. 1. TIC of HS-SPME-GC–MS analysis for peach slices(a), hot air dried peach slices(b), vacuum freeze-dried peach slices(c), and pilot-scale vacuum freeze-dried peach slices(d).

after the drying process applied to peach slices were dried.

Alcohols are known for their fruity, leafy, and grassy aromas, with a pleasant floral and fruity aroma that increases with increasing number of carbon atoms (Hidalgo & Zamora, 2019). Ten alcohol compounds were detected in the four groups of samples, with seven in fresh peaches, six in HD, nine in FD, and seven in PSFD. Among the alcohol compounds present in all the samples, 2-ethylhexanol, linalool, dihydro-linalool, and α-terpineol were the most prevalent. The fresh peach exhibited the highest concentration of the linear terpenoid alcohol linalool (1.659 mg/kg), which is typically linked to floral, fruity, and woody aromas (Jirapakkul, Tinchan, & Chaiseri, 2013). However, when subjected to hot air drying and experimental vacuum freeze-drying, its content significantly decreases (Lin, Hsiao, & Chen, 2022). Dihydrolinalool is a derivative formed by esterification and dehydration reactions of linalool. Statistically significant differences were observed in the amounts found in PSFD (4.690 mg/kg), HD (1.573 mg/kg), FD (0.213 mg/kg), and fresh peaches (0.147 mg/kg). This indicates that heat treatment can promote the oxidation of linalool to other terpenoid alcohol compounds.

Among the aldehydes detected, it mainly contrbuited “fatty,” “grassy,” “fresh,” “cirtus” and “floral” flavor attributes. Drying induced the aldehyde loss of both hexanal as a saturated aldehyde and trans-2-hexenal as a saturated aldehyde, which are the key natural aroma components in fresh peach; these compounds were not detected in dried apple slices, consistent with previous research showing upon drying of bell peppers (De Aguiar et al., 2022), and mango (Bonneau et al., 2016). Phenylacetaldehyde, which has an almond and caramel flavor, had the highest content in PSFD (0.310 mg/kg). Phenylacetaldehyde is produced as a result of Strecker degradation of isoleucine during the drying process (Liu et al., 2019). The phenylacetaldehyde content significantly decreased in the other three groups of samples. 2-hexenal was only detected in the FD sample at a concentration of 0.085 mg/kg. It is derived from the oxidation of (E)-2-hexen-1-ol and has a green fatty flavor. After the high-temperature drying treatment, both benzyl alcohol and cis-rose oxide were detected in the HD and PSFD peach slices, which had a flavor reminiscent of berry and honey flavor, with no discernible difference in content. Vacuum freeze-dried fruit and vegetable samples have distinct fruity aromas, whereas hot-air-dried samples have roasted and toasted aromas.

Ketone compounds are prevalent in fruits and vegetables and are known for their high flavor thresholds. The possible formation mechanisms of ketones are sugar degradation, oxidation of unsaturated fatty acids, and the Maillard reaction (Chung, Yung, Ma, & Kim, 2002), which exhibit flavors such as fatty and toasted aromas, and with an increase in carbon atoms, they can also exhibit floral aromas. PSFD had considerably greater types and contents of ketones than the other drying methods, followed by HD, which may be attributed to the Maillard reaction in peach slices during high-temperature treatment, and a variety of aldehyde-ketone volatile compounds were obtained. The ester is the main substance of the peach aroma, with fruit and oil tastes. Hexyl acetate and (E)-2-hexenyl acetate, both straight-chain ester compounds, are primarily responsible for the aroma of peaches. They exhibit sweet fruity, grass, and fruity aromas. Acid compounds are generally formed during heating when unsaturated fatty acids undergo thermal decomposition. Four acid compounds were identified in the three categories of dried samples: acetic acid, 3-methylbutanoic acid, hexanoic acid, and octanoic acid. Volatile compounds were created through the transformation of alkane compounds. They have higher flavor thresholds and contribute less to the overall aroma of the samples, but can still have a modifying effect on the aroma of the samples.

Lactones are an important component of peach aroma, an important source of “peach flavor,” and play a key role in the contour of the peach aroma (Fanesi et al., 2023). Saturated fatty acids serve as catalysts for their production via β-oxidation and acyl-CoA oxidase (Kumari et al., 2023). Common substances in the four groups of samples were γ-hexalactone, propyl decyllactone, and 5-decanolide. The types and content of lactone compounds in the PSFD samples were significantly higher than those in the other three groups. 5-decanolide (5.456 mg/kg) has a high concentration and produces peach, apricot, and sweet aromas. The second highest concentration was propyl decanoate (3.071 mg/kg), which exhibited peach, apricot, and fatty aromas.

Heterocyclic compounds primarily consist of furan compounds, which are characterized by sweet and cereal aromas. In food processing, the Maillard reaction, lipid oxidation, and the thermal degradation of carbohydrates are the primary pathways for the formation of furan compounds (Wong, Aziz, & Mohamed, 2008). Both the HD and PSFD samples revealed the presence of 3-furfural, 2-acetylfuran, 5-methyl-2-furfural, and 5-hydroxymethylfurfural. This is because both drying methods involve high temperatures, which leads to the occurrence of the Maillard reaction (D. Zhang, Ji, Liu, & Gao, 2020). Among these, 5-hydroxymethylfurfural, a primary product of the Maillard reaction, possesses caramel and fatty aromas. It is a crucial indicator of the Maillard reaction that occurs during the thermal processing of food (Cho, Lee, Jun, Roh, & Kim, 2010). 3-furfural and 5-methyl-2-furfural are derivatives of furfural. PSFD samples contained a greater variety and concentration of heterocyclic substances than HD samples.

The overall aroma of the dried peach slices was determined by the collective interaction of various substances. Alcohols, aldehydes,

Table 1
Volatile compounds of dried peach slices.

