

Original Article



Differences in Volatile Organic Compounds (VOCs) Released by Fresh *Syringa* Flowers in the Frigid and Arid Regions of China Based on Metabolomics

Yan Xiaoyun¹, Ayalage¹, Tuoya¹, Dai Xuyang¹

¹College of Forestry, Inner Mongolia Agricultural University, Hohhot 010010, China

*Corresponding Author: Tuoya

Abstract:

This study aimed to reveal the differential distribution of volatile organic compounds (VOCs) emitted by *Syringa* species under natural conditions in semi-arid regions. Dynamic headspace sampling coupled with gas chromatography-mass spectrometry (GC-MS) was used to collect and analyze the VOCs emitted by flowers of lilac *oblata*, *Syringa pubescens* subsp. *microphylla*, and *Syringa reticulata* subsp. *amurensis*. The results showed that the flowers of *S. oblata*, *Syringa pubescens* subsp., and *Syringa reticulata* subsp emitted 57, 60, and 55 VOCs, respectively, belonging to 8, 7, and 7 classes. Significant differences ($P < 0.05$) were observed in the types and relative contents of VOCs emitted by the three species. Orthogonal partial least squares-discriminant analysis (OPLS-DA) showed a prediction accuracy of 96.8% for distinguishing the VOCs emitted by the three species. Among the VOCs, 14, 8, and 16 compounds were upregulated in *S. oblata*, *Syringa pubescens* subsp., and *Syringa reticulata* subsp, respectively. The main components of VOCs emitted by *S. oblata* were 1-caryophyllene, ocimene, and linalool; those emitted by *Syringa pubescens* subsp. were δ -cadinene, heptadecane, and methyl benzoate; and those emitted by *Syringa reticulata* subsp were m-xylene, o-cymene, and thujopsene. These results provide a deeper understanding of the differences in the types and components of VOCs emitted by *Syringa* species in cold and arid regions of China, offering references for the rational configuration of landscape plants and the selection of potential health-beneficial tree species.

Keywords: Volatile organic compounds; Plant metabolomics; *Syringa*; Gas chromatography-mass spectrometry

Introduction

Plants synthesize and emitted low-boiling-point, small-molecular-weight secondary metabolites during growth and development, collectively known as volatile organic compounds (VOCs) (Dudareva et al., 2004). VOCs emitted by plants play a crucial role in atmospheric environments, ecosystems, and plant interactions. It is estimated that global plant emissions account for approximately 90% of total VOC emissions, significantly impacting atmospheric chemistry, climate change, and ecosystem functions (Schillmiller et al., 2009). In the study of plant VOC emissions, species differences are an important factor. Different species emitted varying types and quantities of VOCs due to

differences in physiological characteristics and genetic backgrounds (Olsson et al., 2009; Feng et al., 2008). For example, conifers like *Pinus tabulaeformis* primarily emitted monoterpenes, while broadleaf trees like *Quercus robur* emitted a variety of VOCs, including isoprene, monoterpenes, and sesquiterpenes (Zhou et al., 2010; Wang et al., 2013; Cui et al., 2004). These differences not only affect the growth, defense, and reproductive strategies of plants but also influence the surrounding environment and other organisms.

China's cold and arid regions are vast and provide unique ecological conditions for the growth of various plants. *Syringa* species are widely

distributed in these regions and hold significant ecological and ornamental value (Agola *et al.*, 2023). However, research on VOC emissions from *Syringa* species in these regions is relatively limited. *S. oblata*, *Syringa pubescens* subsp. *microphylla*, and *Syringa reticulata* subsp. *amurensis* are common and representative species within the *Syringa* genus, yet the differential distribution of VOCs emitted by their flowers has not been thoroughly studied. *S. oblata* exhibits strong cold and drought resistance (Huo *et al.*, 2011) and is widely distributed from the Qinling Mountains to regions such as Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Shandong, Shaanxi, Gansu, Sichuan, Yunnan, and Tibet, as well as cultivated in temperate regions worldwide (Cai *et al.*, 2014; Chen *et al.*, 2015). *Syringapubescens* subsp. is cold-, drought-, and poor soil-tolerant, with strong resistance to pests and diseases (Zhao *et al.*, 2010), and is native to Liaoning, Northwest, and North China, with some distribution in Central China (Wang *et al.*, 2014). *Syringa reticulata* subsp. is highly cold- and barren soil-tolerant (Zhang *et al.*, 2013) and is distributed in China, Korea, Japan, and the Russian Far East, with its primary distribution in Northeast China, Inner Mongolia, Hebei, Henan, Shanxi, Shaanxi, and Gansu (Yi *et al.*, 2013).

