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Research Paper

Characterizing emissions of VOCs from the initial degradation of kitchen waste in household waste bins of residential areas in Beijing

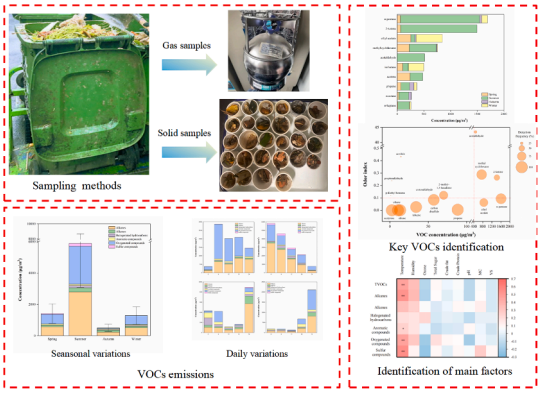
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HIGHLIGHTS

- Oxygenated compounds and alkanes were the most dominant VOCs in HMSW.
- VOCs emission in HMSW presented obvious seasonal and daily characteristics.
- Acetaldehyde contributed most to the theoretical odor concentration.
- Temperature had an overall significant correlation with concentrations of VOCs.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to clarify the emission characteristics of VOCs during the initial degradation of kitchen waste, a year-long sampling campaign of kitchen waste in residential household municipal solid waste (HMSW) bins was conducted. A total of 93 VOCs with an average annual concentration of 2271 μg/m^3 were detected. Alkanes and oxygenated compounds were the dominant released from the initial degradation of kitchen waste. Seasonal and daily variations were observed, with VOC concentrations generally higher in spring (1413 μg/m^3) and summer (5882 μg/m^3) and lower in autumn (505 μg/m^3) and winter (1258 μg/m^3). In addition, peak releases occurred earlier in the spring and summer (at 6 h) than in autumn and winter (at 24 h). Correlation analysis showed that ambient temperature correlated significantly with alkanes and oxygenated compounds ($P < 0.01$). 67 substances have been found to cause odor pollution. Based on the odor index, oxygenated compounds were the most significant odor pollutants. Acetaldehyde and 2-ketone required particular concern because of its high concentration and high odor index. This study not only enriched the understanding of emissions of VOCs from MSW front-end facilities but will also provide a scientific and theoretical basis for holistic management and odor control of MSW.

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1. Introduction

Municipal solid waste (MSW) generation in China has been increasing every year due to rapid economic development and urban population growth [1]. Data from the National Bureau of Statistics showed that MSW collection reached 245 million tons in 2022 [2], with kitchen waste accounting for the highest proportion of MSW at 50–60% [3]. Kitchen waste contains high organic components (OC) with high moisture content (MC), which is prone to producing and releasing of VOCs as well as bio-aerosols [4,5], posing potential hazards to both the environment and public health [6–8].

Previous studies of VOCs emitted from kitchen waste found they primarily consisted of seven categories, including alkanes, alkenes, terpenes, halogenated hydrocarbons, aromatic compounds, oxygenated compounds, and sulfur compounds [1,9–11]. The composition of VOCs is closely related to waste components and easily influenced by the external environment [12]. Usually, microorganisms play an important role in the composting process, thus the oxygenated compounds produced by microbial metabolic processes are absolutely dominant in composting facilities [13]. In contrast, VOCs released from incineration were mainly aromatic compounds and halogenated hydrocarbons inherent in municipal solid waste [14,15]. In addition, components of MSW in landfill was complex, thus leading to the release of complex and variable VOCs. Oxygenated compounds were the dominate category of VOCs at MSW transfer stations, followed by alkenes and aromatic compounds [16–18]. However, characteristics of VOCs generated and emitted at front-end facilities of MSW management systems lack systematic analysis.

In this study, a year-long sampling campaign was conducted on kitchen waste bins from a residential area in Beijing. Temporal variations in emissions of VOCs from HMSW were characterized, including seasonal and daily variations. This study further screened out species with high concentrations and a high odor index as key VOCs. The results of this study not only can enrich the understanding of the emission characteristics of VOCs from MSW at front-end facilities but will also provide theoretical guidance for the prevention and control of pollution from VOCs at the community level.

2. Materials and methods

2.1. Sampling method

The sampling campaign for kitchen waste in household waste bins was carried out in a residential area in Beijing (39°44′12″, 116°19′13″). The sampling period began in May 2022 and ended in February 2023. Sampling times of the current study were in May, August, November and February representing spring, summer, autumn and winter, respectively. Detailed sampling dates were listed in Table 1. During each sampling campaign, five kitchen waste bins were randomly selected from a residential area. All waste from each waste bin was dumped onto a hard surface with a clean plastic sheet, mixed and stirred with a shovel, and then piled into a conical shape. Subsequently, the pile was divided into four parts using the quadrature method, and two parts from the diagonal area were taken and transferred to a new container [3]. All five kitchen waste bins were sampled in the same way, after which all the samples were mixed well and loaded into a new plastic waste bin (120 L). Following this, the samples were brought back to the lab and the experiment was carried out immediately. To guarantee that the ambient air conditions were the same with that of the outdoors, the waste bins were placed in an open building with only a roof for protection from the rain and snow.

Table 1
Sampling schedule and meteorological statistics.

Season	Date	Temperature (℃)	Humidity (%)	O_3 (ppm)
Spring	2022.05.03 - 2022.05.06	9.3 - 22.9	51.0 - 69.5	0.061
Summer	2022.08.13 - 2022.08.16	20.2 - 30.8	57.3 - 73.7	0.091
Autumn	2022.11.08 - 2022.11.11	12.9 - 18.7	36.3 - 76.8	0.147
Winter	2023.02.17 - 2023.02.20	-5.6 - 2.1	48.3 - 84.8	0.191

To describe the seasonal variation of early VOC emissions from kitchen waste bins in a consistent and comparable way, each experiment lasted for three consecutive days, and the average concentrations were presented as the seasonal variation. MSW regulations in China require that solid waste stored in residential area remain there for no more than 24 h, and to reflect these conditions the daily variation in the emission of VOCs in each season was analyzed within the first 24 h after collection. Kitchen waste was collected within 12–24 h of disposal in residential waste bins. Then a 3-day VOC emission test was conducted for each sample. Gas samples were collected from the breathing zone above the waste bin (at a height of 1.5 m above the ground) using a Summa canister (ENTECH, USA) with an effective volume of 3.2 L [19]. Samples were collected every 6 h by opening the lid of the waste bin and each gas sample was collected for 30 s. Additionally, solid HMSW was collected in accordance with the standard CJ/T 313–2009. Sampling intervals were 12 h and 40 g samples were collected in the waste bin each time. All the gas samples and solid samples were tested within 24 hours. Meteorological conditions such as temperature, humidity and ozone concentration were listed in Table 1. Detecting methods were listed in the supplementary material.