NO	Compound[a]	CAS	Identification method[b]	RI[c]		Odor quality	Odor threshold (mg/kg in water)	Concentration(mg/kg d.b.)			
				Exp[d]	Ref[e]			X[f]	HD[g]	FD[h]	PSFD[i]
Alchohols											
1	Ethanol	64-17-5	MS/RI/S	950	952	alcohol, floral	950	ND[j]	ND	0.503 ± 0.044	1.487 ± 0.509
2	1-Pentanol	71–41-0	MS/RI/S	1252	1251	fruit, green	0.1502	ND	0.364 ± 0.126	0.044 ± 0.006	ND
3	1-Hexanol	111–27-3	MS/RI/S	1360	1353	bread, flower	0.0056	0.299 ± 0.005	ND	ND	ND
4	(Z)-3-Hexen-1-ol	928–96-1	MS/RI/S	1390	1383	grass, green	0.0039	0.250 ± 0.003	ND	0.247 ± 0.002	0.283 ± 0.022
5	(E)-2-Hexen-1-ol	928–95-0	MS/RI/S	1420	1406	fat, geranium	0.2319	0.156 ± 0.002	ND	0.158 ± 0.002	0.175 ± 0.129
6	1-Octen-3-ol	3391-86-4	MS/RI/S	1452	1451	earth, fat	0.0015	ND	ND	0.033 ± 0.001	ND
7	2-Ethyl-1-hexanol	104–76-7	MS/RI/S	1484	1490	citrus, green	25.4822	0.206 ± 0.007	0.125 ± 0.004	0.113 ± 0.001	0.126 ± 0.003
8	Linalool	78–70-6	MS/RI/S	1552	1547	floral, flower	0.00022	1.659 ± 0.224	0.086 ± 0.013	0.385 ± 0.045	1.641 ± 0.883
9	3,7-Dimethyl-1,5,7-octatrien-3-ol	29,957–43-5	MS/RI	1616	1607	fresh, hyacinth	-[k]	0.147 ± 0.030	1.573 ± 0.252	0.213 ± 0.035	4.690 ± 2.367
10	α-Terpineol	98–55-5	MS/RI/S	1680	1691	floral, fresh	1.2	0.033 ± 0.005	0.026 ± 0.001	0.028 ± 0.001	0.045 ± 0.011
Aldehydes											
11	Hexanal	66–25-1	MS/RI/S	1078	1072	apple, cut grass	0.005	0.111 ± 0.004	0.108 ± 0.008	0.096 ± 0.028	0.095 ± 0,011
12	2-Hexenal	505–57-7	MS/RI/S	1209	1209	fat, green	0.03	ND	ND	0.085 ± 0.022	ND
13	Nonanal	124–19-6	MS/RI/S	1390	1486	citrus, cucumber	0.0011	0.489 ± 0.004	0.488 ± 0.001	0.487 ± 0.002	0.494 ± 0.006
14	Benzaldehyde	100–52-7	MS/RI/S	1502	1507	almond, berry	0.75089	0.058 ± 0.04	0.044 ± 0,001	0.075 ± 0.131	0.310 ± 0.141
15	Phenylacetaldehyde	122–78-1	MS/RI/S	1626	1625	berry, floral	0.0063	ND	0.740 ± 0.001	ND	0.781 ± 0.022
16	Safranal	116–26-7	MS/RI/S	1629	1630	herb, sweet	–	ND	0.184 ± 0.002	ND	0.183 ± 0.004
17	2,4-Dimethylbenzaldehyde	15,764–16-6	MS/RI/S	1710	1711	–	–	ND	0.005 ± 0.001	ND	ND
18	2-Phenyl-2-butenal	4411-89-6	MS/RI/S	1907	1913	cocoa, honey	–	ND	ND	ND	0.063 ± 0.006
Esters											
19	Hexyl acetate	142–92-7	MS/RI/S	1265	1270	apple, banana	0.115	0.288 ± 0.048	ND	0.128 ± 0.029	0.336 ± 0.154
20	(*Z*)-3-Hexenyl acetate	3681-71-8	MS/RI/S	1315	1313	banana, candy	0.115	0.277 ± 0.046	ND	0.151 ± 0.017	0.305 ± 0.121
21	(E)-2-Hexenyl acetate	2497-18-9	MS/RI	1332	1330	–	0.013	0.144 ± 0.033	ND	0.073 ± 0.023	0.218 ± 0.120
22	Dibutyl phthalate	84–74-2	MS/RI/S	2705	2688	–	–	ND	ND	0.020 ± 0.009	ND
Ketones											
23	3-Hydroxy-2-butanone	513–86-0	MS/RI/S	1285	1275	butter, cream	0.014	ND	ND	0.135 ± 0.004	0.180 ± 0.036
24	2,3-Octanedione	585–25-1	MS/RI/S	1326	1321	–	–	ND	0.521 ± 0.026	0.478 ± 0.028	1.301 ± 0.415
25	6-Methyl-5-hepten-2-one	110–93-0	MS/RI/S	1327	1331	citrus, mushroom	0.068	ND	0.094 ± 0.003	ND	ND
26	2-Decanone	693–54-9	MS/RI/S	1495	1487	fat, fruit	0.0083	ND	ND	0.051 ± 0.001	0.150 ± 0.094
27	(E)-3-Nonen-2-one	18,402–83-0	MS/RI/S	1518	1503	–	–	ND	0.173 ± 0.001	ND	0.197 ± 0.018
28	2-Cyclopentene-1,4-dione	930–60-9	MS/RI/S	1573	1569	–	–	ND	ND	ND	74.490 ± 3.973
29	4-Oxoisophorone	1125-21-9	MS/RI/S	1677	1676	citrus, honey	–	ND	0.091 ± 0.001	ND	ND
30	Geranylacetone	3796-70-1	MS/RI/S	1850	1845	green, hay	0.06	0.068 ± 0.010	0.065 ± 0.003	0.062 ± 0.004	0.104 ± 0.035
Lactone											

(*continued on next page*)

Table 1 (*continued*)

NO	Compound[a]	CAS	Identification method[b]	RI[c]		Odor quality	Odor threshold (mg/kg in water)	Concentration(mg/kg d.b.)			
				Exp[d]	Ref[e]			X[f]	HD[g]	FD[h]	PSFD[i]
31	5-Methyl-2(3H)-furanone	591–12-8	MS/RI/S	1430	1419	–	–	ND	0.019 ± 0.001	ND	0.055 ± 0.018
32	γ-Hexalactone	695–06-7	MS/RI/S	1694	1682	coconut, coumarin	0.26	0.199 ± 0.003	0.177 ± 0.001	0.212 ± 0.003	0.339 ± 0.098
33	γ-Heptalactone	105–21-5	MS/RI/S	1796	1783	caramel, fat	0.4	ND	ND	0.005 ± 0.001	0.015 ± 0.007
34	γ-Octalactone	104–50-7	MS/RI/S	1910	1897	coconut, fruit	0.012	0.139 ± 0.001	ND	0.145 ± 0.001	ND
35	γ-Nonalactone	104–61-0	MS/RI/S	2023	2010	apricot, cocoa	0.0097	ND	ND	0.016 ± 0.000	ND
36	γ-Decalactone	706–14-9	MS/RI/S	2136	2127	apricot, fat	0.0011	1.717 ± 0.146	0.632 ± 0.009	1.428 ± 0.028	3.071 ± 1.413
37	6-Pentyl-2-pyrone	27,593–23-3	MS/RI/S	2175	2162	–	0.15	0.016 ± 0.014	ND	0.155 ± 0.005	0.387 ± 0.180
38	5-Decanolide	705–86-2	MS/RI/S	2190	2177	apricot, butter	0.066	0.985 ± 0.083	0.701 ± 0.463	1.414 ± 0.074	5.456 ± 3.113
39	(Z)-Jasmin lactone	25,524–95-2	MS/RI/S	2239	2239	–	–	ND	0.163 ± 0.001	0.164 ± 0.001	0.190 ± 0.018
40	γ-Undecalactone	104–67-6	MS/RI/S	2247	2243	apricot, fruit	0.0021	ND	ND	ND	0.110 ± 0.087
Heterocyclic compounds											
41	2-Pentylfuran	3777-69-3	MS/RI/S	1230	1226	butter, floral	0.0058	ND	0.036 ± 0.001	ND	ND
42	2-Ethylpyrazine	13,925–00-3	MS/RI/S	1344	1326	butter, earth	4	ND	ND	ND	0.114 ± 0.010
43	Trans-linalool oxide	34,995–77-2	MS/RI/S	1442	1437	citrus, earth	0.19	ND	9.330 ± 1.214	2.270 ± 0.733	23.622 ± 7.186
44	3-Formylfuran	498–60-2	MS/RI/S	1455	1454	–	–	ND	2.033 ± 0.213	ND	2.856 ± 1.241
45	2-Acetylfuran	1192-62-7	MS/RI/S	1501	1493	balsamic, cocoa	15.0252	ND	0.033 ± 0.001	ND	0.042 ± 0.007
46	5-Methyl-2-furfural	620–02-0	MS/RI/S	1570	1560	almond, caramel	1.11	ND	0.070 ± 0.004	ND	0.106 ± 0.030
47	Linalool oxide	14,049–11-7	MS/RI/S	1731	1733	flower	0.32	ND	ND	73.240 ± 0.329b	79.938 ± 5.148
48	2-Acetylpyrrole	1072-83-9	MS/RI/S	1971	1959	bread, cocoa	58.58525	ND	ND	ND	0.023 ± 0.001
49	2-Formylpyrrole	1003-29-8	MS/RI/S	2028	2009	–	65	ND	ND	ND	89.991 ± 35.474a
50	Norfuraneol	19,322–27-1	MS/RI/S	2124	2106	caramel, cotton candy	2.5	ND	ND	ND	29.433 ± 13.063a
51	2,3-Dihydro-3-hydroxymaltol	28,564–83-2	MS/RI	2239	2256	bitter, earth	35	ND	ND	ND	0.505 ± 0.348
52	2,4-Di-tert-butylphenol	96–76-4	MS/RI/S	2316	2309	–	0.5	0.026 ± 0.001	0.016 ± 0.001	0.015 ± 0.001	0.019 ± 0.004
53	5-Hydroxymethyl-2-furfural	67–47-0	MS/RI/S	2487	2489	caramel, cardboard	1000	ND	10.819 ± 3.680	ND	21.667 ± 12.248a
Acids											
54	Acetic acid	64–19-7	MS/RI/S	1460	1445	acid, fruit	99	ND	0.177 ± 0.012	0.123 ± 0.001	0.191 ± 0.049
55	3-Methylbutanoic acid	503–74-2	MS/RI/S	1680	1664	acid, cheese	0.49	ND	0.482 ± 0.050	0.073 ± 0.005	0.911 ± 0.358
56	Hexanoic acid	142–62-1	MS/RI/S	1849	1841	acid, cheese	0.89	ND	0.124 ± 0.001	ND	0.126 ± 0.005
57	Octanoic acid	124–07-2	MS/RI/S	2050	2055	acid, cheese	3	ND	0.392 ± 0.004	ND	ND
Alkane											
58	Undecane	1120-21-4	MS/RI/S	1100	1088	alkane	10	0.011 ± 0.003	0.010 ± 0.002	0.010 ± 0.001	0.010 ± 0.001
59	Tetradecane	629–59-4	MS/RI/S	1399	1396	alkane, hydrocarbon	1	ND	ND	0.009 ± 0.001	ND

[a] Volatiles were identified in peach fruits and dried slices(X,HD,FD, and PSFD).
[b] Identification methods for volatils: MS, RI, and S represent identification by mass spectra, Kováts retention indices, olfactometry, and aroma anthentic standard, respectively.
[c] RI, retention indices.
[d] The RI of the volatiles in dried apple slices was calculated using a homologous series of n-alkanes (C7–C40).
[e] The RI of the volatiles on a DB-WAX capillary column (30 m × 0.25 mm × 0.25 μm) reported.
[f] X, peach fruit
[g] FD, vacuum freeze drying peach slices.