2.2. Assessment of odor pollution - Odor index calculation

The Ministry of the Environment of Japan (MOE) and the United States Environmental Protection Agency (USEPA) have conducted numerous studies on olfactory thresholds and established values for 262 common odors [20,21]. This study primarily used the odor thresholds from the MOE. In case of missing values, the data from the USEPA was used, with specific values presented in Table S1. The odor index for each substance was determined using the ratio of its concentration to the corresponding olfactory threshold, as presented in Eq.(1) [22–24].

$$OI_i = \frac{C_i}{OT_i} \tag{1}$$

Where: OI_i is the odor index of odorant i, dimensionless; C_i is the concentration of odorant i in the gas sample, μg/m^3; OT_i is the olfactory threshold of odorant i, (μg/m^3).

2.3. Statistical analysis

The correlation analysis of VOCs concentrations, meteorological conditions and the physical and chemical properties in all samples were done using SPSS 27.0 statistical software. Subsequently the main influencing factors were screened out based on the statistical significance (P) and correlation coefficient (r).

3. Results and discussions

3.1. Temporal variation of physical and chemical properties of kitchen waste samples

Physical and chemical properties in all samples were listed in Table S2 in the supplementary material. The results showed that the mean pH, MC, and VS in kitchen waste from a residential area in Beijing were 3.84 ± 0.60, 74.95% ± 8.57%, and 88.30% ± 4.70%, respectively. The average value of these properties of kitchen waste based on national statistical data were investigated in previous research and were

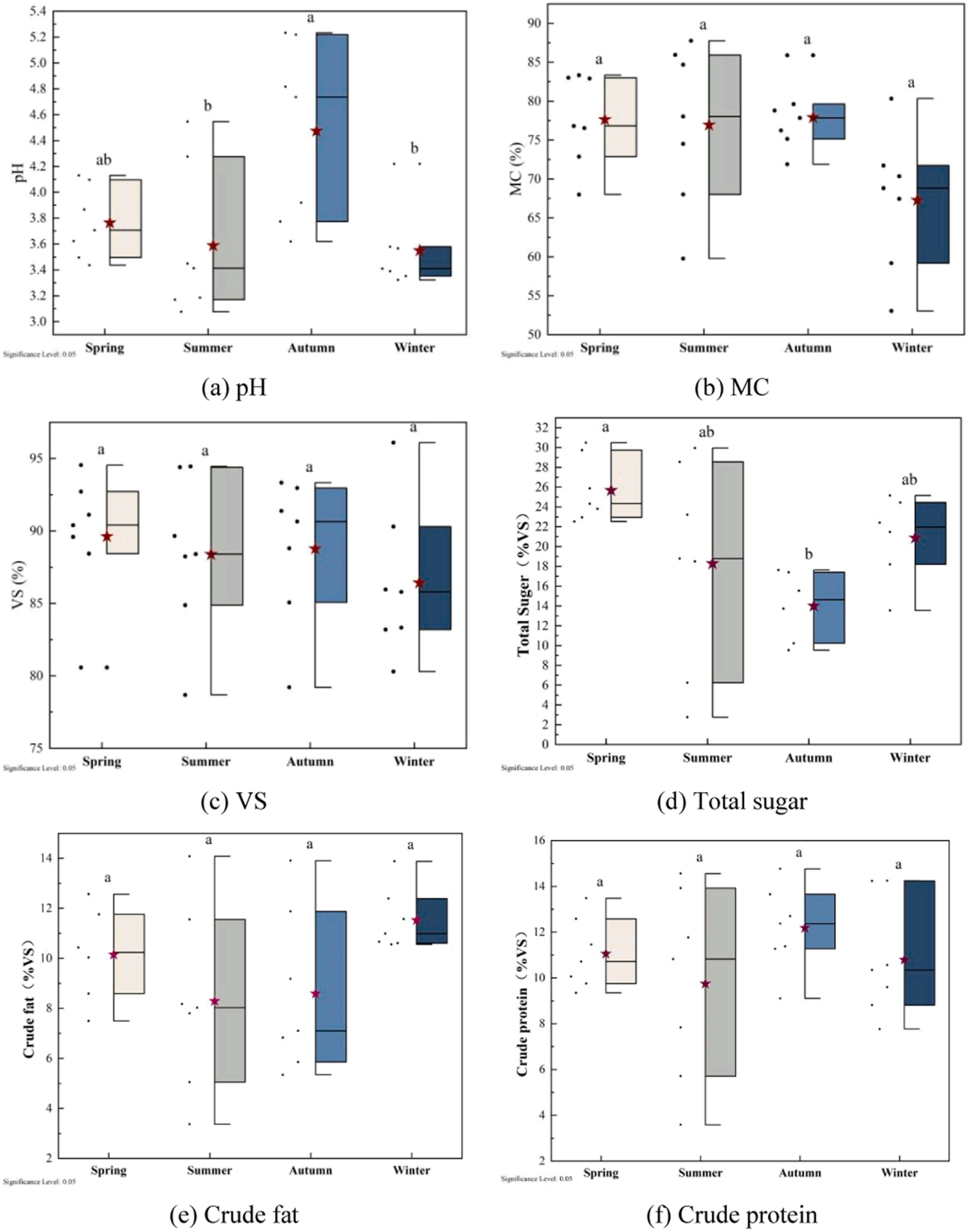


Fig. 1. Distribution of HMSW indicators in four seasons. (The star represents the mean value and the horizontal line in the box represents the median value).