[h] HD, hot air drying peach slices.
[i] PSFD, pilot-scale vacuum freeze drying peach slices.
[j] ND, not detected.
[k] "-", not found.

ketones, esters, and lactones are vital flavor compounds. Aliphatic compounds play a modifying role, while heterocyclic compounds contribute to the aroma's enhancement. The types and amounts of volatile compounds in peach slices vary significantly, depending on the drying method used. Among these, hot air drying (HD) is primarily responsible for the formation of aldehydes, ketones, and heterocyclic compounds. However, due to prolonged exposure to high temperatures, some heat-sensitive compounds in peach slices may be lost significantly; multiple compounds, including alcohols, aldehydes, ketones, esters, and lactones, interact to produce the overall aroma of dried peach slices. Alkane compounds play modifying roles, whereas heterocyclic compounds contribute to their complexity. The drying method had a substantial effect on the type and content of volatile compounds in peach slices. HD primarily facilitates the formation of aldehydes, ketones, and heterocyclic compounds; however, owing to prolonged exposure to high temperatures, some heat-sensitive compounds in peach slices may be lost. FD effectively preserves the volatile compounds of fresh peaches while enriching the diversity and content of volatile compounds in

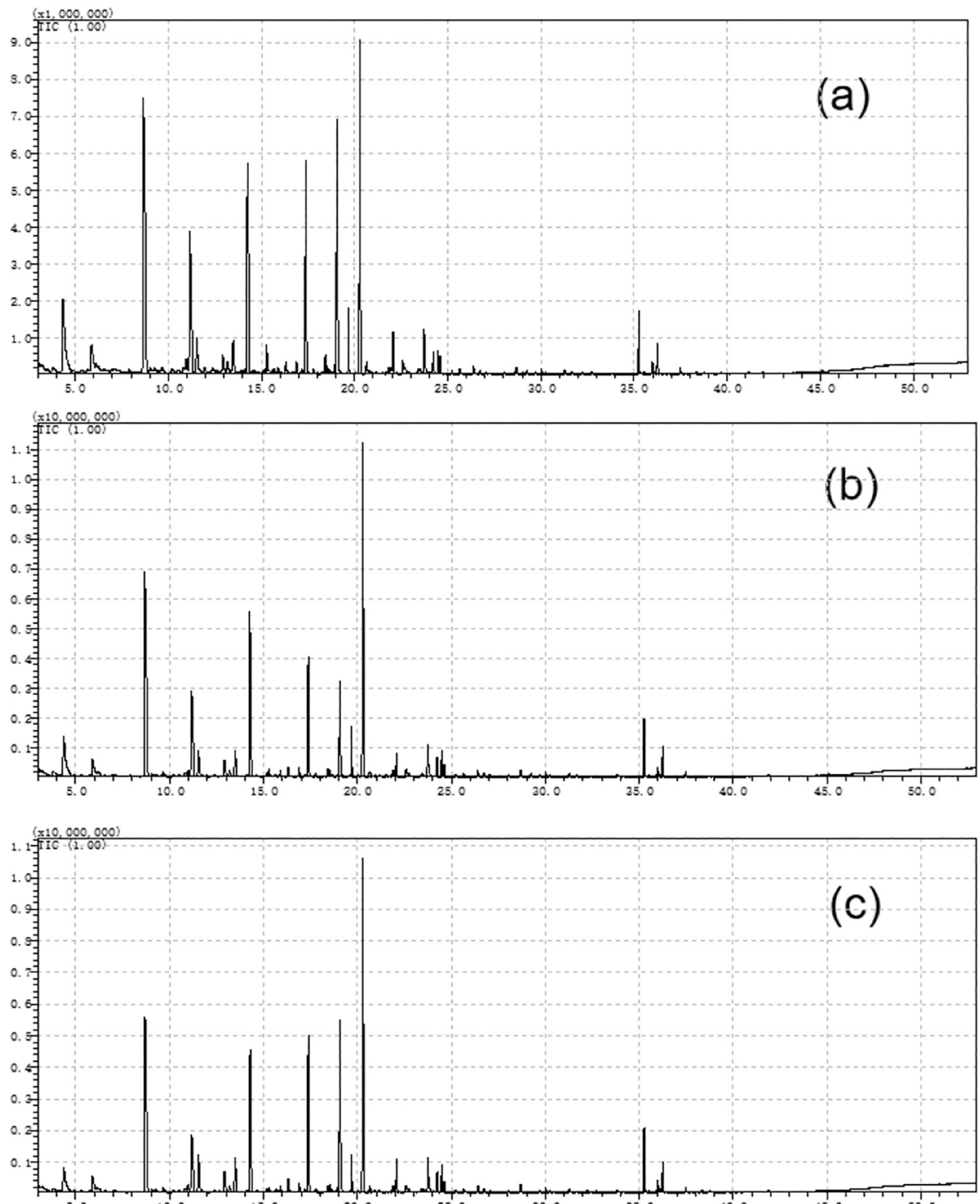

Fig. 2. TIC of HS-SPME-GC–MS analysis for permeation dehydration with 10°Brix sucrose combined with pilot vacuum freeze-drying of peach slices(a); Permeation dehydration with 20°Brix sucrose concentration combined with pilot vacuum freeze-drying of peach slices (b); Permeation dehydration with 30°Brix sucrose concentration combined with pilot vacuum freeze-drying of peach slices(c).

peach slices. PSFD promotes the formation of lactones and heterocyclic compounds, resulting in a more robust and rich flavor in peach slices.

The experimental findings presented in this section indicate that PSFD exhibits a superior variety, content, and aroma profile of volatile compounds compared to HD and FD. Therefore, the PSFD was selected for further experiments.

3.2. The effect of combined penetration dehydration and pilot-scale vacuum freeze-drying on the characteristic aroma of peach slices

3.2.1. The effect of combined penetration dehydration and pilot-scale vacuum freeze-drying on the volatile compounds of peach slices

The volatile compounds in peach slices, which were subjected to different sucrose concentrations during combined penetration dehydration and pilot-scale vacuum freeze-drying, were analyzed using the HS-SPME-GC–MS technique. Fig. 2 displays the total ion chromatogram and Table 2 presents the analysis results. As shown in Table 2, 44 volatile compounds were detected in the three dried samples, including eight aldehydes, five esters, nine alcohols, four ketones, eight lactones, six heterocyclic compounds, and two acid compounds. PSFD30 contained the highest content of volatile compounds (107.032 mg/kg), followed by PSFD10 (96.726 mg/kg), and PSFD20 (92.679 mg/kg). Sucrose penetration dehydration affects the volatile component content of freeze-dried peach slices, as evidenced by a reduction in the content of volatile compounds following penetration dehydration compared to the results in Section 3.1 (Mercali, Ferreira Marczak, Tessaro, & Zapata Noreña, 2011).

Aldehydes contributed significantly to the overall aroma profile, and their odor thresholds were low. C6 aldehydes, such as hexanal and trans-2-hexenal, are largely responsible for peachy and green notes in peach fruits. Hexanal, nonanal, and phenylacetaldehyde were aldehydes found in all three categories of peach slices. The primary source of these aldehydes is the oxidative degradation of fatty acids (Azad Shah, Tokunaga, Kurihara, & Takahashi, 2009). The samples had a comparatively high concentration of phenylacetaldehyde, which has a flavor similar to that of bitter almond and caramel. It is partly derived from the enzymatic breakdown of amygdalin in peaches and partly from Strecker degradation of isoleucine during the drying process. Hexanal exhibits fruity and grassy notes, whereas nonanal presents citrus and fruity aromas. 2-methylbutanal and phenylacetaldehyde are derived from Strecker degradation of isoleucine and phenylalanine, respectively, in the Maillard reaction (Liu et al., 2019). The flavors of almond, grassy, and oily are carried by pentanal, while safranal contributes to herbal and sweet aromas. PSFD30 has a greater variety of compounds and a more complex flavor profile, which is attributed to the increased levels of fructose and glucose resulting from higher sucrose concentrations, which enhances the Maillard reaction.

A portion of the alcohol compounds is obtained through the oxidation and decomposition of fats, whereas another part is derived from the reduction of carbonyl compounds (Barreira et al., 2019). They play a significant role in enhancing the overall aroma of peaches. The highest concentrations of alcohol compounds were found in PSFD30; specifically, 1-pentanol (0.127 mg/kg), (E)-2-hexen-1-ol (0.162 mg/kg), linalool (0.796 mg/kg), dihydro-linalool (1.848 mg/kg), and α-terpineol (0.037 mg/kg) were significantly higher than those in the other treatment groups. Both 1-octene-3-ol and 1-octanol originate from the oxidation of linoleic acid in peaches. Ester compounds generally have fruity and fatty aromas and are the foundation of peach aroma. Hexyl acetate, ethyl acetate, and (E)-2-hexenyl acetate, the primary peach aroma compounds, were detected in all three sample groups and exhibited fruity, banana, and candy flavors, respectively. At 30°Brix, ethyl acetate (5.069 mg/kg) was a significant aroma compound that contributed to fruity and pineapple notes to the sucrose concentration. In addition to having fatty and caramel flavors, ketone compounds can also have floral aromas as their carbon atom concentration increases. 4-oxoisophorone has aromas that are sweet, fruity, and floral aromas (Chen, Zhang, & Guo, 2019). Citrus flavors and aromas can be found in 2,5-octanedione, 3-nonene-2-one, and 6-Methyl-5-hepten-2-one.

Most heterocyclic compounds are produced via the Maillard process. The samples were divided into three groups: toluene, p-xylene, furfural, 2-acetylfuran, and 5-methylfuran aldehyde. Dehydration and cyclization of sugar and acid compounds in the presence of heat and oxygen yields furfural, which has floral, almond, and bread aromas. The flavors of chocolate and coffee are also apparent in 2-acetylfuran. 5-methyl-2-furfural, a furfural derivative, has a flavor profile somewhere between that of almond and caramel. Toluene has a pleasant flavor and odor similar to benzene, whereas xylene has an aromatic aroma. PSFD30 exhibited a larger concentration of heterocyclic compounds than PSFD10 and PSFD20, suggesting that the Maillard process is more active when a higher concentration of sucrose is used. The scent of peaches is primarily derived from lactone molecules. It was found that PSFD30 peach slices had a greater lactone content than PSFD10 and PSFD20 varieties when the sucrose concentration was 30°Brix.

According to 3.1 analysis, the nature and concentration of volatile compounds in peach slices were drastically altered by the drying method used. The peach slices were immersed in a sucrose solution of varying concentrations and then freeze-dried in a pilot plant'sworth of vacuum dehydrators to meet realistic production goals. The aldehyde, ketone, and furan compounds were found to have higher concentrations after this process. When sucrose concentrations were compared during pre-treatment and drying, it was found that a higher sucrose concentration led to a stronger engagement in the Maillard reaction, which in turn led to a higher content of the produced compounds and a more appealing product. Peach slices that were pre-treated with a sucrose concentration of 30°Brix and then subjected to vacuum freeze-drying on a pilot scale were found to have much better flavor qualities than those processed using any of the other methods.

3.2.2. The effects of osmotic dehydration combined with pilot vacuum freeze-drying on key aroma compounds of peach slices

The current study, in conjunction with OAV analysis, aimed to elucidate the principal aroma compounds present in peach slices and to assess the relative impact of each volatile compound on the overall aroma profile of these slices. The overall flavor contribution of peach slices was positively correlated with volatile compounds when OAV ≥ 1, and vice versa. The detemination of aroma-active compounds depend on not only the concentrations but also their odor threshold values (Munafo Jr., Didzbalis, Schnell, & Steinhaus, 2016).

As shown in Table 3, PSFD10, PSFD20, and PSFD30 contained 14, 19, and 21 compounds, respectively, with an odor activity value (OAV) $\geq$1. Compounds with an OAV $\geq$1 that were common to all three groups of samples included hexanal, nonanal, phenylacetaldehyde, ethyl acetate, linalool, linalool oxide, 2-undecanone, geranylacetone, γ-octalactone, γ-decalactone, butyl decalactone, trans-linalool oxide, and linalool oxide. Among them, linalool (grape and lavender flavors) has a relatively low content, but an extremely low flavor threshold (0.00022 mg/kg). It had the highest OAV value in all three groups of samples, with values of 2668.175, 2928.204, and 3618.255 for PSFD10, PSFD20, and PSFD30, respectively. Therefore, linalool is the most important aroma compound in peach slices. The key aromatic compounds in PSFD include 2-methylbutanal, pentanal, hexanal, nonanal, phenylacetaldehyde, methyl 2-methylbutyrate, ethyl acetate, linalool, linalool oxide, 6-Methyl-5-hepten-2-one, 2-undecanone, 4-oxoisophorone, γ-decalactone, γ-dodecalactone, γ-undecalactone, trans-linalool oxide, and linalool oxide. Flavors of mushroom, almond, fatty, and chocolate are accentuated by these compounds, as are scents of fruit, floral, sweet, and peach. This is because the elevated temperature of the PSFD sample and the decomposition products of sucrose increased the intensity of the Maillard reaction in specific components and the abundance of reaction products, lending the peach slices a flavor reminiscent of that of baked products such as bread, caramel, and yeast. Overall, PSFD30 had the most distinctive peach flavor because it contained the highest

Table 2
Volatile compounds of permeation dehydration combined withpilot-scale vacuum freeze drying peach slices.