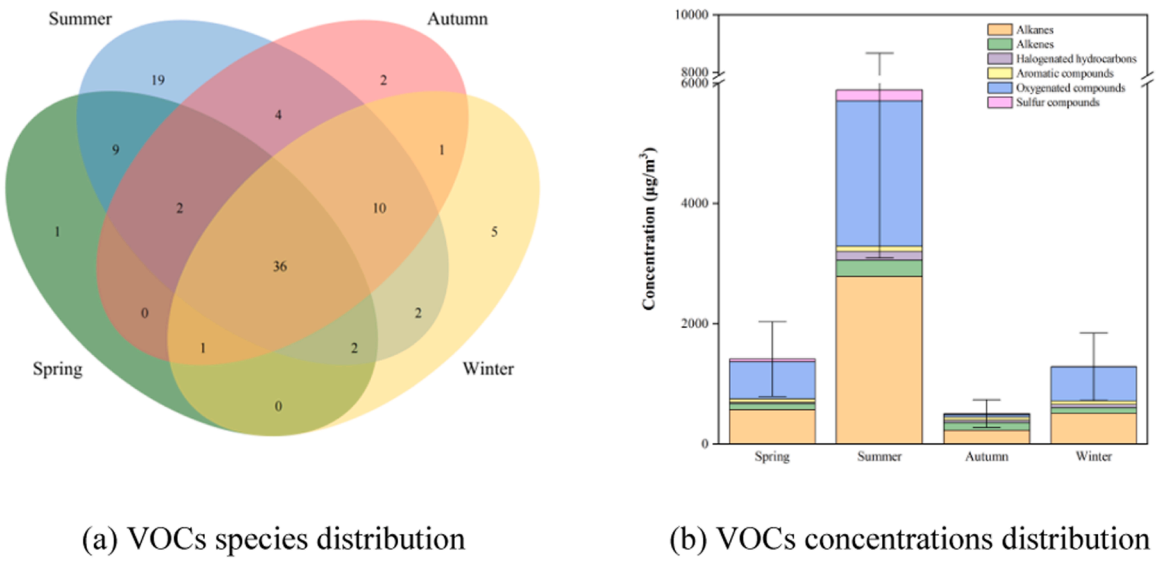


Fig. 2. Seasonal distribution characteristics of VOCs.

as follows, MC (80.05% ± 6.88%), VS (81.05% ± 11.81%), which is consistent with our experimental results [25]. Subsequent analyses also revealed seasonal variation in the physical properties of kitchen waste. VS were highest in summer (89.63%) and lowest in winter (86.43%), while MC was relatively high in autumn (77.92%) and lower in winter (67.28%). The maximum pH value was found in autumn (4.47) and the minimum in winter (3.55). The main reason for the differences in pH, MC and VS between seasons was the variation of the MSW components, mainly from the vegetable and fruit residues which were significantly different between seasons. Statistical analysis of these indicators using one-way Anova showed that MC and VS were not significantly different across seasons (Fig. 1). However, the pH showed significant variation, which was closely related to the amount of vegetable and fruit residues found in HMSW.

Additionally, results indicated that the total sugar content in the kitchen waste exhibited seasonal variation, reaching its highest level in spring (32.45%) and lowest in autumn (22.94%); while crude protein showed the opposite trend, having the highest in autumn (15.39%) and lowest in summer (12.31%). For crude fat, the highest value was found in winter (14.56%) and lowest in summer (10.48%). The significant difference analysis of the chemical properties of kitchen waste was conducted, and the results showed no significant differences between crude fat and crude protein, while there was a significant difference in total sugar between spring and autumn (Fig. 1(d)). Further analysis showed that this was related to the composition of the kitchen waste (i.e. components of vegetable and fruit residues). The average value of these nutrients in kitchen waste samples (nationwide) were 42.7% ± 17.5% for total sugar, 21.7% ± 8.0% for crude fat and 17.8% ± 8.0% for crude protein [26]. It is obvious the nutrient content in this study was low. However, they were still within reasonable ranges.

3.2. Emissions of VOCs from the initial degradation of kitchen waste

93 VOCs were detected in all samples during the initial degradation of kitchen waste, including 27 alkanes, 12 alkenes, 16 halogenated hydrocarbons, 20 aromatic compounds, 17 oxygenated compounds and 1 sulfur compound. Of these, 36 VOCs were detected in all seasons (Fig. 2 (a)). Specifically, the species and average concentration of each substance were listed in Table S3 in the supplementary material. The average concentration of total volatile organic compounds (TVOCs) was 2271 ± 409 μg/m^3. Overall, the concentrations at terminal facilities were generally higher than those at mid-range and front-end facilities. Specifically, among terminal facilities, concentrations of VOCs (up to 15,000 μg/m^3) at composters, landfills, and incinerators (ranging from 5000 μg/m^3 to 10,000 μg/m^3) were higher than those at mid-range facilities such as transfer stations (around 3000 μg/m^3) and transfer trucks (around 500 μg/m^3) [13,14,27,28]. This study found that the emission characteristics of VOCs from residential kitchen waste were different from those of terminal facilities, mainly because both the VOCs species and their concentrations were different, and therefore the following three main reasons were hypothesized: First, waste components change from facility to facility, which has a significant impact on the VOC components as well as concentration. Waste from front-end facilities has a relatively simple composition, whereas that in the terminal facilities can become more complex, involving industrial waste, sewage sludge, plastics, etc. Second, the emission of VOCs from the same material changes at different degradation stages. In different facilities kitchen waste will be at a different stage of biodegradation. In general, waste in terminal facilities is at a later stage of degradation, affecting the characteristics of VOCs. For instance, when comparing the emissions of VOCs between transfer stations and waste bins there was a significant difference between them as those in the former were dominated by ethanol while aldehydes and esters were dominant in the latter. Third, tailpipe emissions from terminal facilities (i.e., operating tools and transportation vehicles) can also contribute to composition and concentrations of VOCs, whereas those at front-end facilities are much less affected by the tailpipe emissions.

3.2.1. Seasonal variation of VOCs from the initial degradation of kitchen waste

The average concentration of VOCs emitted over 72-h was chosen when presenting and discussing the seasonal characteristics of VOCs emissions from kitchen waste bins.

The result showed that emissions of VOCs from the initial degradation of kitchen waste had a clear seasonal pattern with the highest values in summer (5882 ± 3317 μg/m^3), followed by spring (1413 ± 529 μg/m^3) and winter (1285 ± 606 μg/m^3), and the lowest in autumn (505 ± 192 μg/m^3) (Fig. 2(b)). Similar trends were observed at a MSW transfer station in Suzhou, where the average concentrations of VOCs were significantly higher in summer (65,867 μg/m^3) than in winter (337 μg/m^3) [17]. In addition, a landfill in Beijing was found to have concentrations of VOCs reaching 131,826 μg/m^3 in summer, which was 135 times higher than that in winter, demonstrating a very significant seasonal pattern [29]. This is due to higher extent of biochemical reactions under high temperatures in summer, resulting in a greater amount of decomposition of the perishable components in kitchen

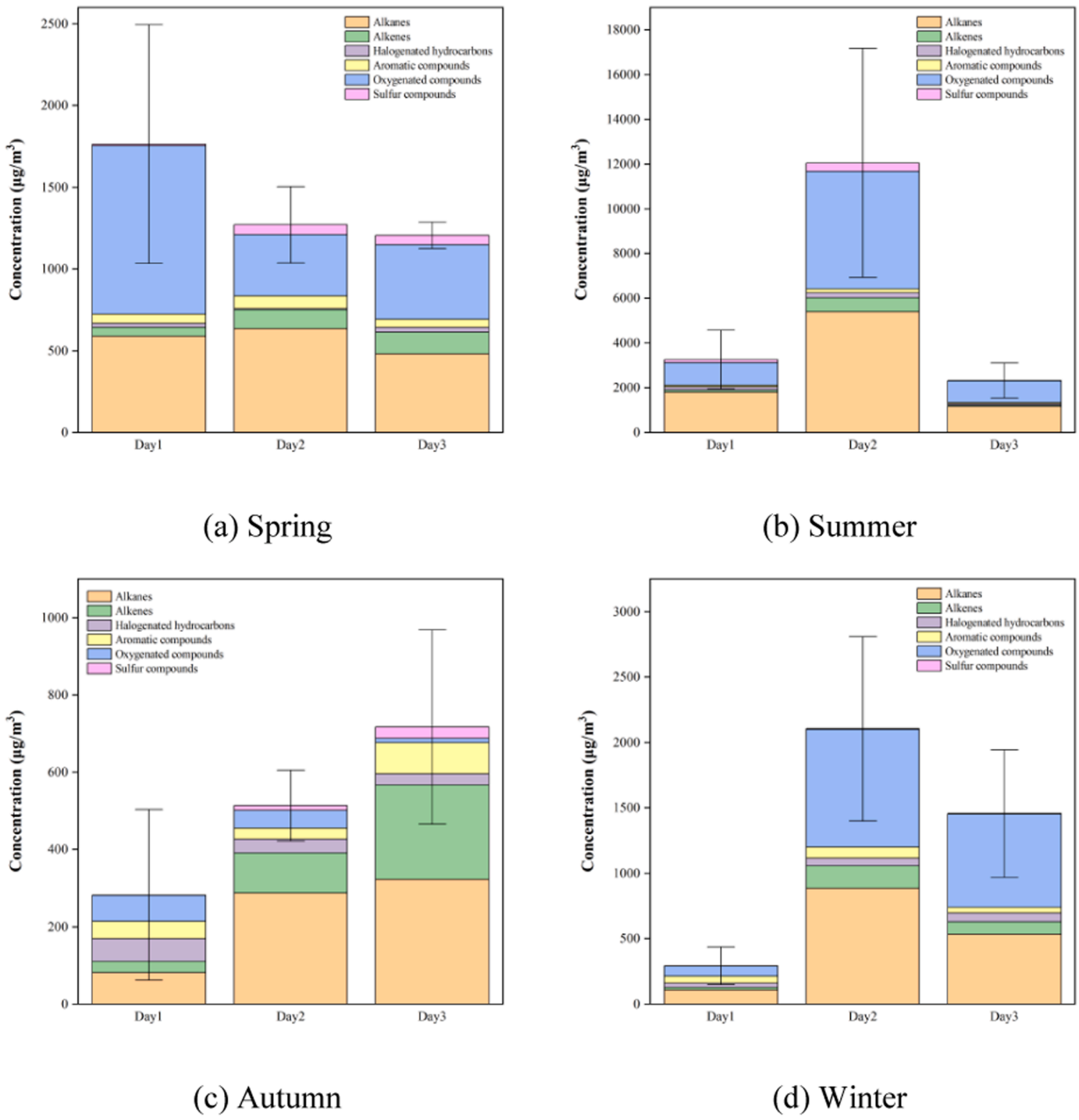


Fig. 3. Daily characteristics of VOCs in different seasons.

waste. During winter, the temperature difference between the interior of the waste bin and the ambient air was large, which caused a larger difference in atmospheric pressure, promoting a higher emission of VOCs than in winter. The main mechanism for landfill odor emission in winter was explained by a previous study as being due to the large difference between the temperatures of the internal part of the landfill and the ambient air, which could also boost the emission of VOCs by accelerating their migration from within the landfill to its surface [10]. Continuous steam up-flow was observed on the working surface in winter, indicating an upward gas migration trend from inside the landfill.

Composition analysis of the VOCs showed that oxygenated compounds (909.56 μg/m^3) and alkanes (1024.43 μg/m^3) were dominant in all seasons. More specifically, oxygenated compounds contributed the most in spring and winter, accounting for 43.9% and 43.8% of TVOCs, respectively. In contrast, alkanes had the highest percentage of TVOCs in summer and autumn, accounting for 47.4% and 45.7%, respectively. A previous study also showed that oxygenated compounds and alkanes were the main products of kitchen waste [30]. Specifically, alkanes mainly come from organic substances such as oils, fats, proteins, and starches in kitchen waste [19,31] and oxygenated compounds are mainly derived from organic substances such as starch, protein, and