NO	Compound[a]	CAS	Identification method[b]	RI[c]		Concentration(mg/kg d.b.)		
				Exp[d]	Ref[e]	PSFD10[f]	PSFD20[g]	PSFD30[h]
Aldehydes								
1	2-Methylbutanal	96–17-3	MS/RI/O	916	906	ND[i]	ND	0.309 ± 0.043
2	Pentanal	110–62-3	MS/RI/S/O	971	973	ND	ND	0.059 ± 0.002
3	Hexanal	66–25-1	MS/RI/S/O	1078	1071	0.182 ± 0.056	0.138 ± 0.014	0.147 ± 0.019
4	2-Hexenal	505–57-7	MS/RI/S/O	1209	1209	ND	ND	0.053 ± 0.001
5	Nonanal	124–19-6	MS/RI/S	1390	1386	0.515 ± 0.013	0.492 ± 0.001	0.489 ± 0.001
6	Benzaldehyde	100–52-7	MS/RI/S	1502	1507	0.274 ± 0.096	0.125 ± 0.016	0.261 ± 0.072
7	Phenylacetaldehyde	122–78-1	MS/RI/S/O	1626	1625	0.790 ± 0.022	0.755 ± 0.003	0.766 ± 0.010
8	Safranal	116–26-7	MS/RI/S	1629	1630	0.182 ± 0.003	ND	0.180 ± 0.003
Esters								
9	Ethyl acetate	141–78-6	MS/RI/S/O	921	943	ND	ND	5.069 ± 0.676
10	Methyl 2-methylbutyrate	868–57-5	MS/RI/O	1008	1006	ND	ND	0.010 ± 0.002
11	Hexyl acetate	142–92-7	MS/RI/S	1265	1269	0.113 ± 0.024	0.100 ± 0.004	0.140 ± 0.023
12	(Z)-3-Hexenyl acetate	3681-71-8	MS/RI/S/O	1313	1312	0.139 ± 0.019	0.135 ± 0.005	0.156 ± 0.015
13	(E)-2-Hexenyl acetate	2497-18-9	MS/RI/S	1332	1330	0.092 ± 0.036	0.080 ± 0.010	0.134 ± 0.032
Alchohols								
14	Ethanol	64–17-5	MS/RI/S/O	950	952	ND	ND	0.207 ± 0.009
15	1-Pentanol	71–41-0	MS/RI/S/O	1252	1251	0.135 ± 0.041	0.090 ± 0.012	0.127 ± 0.020
16	(Z)-3-Hexen-1-ol	928–96-1	MS/RI/S	1390	1386	0.237 ± 0.005	0.229 ± 0.002	0.236 ± 0.001
17	(E)-2-Hexen-1-ol	928–95-0	MS/RI/S	1420	1406	0.157 ± 0.006	0.160 ± 0.003	0.162 ± 0.003
18	2-Ethyl-1-hexanol	104–76-7	MS/RI/S	1484	1490	0.115 ± 0.002	0.118 ± 0.005	0.116 ± 0.001
19	Linalool	78–70-6	MS/RI/S/O	1552	1547	0.587 ± 0.241	0.644 ± 0.104	0.796 ± 0.170
20	1-Octanol	111–87-5	MS/RI/S	1560	1558	0.067 ± 0.008	0.054 ± 0.001	ND
21	3,7-Dimethyl-1,5,7-octatrien-3-ol	29,957–43-5	MS/RI	1616	1607	1.745 ± 0.702	1.100 ± 0.171	1.848 ± 0.358
22	α-Terpineol	98–55-5	MS/RI/S	1680	1691	0.032 ± 0.003	0.034 ± 0.001	0.037 ± 0.003
23	Benzyl alcohol	100–51-6	MS/RI/S/O	1877	1866	0.233 ± 0.002	0.233 ± 0.001	0.231 ± 0.003
Ketones								
24	Octane-2,5-dione	3214-41-3	MS/RI/S	1326	1321	0.946 ± 0.394	0.602 ± 0.098	0.785 ± 0.148
25	2-Decanone	693–54-9	MS/RI/S	1495	1487	0.072 ± 0.012	0.059 ± 0.002	0.058 ± 0.001
26	(E)-3-Nonen-2-one	18,402–83-0	MS/RI/S	1518	1503	0.184 ± 0.008	ND	0.179 ± 0.003
27	Geranylacetone	3796-70-1	MS/RI/S	1850	1845	0.075 ± 0.012	0.076 ± 0.004	0.086 ± 0.008
Lactone								
28	5-Methyl-2(3H)-furanone	591–12-8	MS/RI/S	1430	1419	0.034 ± 0.010	0.030 ± 0.003	0.044 ± 0.010
29	γ-Hexalactone	695–06-7	MS/RI/S/O	1694	1682	0.208 ± 0.014	0.145 ± 0.103	0.223 ± 0.017
30	γ-Octalactone	104–50-7	MS/RI/S/O	1910	1896	0.143 ± 0.003	0.142 ± 0.001	0.146 ± 0.003
31	5-Octanolide	698–76-0	MS/RI/S/O	1965	1973	ND	ND	0.009 ± 0.001
32	γ-Decalactone	706–14-9	MS/RI/S	2136	2126	1.769 ± 0.480	1.622 ± 0.101	2.142 ± 0.363
33	6-Pentyl-2-pyrone	27,593–23-3	MS/RI/S	2175	2162	0.179 ± 0.048	0.148 ± 0.005	0.231 ± 0.045
34	5-Decanolide	705–86-2	MS/RI/S	2190	2176	2.241 ± 0.887	2.136 ± 0.164	3.117 ± 0.728
35	(*Z*)-Jasmin lactone	25,524–95-2	MS/RI/S	2239	2238	0.167 ± 0.003	0.166 ± 0.002	0.168 ± 0.002
	Heterocyclic compounds							
36	Methylbenzene	108–88-3	MS/RI/O	1032	1036	ND	ND	0.039 ± 0.005
37	1,4-Dimethylbenzene	106–42-3	MS/RI/O	1130	1125	ND	ND	0.014 ± 0.003
38	Trans-linalool oxide	34,995–77-2	MS/RI/S	1442	1437	11.847 ± 4.267a	10.328 ± 2.241	14.016 ± 2.088
39	Furfural	98–01-1	MS/RI/S/O	1460	1453	0.637 ± 0.262	0.365 ± 0.057	0.608 ± 0.121
40	2-Acetylfuran	1192-62-7	MS/RI/S	1501	1493	ND	0.029 ± 0.002	ND
41	5-Methyl-2-furfural	620–02-0	MS/RI/S/O	1570	1560	0.042 ± 0.010	0.029 ± 0.001	0.031 ± 0.002
42	Linalool oxide	14,049–11-7	MS/RI/S	1731	1732	72.161 ± 0.879abc	71,985 ± 0.046c	73.087 ± 0.961
Acids								
43	Acetic acid	64–19-7	MS/RI/S	1452	1447	0.141 ± 0.011	0.134 ± 0.006	0.145 ± 0.011
44	3-Methylbutanoic acid	503–74-2	MS/RI/S/O	1680	1666	0.285 ± 0.104	0.196 ± 0.059	0.301 ± 0.062

[a] Volatiles were identified in dried slices(PSFD10, PSFD20 and PSFD30).
[b] Identification methods for volatils: MS, RI, and S represent identification by mass spectra, Kováts retention indices, olfactometry, and aroma anthentic standard, respectively.
[c] RI, retention indices.
[d] The RI of the volatiles in dried apple slices was calculated using a homologous series of n-alkanes (C_7–C_{40}).
[e] The RI of the volatiles on a DB-WAX capillary column (30 m × 0.25 mm × 0.25 μm) reported.
[f] PSFD10, Permeation dehydration with 10°Brix sucrose concentration combined with pilot vacuum freeze-drying of peach slices.
[g] PSFD20, Permeation dehydration with 20°Brix sucrose concentration combined with pilot vacuum freeze-drying of peach slices.
[h] PSFD30, Permeation dehydration with 30°Brix sucrose concentration combined with pilot vacuum freeze-drying of peach slices.
[i] ND, not detected.

Table 3
OAV of permeation dehydration combined withpilot-scale vacuum freeze drying peach slices.

Compound[a]	Odor quality[b]	Odor threshold (mg/kg in water)	OAV		
			PSFD10	PSFD20	PSFD30
2-Methylbutanal	Almond, chocolate	0.001	-[d]	–	309.478
Pentanal	Almond, chemical	0.012	–	–	4.910
Hexanal	Apple, cut grass	0.005	36.337	27.611	29.541
2-Hexenal	Fat, green	0.03	–	–	1.777
Nonanal	Citrus, cucumber	0.001	468.201	447.153	444.887
Benzaldehyde	Almond, berry	0.75089	0.364	0.166	0.348
Phenylacetaldehyde	Berry, floral	0.0063	125.452	119.873	121.648
Ethyl acetate	Balsamic, contact glue	0.005	–	–	1013.763
Methyl 2-methylbutanoate	Apple, fruit	0.00025	–	–	39.530
Hexyl acetate	Apple, banana	0.115	0.986	0.866	1.221
(Z)-3-Hexenyl acetate	Banana, candy	0.013	10.718	10.363	12.006
Ethanol	Alcohol, floral	950	–	–	0.001
1-Pentanol	Almond, balsamic	0.1502	0.900	0.601	0.849
(Z)-3-Hexen-1-ol	Bell pepper, grass	0.0039	60.868	61.272	60.574
(E)-2-Hexen-1-ol	Bell pepper, fat	0.2319	0.679	0.690	0.700
2-Ethyl-1-hexanol	Citrus, green	25.4822	0.005	0.005	0.005
Linalool	Bergamot, coriander	0.00022	2668.175	2928.204	3618.255
1-Octanol	Citrus, detergent	0.1258	0.536	0.433	–
α-Terpineol	Floral, fresh	1.2	0.027	0.028	0.031
Benzyl alcohol	Almond, boiled cherries	2.54621	0.091	0.091	0.091
6-Methyl-5-hepten-2-one	Citrus, mushroom	0.068	–	–	1.036
2-Decanone	Fat, fruit	0.0083	8.648	7.068	7.004
Geranylacetone	Green, hay	0.06	1.250	1.272	1.434
γ-Hexalactone	Coconut, coumarin	0.26	0.799	0.791	0.856
γ-Octalactone	Coconut, fruit	0.012	11.907	11.844	12.153
5-Octanolide	Butter, coconut	0.2	–	–	0.044
γ-Decalactone	Apricot, fat,	0.0011	1608.255	1474.391	1947.503
6-Pentyl-2-pyrone	/[c]	0.15	1.191	0.989	1.543
5-Decanolide	Apricot, butter	0.066	33.953	32.359	47.221
Toluene	Bitter almond	0.527	–	–	0.075
1,4-Dimethylbenzene	Cold meat fat, metal	1	–	–	0.014
Trans-linalool oxide	Citrus, earth	0.19	62.352	54.357	73.766
Furfural	Almond, baked potatoes	9.562	0.051	0.022	0.048
2-Acetylfuran	Balsamic, cocoa	15.0252	0.002	–	–
5-Methyl-2-furfural	Almond, caramel,	1.11	0.038	0.026	0.028
Linalool oxide	Flower	0.32	225.502	224.952	228.397
Acetic acid	Acid, fruit	99	0.001	0.001	0.001
3-Methylbutanoic acid	Acid, cheese	0.49	0.582	0.582	0.614

[a] Volatiles were identified in dried slices(PSFD10,PSFD20,PSFD30).
[b] Aroma description query from http://www.flavornet.org/flavornet.html.
[c] "/", odor descriptor indicating that the substance has not been found.
[d] "-", indicates that the substance has not been detected.

concentration of important aroma compounds with OAV1, offered more substances associated with peach, apricot, and other fruits, and had a substantially higher total OAV value than the other treatment groups.