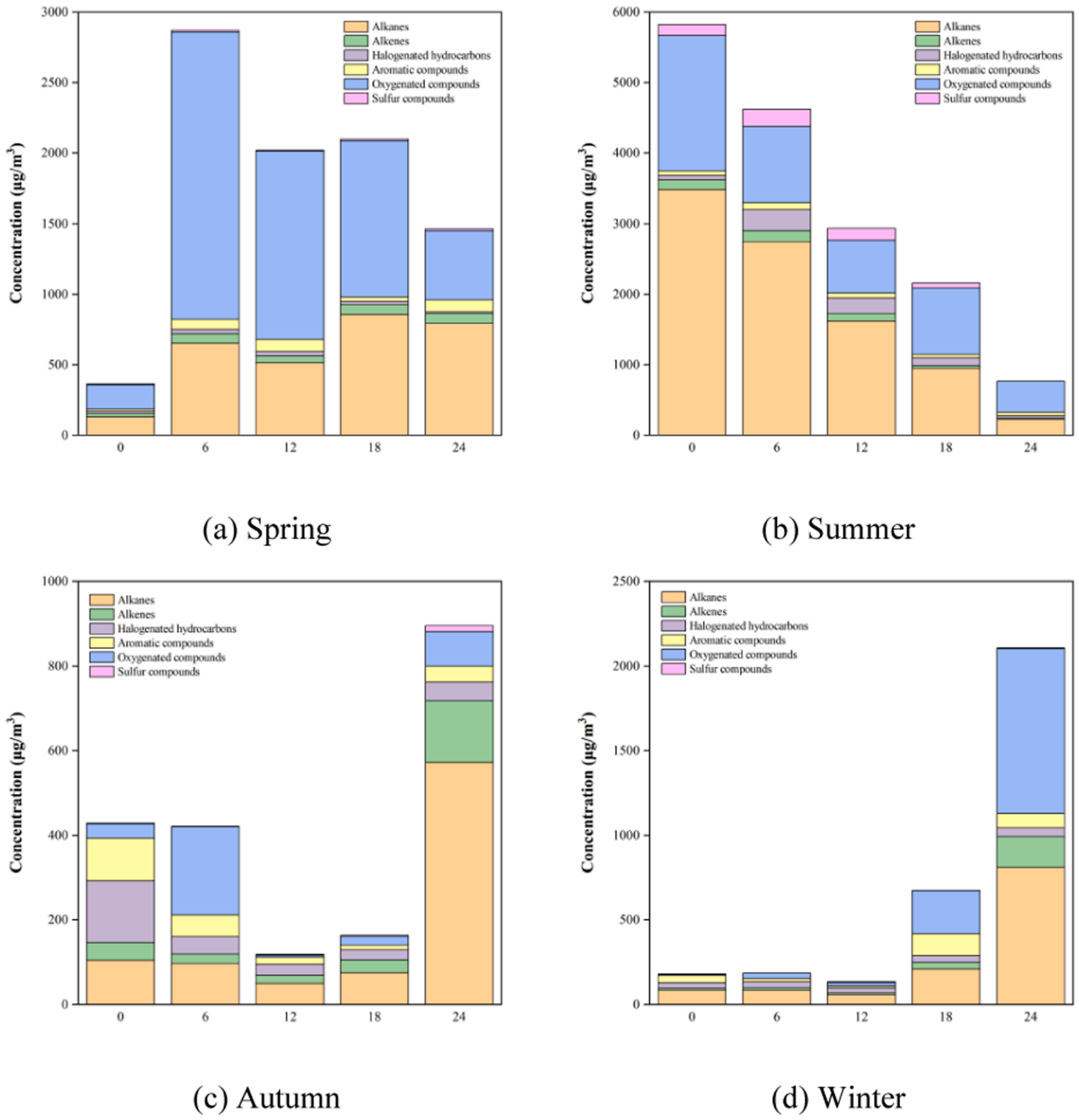


Fig. 4. Characteristics of first-day varations of VOCs in different seasons.

cellulose [32,33].

3.2.2. Daily variation of VOCs from the initial degradation of kitchen waste

The average concentration of VOCs emitted over 24-hours was caculated for characterizing the daily variation. Hence, the average concentration of VOCs emitted from HMSW during 0–24 h, 24–48 h, and 48–72 h represented the daily variation of the first day, second day, and third day, respectively (Fig. 3). In general, the daily variation of TVOCs emission showed interactions with seasons. Mean concentrations of TVOCs in spring were highest on the first day (1763 ± 730 μg/m^3) and then decreased. In summer and winter TVOCs reached their maximum concentration on the second day, with a concentration of 12054 ± 5120 μg/m^3 and 2105 ± 703 μg/m^3, respectively. During autumn, in contrast, TVOCs increased over time and reached maximum concentrations on the third day (757 ± 252 μg/m^3), which was significantly lagging behind compared with other seasons. Therefore, peak emissions of VOCs from kitchen waste occurred earlier in spring than in other seasons. Nevertheless the concentration of TVOCs was much lower than that at the same time in summer. Only one sulfur compound (carbon disulfide) was detected in this study. As can be seen in Fig. 3(b), the CS_2 released on the second day reached 380.08 μg/m^3, which was 3 times that of the first day (127.76 μg/m^3). In other seasons the

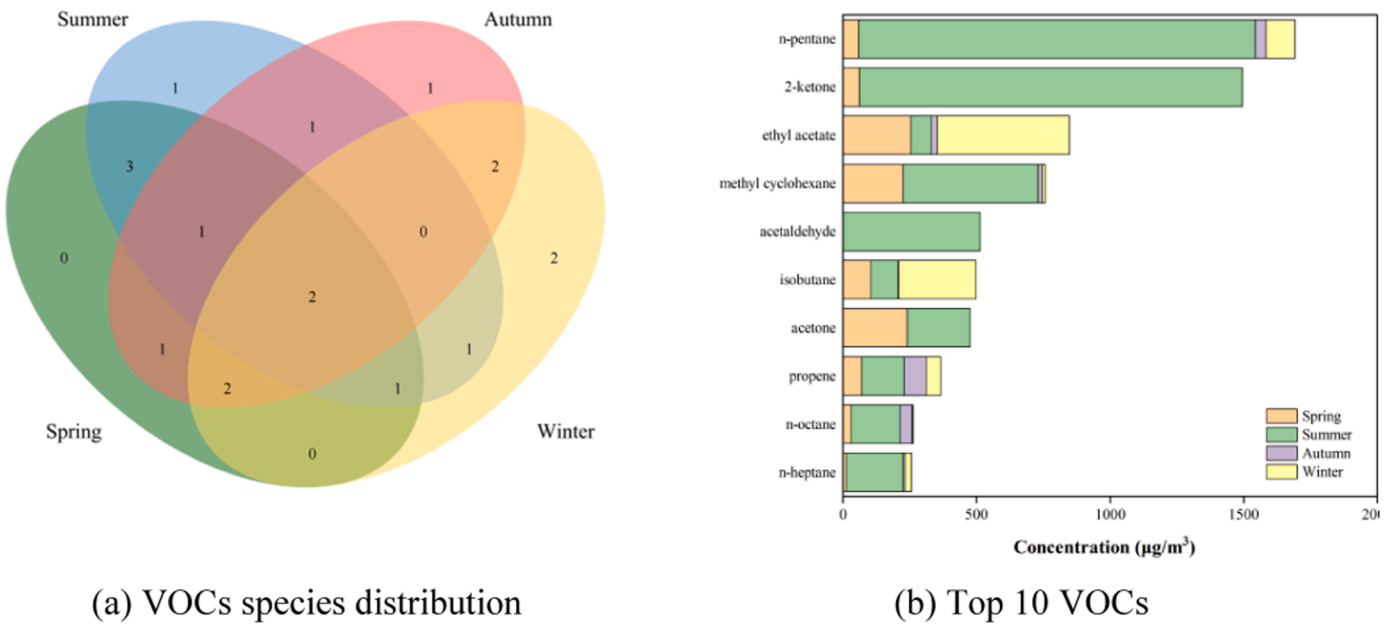


Fig. 5. Top 10 VOCs emitted from waste bins.

concentrations of CS_2 were below 100 μg/m^3. A possible reason for the high levels of CS_2 in summer is that the higher temperatures leads to a greater amount of microbiological activity, and thus an increase in the generation CS_2 [34,35]. It is important to mention that even during the aerobic treatment of food waste anaerobic conditions can exist through the formation of dead zones, and thus reduced S compounds (H_2S and CS_2) from S-containing amino acids can be generated. This was confirmed in a study by Yang et al. [36] that showed that sulfur compounds were the most important factor for the generation of odors from composting, which mainly originated from the degradation of sulfur amino acids under anaerobic conditions [36]. In our study, due to the rapid consumption of O_2 in the waste bins during summer, there were anoxic and anaerobic niches in the kitchen waste leading to larger amount of CS_2 formation and emission [37].

Due to the urban sanitation requirement and MSW management policy in China, storage of MSW in waste bins in residential areas should be less than 1 day. Therefore, further study focused on the emission characteristics for the first day in different seasons (Fig. 4). The peaks in spring and summer appeared roughly at 6 h and decreased subsequently. This might be due to the higher temperatures in spring and summer, which were favorable for microbial and enzymatic activity, leading to intensified generation and release of VOCs [38]. In addition, oxygenated compounds, as the main contributors to VOCs, are mainly derived from the degradation of microorganisms, which are more active at high temperature [10,39,40]. Whereas the delayed emission peaks of VOCs in autumn and winter were due to lower ambient temperatures and led to reduced microbial and enzymatic activity. On the other hand, temperature differences which create the so called “chimney effect” became an important driving force in flushing VOCs from the MSW facilities in winter [41].

Finally, analysis of VOCs released on the first day of all seasons showed that alkanes and oxygenated compounds were the dominant categories, and the sum of the two accounted for more than 85% of TVOCs. Moreover, higher concentrations of oxygenated compounds than alkanes were released in spring and winter, while summer and autumn had the opposite trend.

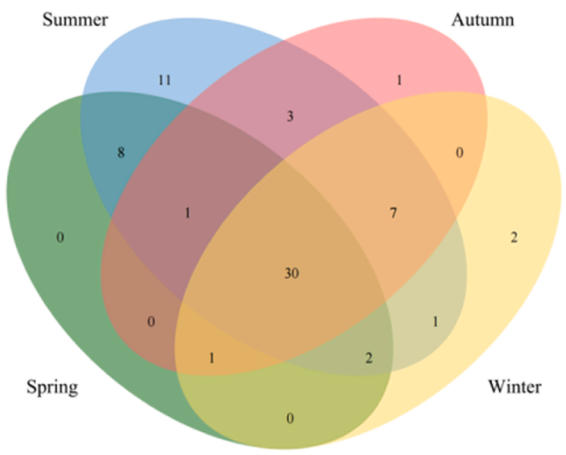
3.3. Identification of key VOCs

3.3.1. Key VOCs with high concentration

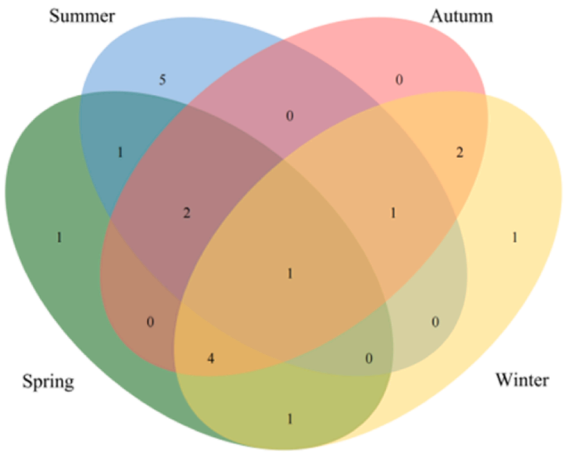
Based on the above results, the top 10 substances were further screened out according to the mean value of their concentrations in each season. N-pentane and propane were detected in all seasons, acetaldehyde was detected only in summer, n-butane was detected only in autumn, and dichloromethane and 1-butene were detected only in winter (Fig. 5(a)). The top ten substances were further screened according to their average concentrations, and the results were shown in Fig. 5(b). Among them, the individual compound with the highest concentration was n-pentane (1691 μg/m^3), followed by 2-ketone (1496 μg/m^3) and ethyl acetate (847 μg/m^3). Nevertheless, the dominant species varied between seasons. In spring, the main VOCs were ethyl acetate (254 μg/m^3) and acetone (240 μg/m^3). In summer, the main VOCs were n-pentane (1483 μg/m^3) and 2-ketone (1434 μg/m^3). In autumn and winter, the main VOCs respectively were propylene (84 μg/m^3) and ethyl acetate (496 μg/m^3). There are two main reasons for the different VOCs in different seasons: First, the waste components change from season to season, leading to significant impact on the VOC components as well as concentration [42]; Second, the VOCs emission from the same material change at different degradation stages of the process. In different seasons kitchen waste may undergo different stages before they were placed into the waste bin of communities [43]. In general, seasons with higher temperature (summer) cause further degradation while those with lower temperature season (winter) can delay the degradation [44]. Also, when comparing the VOCs emissions between transfer stations and waste bins there was a significant difference between them as those in the former were dominated by ethanol while aldehydes and esters (95.9%) were dominant in waste bins [17].

3.3.2. Key VOCs with high odor index

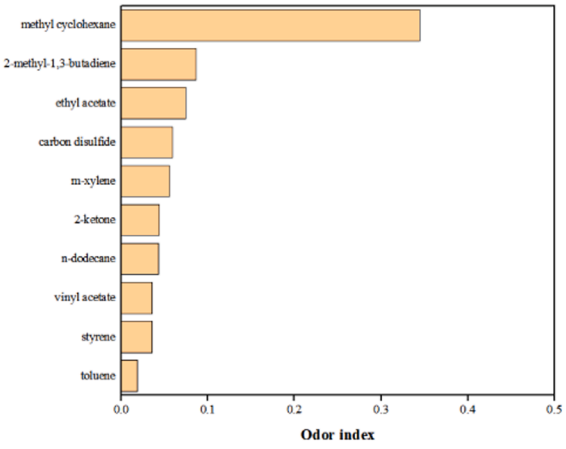
According to the MOE database (2003), 67 substances were detected in the aforementioned ambient samples, including 22 alkanes, 6 alkenes, 8 halogenated hydrocarbons, 17 aromatic compounds, 13 oxygenated compounds, and 1 sulfur compound. The odor index of these VOCs was assessed based on Eq. (1) and the OI value of each substance was presented in Table S4 in the supplementary material. Among them, 30 substances were detected in all seasons, including 12 alkanes, 3 alkenes, 4 halogenated hydrocarbons, 7 aromatic compounds, 3 oxygenated