3.2.3. GC-O analysis

In addition, DFA using GC-O has been widely used for the assessment of aroma-active compounds. DF values can characterize the odor quality of the aroma profile contributors (Y. Feng et al., 2018).

PSFD30 peach slices had superior flavor attributes, as determined by GC–MS and OAV analyses. Frequency analysis of the PSFD30 sample was performed to identify the most frequently occurring aroma compounds in the peach slices. The most prominent aroma compounds were determined using olfactory frequency (DF $\geq$ 2) and are presented in Table 4.

PSFD30 contained 21 aroma components. 2-methylbutanal (DF = 5) possesses a strong almond and chocolate flavor. Pentanal (DF = 5) had a pronounced grassy and fatty aroma. Linalool (DF = 5) primarily contains grape and lavender flavors. Phenylacetaldehyde (DF = 5) has a berry and honey flavor. 3-methylbutanoic acid (DF = 5) has a cheesy and fecal odor, which is distinct from fruity aromas. γ-Hexalactone (DF = 5) imparts peach and coconut flavors with a refreshed aroma. In addition, 2-hexenal (DF = 4) has a green aroma. 1-pentanol (DF = 4) contains almond and grassy flavors. 6-Methyl-5-hepten-2-one (DF = 4) contains citrus and mushroom flavors. Furfural (DF = 4) imparts floral and almond aromas. Ethanol (DF = 3) has floral aroma. Methyl 2-methylbutyrate (DF = 3) had a fruity aroma. Hexanal (DF = 3) has a green-grassy flavor. 5-methyl-2-furfural (DF = 3) has a caramel flavor. Ethyl acetate (DF = 2) had a fruity aroma. Toluene (DF = 2) has a bitter almond flavor. Xylene (DF = 2) has a sweet aroma. Ethyl acetate (DF = 2) has a banana flavor. Benzyl alcohol (DF = 2) has floral aroma. γ-decalactone (DF = 2) has a fruity aroma. γ-Undecalactone (DF = 2) has a peach flavor. In addition to γ-nonalactone, 3-methylbutanoic acid, furfural, 1-pentanol, 5-methyl-2-furfural, ethanol, ethyl butyrate, benzyl alcohol, toluene, and p-xylene with OAV < 1, nonanal, ethyl caproate, linalool, 2-decanone, geranylacetone, 6-pentyl-2-pyrone, 5-decanolide, trans-linalool oxide, and linalool oxide with OAV $\geq$ 1 were identified as key aroma compounds.

4. Conclusion

The following conclusions were drawn from the results of this investigation. First, 33, 36 and 46 volatile compounds were identified and quantified in HD, FD and PSFD, respectively. PSFD was selected for subsequent permeation and dehydration experiments based on actual production requirements. The results showed that the PSFD30 group had the highest number of key aroma components with OAV $\geq$ 1, and the total OAV value and proportion of key aroma components with OAV $\geq$ 1 were both considerably greater in the PSFD30 group than in any of

Table 4
OAV and DF of volatile compounds of dried peach slices by PSFDS30.

Compound	Odor threshold (mg/kg in water)	PSFD30	
		OAV	DF
2-Methylbutanal	0.001	309.478	5
Pentanal	0.012	4.910	5
Hexanal	0.005	29.541	3
2-Hexenal	0.03	1.777	4
Nonanal	0.001	444.887	
Benzaldehyde	0.0063	121.648	5
Ethyl acetate	0.005	1013.763	2
Methyl 2-methylbutanoate	0.00025	39.530	3
Hexyl acetate	0.115	1.221	
(Z)-3-Hexenyl acetate	0.013	12.006	2
Ethanol	950	0.001	3
1-Pentanol	0.1502	0.001	4
Benzyl alcohol	2.54621	0.001	2
(Z)-3-Hexen-1-ol	0.0039	60.574	
Linalool	0.00022	3618.255	5
6-Methyl-5-hepten-2-one	0.068	1.036	4
2-Decanone	0.0083	7.004	
Geranylacetone	0.06	1.434	
γ-Hexalactone	0.26	0.001	5
γ-Octalactone	0.012	12.153	2
5-Octanolide	0.2	0.001	2
γ-Decalactone	0.0011	1947.503	
6-Pentyl-2-pyrone	0.15	1.543	
5-Decanolide	0.066	47.221	
Methylbenzene	0.527	0.001	2
1,4-Dimethylbenzene	1	0.001	2
Trans-linalool oxide	0.19	73.766	
Furfural	9.562	0.001	4
5-Methyl-2-furfural	1.11	0.001	3
Linalool oxide	0.32	228.397	

the other groups. PSFD30 exhibited a characteristic peach flavor. The PSFD30 group was analyzed using GC-O analysis, and preliminary results indicated that 2-methylbutanal, pentanal, hexanal, 2-hexenal, phenylacetaldehyde, ethyl acetate, 2-methylbutyl acetate, ethyl lactate, linalool, 6-Methyl-5-hepten-2-one, and γ-octalactone contributed to the characteristic aroma of dried peach slices.

Authors' contributions

Professor Cheng-bi CUI and Jin-feng BI provided overall thinking and supervision. Jin-ru WANG:conducted the experiment,statistical analysis,writing - original draft, Xin-ye Wu:writing-revision. All authors have read and approved the final manuscript.

CRediT authorship contribution statement

Jin-Ru Wang: Data curation, Validation, Writing – original draft. **Xin-Ye Wu:** Supervision, Writing – review & editing. **Cheng-Bi Cui:** Investigation, Supervision. **Jin-Feng Bi:** Project administration, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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