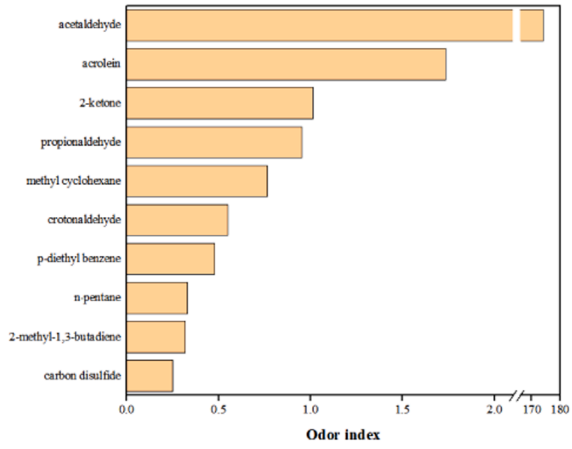
(a) Distribution of all VOCs with OI value



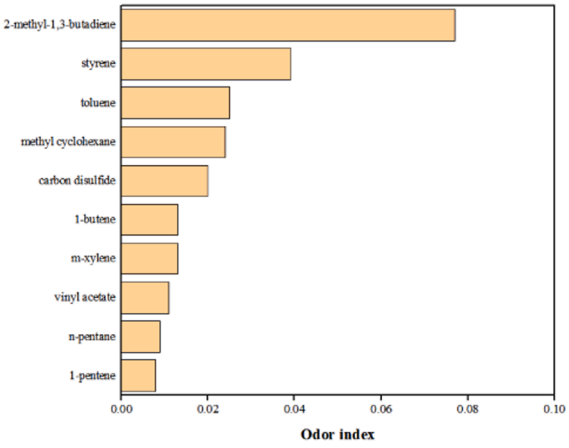
(b) Distribution of top 10 VOCs with OI value



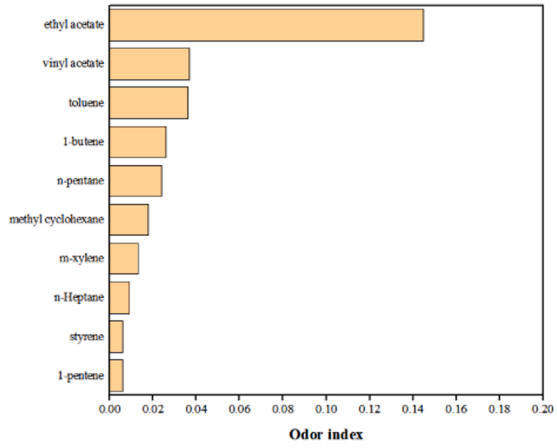
(c) Distribution of top 10 VOCs with OI value in spring



(d) Distribution of top 10 VOCs with OI value in summer



(e) Distribution of top 10 VOCs with OI value in autumn



(f) Distribution of top 10 VOCs with OI value in winter

Fig. 6. Top 10 VOCs with high odor index in each season.

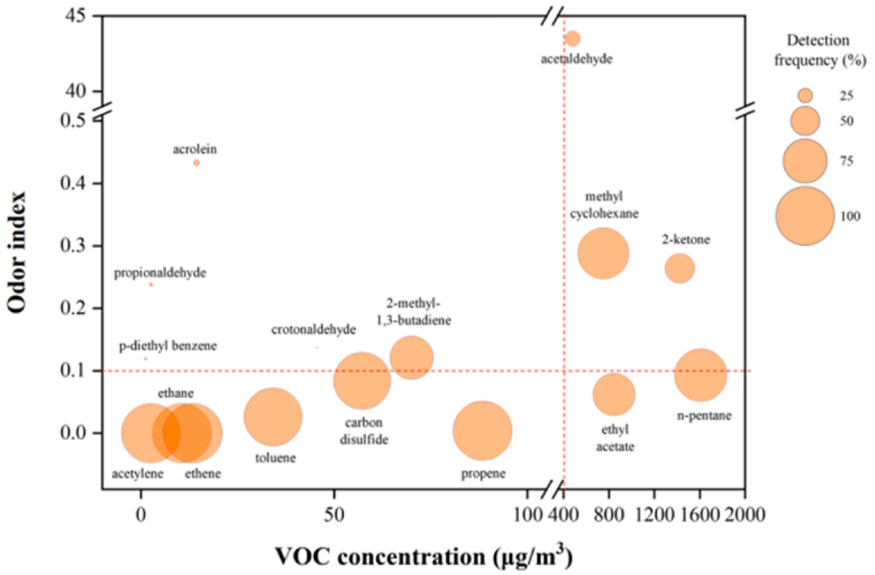


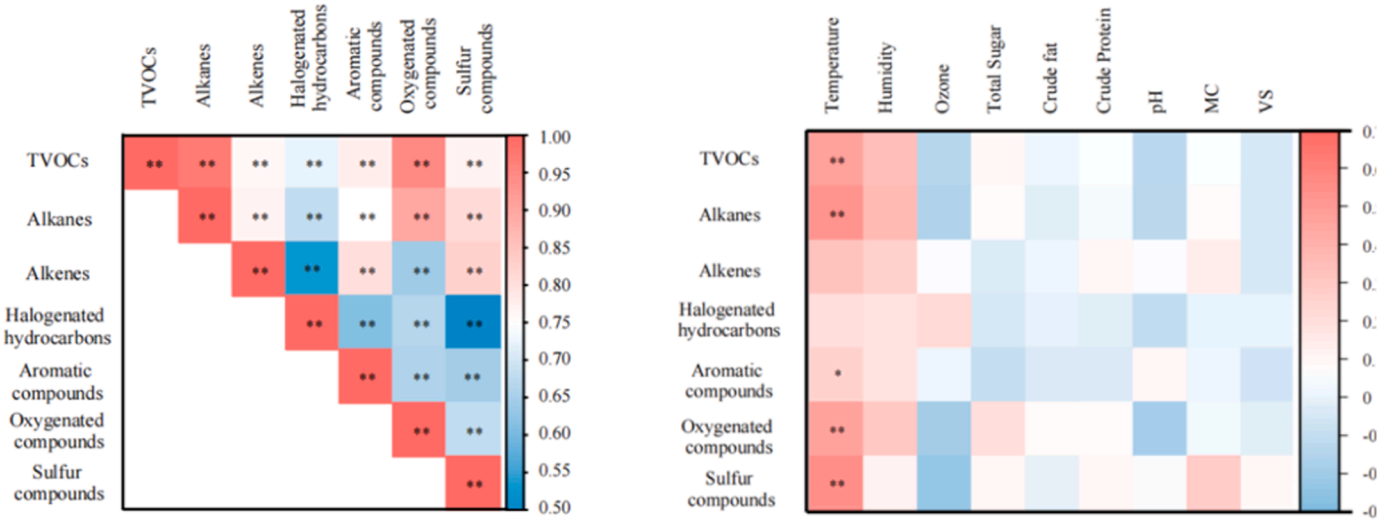
Fig. 7. The crucial VOCs emitted at the initial degradation of kitchen waste.

compounds, and 1 sulfur compound (Fig. 6(a)-(b)). 11 substances were detected only in summer, seven of which were oxygenated compounds. In addition, spring and winter-specific VOCs were n-dodecane, n-heptane, respectively.

The top 10 substances with high odor index in each season were shown in Fig. 6(c)-(f). Among them, methyl cyclohexane, acetaldehyde, 2-methyl-1,3-butadiene, and ethyl acetate were the top 10 substances with high odor index in spring, summer, autumn, and winter, with OI of 0.344, 174.0, 0.077, and 0.145, respectively. The results showed that the OI of acetaldehyde was much larger than the other substances in summer, mainly due to its high concentration (128.16 μg/m^3) and low olfactory threshold (0.0015). Moreover, acetaldehyde was detected only in summer. In addition, the OI values of acrolein (1.73) and 2-ketone (1.01) in summer were both found to be greater than 1, respectively. A study of VOCs released from different types of kitchen waste showed similiar results, VOCs released from vegetables had an odor index in the range of 3.69 - 27.8, while that in barbecue waste reached an odor index of 56.52 [45]. In addition, the OI value of methyl-cyclohexane, a substance common to all four seasons, was low, ranging from 0.018 to 0.77.

3.3.3. *Indentification of crucial VOCs*

VOCs emitted at the initial degradation of kitchen waste were identified as crucial VOCs if they meet one of the following three conditions, high detection frequency (> 95%), high concentration (average annual concentration > 400 μg/m^3), and high odor index (OI$_i$ > 0.1) (Fig. 7). A total of 18 VOCs were screened. Five substances with high detection frequency, including acetylene, ethene, propene, toluene, and carbon disulfide, had very low concentrations and low odor index. Four



(a) Between various types of VOCs

b) between various types of VOCs and meteorological conditions, physical and chemical properties

Fig. 8. Pearson correlation analysis of the main factors influencing the emission of VOCs.

substances (n-pentane, 2-ketone, ethyl acetate and methyl cyclohexane) were selected with high concentration, while eight substances with high odor index were screened, i.e. acetaldehyde, acrolein, methyl cyclohexane, 2-ketone, propionaldehyde crotonaldehyde, 2-methyl-1,3-butadiene, and p-diethyl benzene. It must be noted that acetaldehyde, 2-ketone and methyl cyclohexane requires particular concern because of its high concentration and high odor index.

3.4. Key influencing factors on the initial degradation of kitchen waste

The Pearson correlation analysis was performed on the 93 VOCs in all 52 samples. The results showed that concentrations of six major categories of VOCs were significantly correlated with each other ($P < 0.01$), with the correlation cofficient (r) ranging from 0.725 to 0.983 (Fig. 8(a)). Meanwhile, alkanes and oxygenated compounds were both significantly correlated ($P < 0.01$) with TVOCs, with a high correlation value of 0.983 and 0.976, respectively, confirming that they were both major contributors for the VOCs at the initial degrading of kitchen waste.

The physical and chemical properties of HMSW, i.e. pH, MC, and VS, were not significantly correlated with the concentration of VOCs (Fig. 8 (b)). Neither was the nutrient content of kitchen waste, i.e. total sugar, crude fat and crude protein, which implied that the organic matter in kitchen waste was over-saturated for the microorganisms and was not a limiting factor for microbial degradation and transformation in terms of emissions of VOCs. Considering the effect of meteorological conditions, temperature had an overall significant correlation with concentrations of VOCs, except for alkenes and halogenated hydrocarbons. It was significantly correlated ($P < 0.01$) with the concentration of sulfur compounds (0.629), alkanes (0.601) and oxygenated compounds (0.497) and was also highly correlated with aromatic compounds (0.425). However, the humidity and ozone concentration were not correlated with the emissions of VOCs. Further Pearson correlation analyses were also performed for each category of VOCs and the physical and chemical properties of HMSW and the meteorological conditions. The results were presented in Table S5 in the supplementary material. Neither the nutrient content nor the physical and chemical properties of HMSW and the meteorological conditions had a significant correlation with each category of VOCs.

4. Conclusion

The VOCs released during the initial stage of the degradation of kitchen waste in residential areas were mainly alkanes (1024 $\mu g/m^3$) and oxygenated compounds (910 $\mu g/m^3$), with small amounts of alkenes (146 $\mu g/m^3$), halogenated hydrocarbons (66 $\mu g/m^3$), aromatic compounds (65 $\mu g/m^3$) and sulfur compounds (60 $\mu g/m^3$). The emission characteristics were characterized by certain seasonal and daily variations, with the maximum concentration (5882 $\mu g/m^3$) usually occurring in summer. For the daily variation characteristics, the release peaked on the first day in spring, on the second day in summer and winter, while it was more lagged in autumn, reaching the peak on the third day. In terms of peak waste emissions under the waste policy in China, the peak emissions in spring and summer (at 6 h) appeared earlier than in autumn and winter (at 24 h). Out of the 93 VOCs detected, 67 could lead to odor pollution, especially oxygenated compounds. The OI value of acetaldehyde was the largest and much higher (1×10^{-6} - 1.73) than other species. In this study, temperature was found to have a significant effect on the release of oxygenated compounds and alkanes ($P < 0.01$). In addition, VOCs from kitchen waste with high conentrations and OI values fluctuated greatly among seasons.

This study clarified the compositions, seasonal characteristics, and daily characteristics of VOCs at the early degration stage of kitchen waste, and identified the key VOCs. It enriched the understanding of VOCs from kitchen waste and provided a theoretical basis for the prevention and control of odor pollution from front-end facilities handling kitchen waste.

CRediT authorship contribution statement

Zheng Xiangyu: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft. **Liu Yanqing:** Conceptualization, Writing – review & editing, Data curation**. Kong Boning:** Methodology, Writing – review & editing. **Bultinck Trevor:** Validation, Visualization, Writing – review & editing. **Lu Wenjing:** Funding acquisition, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jhazmat.2024.133479.

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