This study focused on the flowers of *S. oblata*, *Syringapubescens* subsp., and *Syringa reticulata* subsp. Using dynamic headspace sampling and GC-MS, the VOCs emitted by these flowers were collected and analyzed to determine the differences in types and relative contents. The results provide a theoretical basis for further research on plant community structure and ecosystem stability, as well as scientific guidance for the selection and configuration of urban landscape plants in cold and arid regions, thereby enhancing the environmental, climatic, and ecological service functions of landscape plants.

Materials and Methods

Materials

The experimental materials, *S. oblata*, *Syringapubescens* subsp., and *Syringa reticulata* subsp., were collected from the Inner Mongolia Academy of Forestry Sciences Arboretum in Hohhot, China (111°42'E, 40°49'N). Healthy, pest-free, and mechanically undamaged plants with low branching points and abundant flower buds were

selected during the bud, initial bloom, full bloom, and wilting stages under natural conditions.

Methods

VOC Collection

From April to June 2024, the flowering period was monitored, and VOCs emitted during the bud, initial bloom, full bloom, and wilting stages were collected. On clear, windless days, a QC-2 atmospheric sampler was used to collect VOCs from the three *Syringa* species at different flowering stages using dynamic headspace sampling. Sampling was repeated three times for each stage, with a gas flow rate of 100 mL/min and a sampling duration of 2 hours.

VOC Analysis

The VOCs emitted by the three *Syringa* species were analyzed using GC-MS. The GC (7890A, Agilent) conditions were as follows: a 30 m × 250 μm × 0.25 μm HP-5MS column; temperature program: initial temperature of 40°C (held for 4 min), increased to 250°C at 6°C/min (held for 3 min), then increased to 270°C at 10°C/min (held for 5 min). The MS (5975C, Agilent) conditions were: electron ionization (EI) at 70 eV, mass range of 28–450, interface temperature of 280°C, ion source temperature of 230°C, and quadrupole temperature of 150°C.

Data Analysis

GC-MS raw data were processed using MassHunter Workstation software (ver. B.08.00, Agilent Technologies) for peak identification and integration. Compounds were identified using the NIST 17 and Wiley 11 mass spectral libraries, with a match score >80% and retention index deviation <±20 units. Peaks detected in at least 75% of the samples were considered for analysis. The relative content of each compound was calculated using the peak area normalization method. Data were summarized and organized using Microsoft Excel 2010 and IBM SPSS Statistics 25, and cluster heatmaps and correlation heatmaps were generated using Origin 2023 and the Metware Cloud Platform.

Results and Discussion

VOC Composition Analysis

A total of 85 VOCs, including terpenes, alcohols, ketones, aldehydes, esters, acids, alkanes, and aromatic hydrocarbons, were detected in the three

Syringa species (Table 1). The types and relative contents of VOCs emitted by the three species showed significant differences (Figure 1). *S. oblata* emitted 8 classes of VOCs, with terpenes (44.28%) and aromatic hydrocarbons (14.88%) being the most abundant. *Syringapu bescens*

subsp. emitted 7 classes of VOCs, with terpenes (52.26%) and alkanes (7.22%) being dominant. *Syringa reticulata subsp.* emitted 7 classes of VOCs, with terpenes (46.71%) and aromatic hydrocarbons (11.59%) being the most abundant.

Tab. 1 Analysis of VOCs composition emitted from flowers in three *Syringa* species

Type	NO.	Compound	Molecular formula	Relative amount (%)			
				<i>S. oblata</i>	<i>Syringapu bescens subsp.</i>	<i>Syringa reticulata subsp.</i>	
Terpene	1	3-ethenylcyclooctene	C10H16	0.19±0.03	0.16±0.03	0.30±0.12	
	2	α-pinene	C10H16	25.87±3.43	30.81±5.36	34.44±4.36	
	3	LevL-β-ene	C10H16	1.98±0.02	1.93±0.66	1.59±0.21	
	4	α-cobiene	C15H24	—	0.45±0.18	0.14±0.03	
	5	3-Adventitene	C10H16	0.34±0.06	—	0.22±0.05	
	6	Dexterpane diene	C10H16	1.33±0.65	0.93±0.13	1.53±0.62	
	7	(3E)-3,7-dimethzine-1,3,6-trienes	C10H16	9.72±4.56	11.58±4.04	7.07±4.11	
	8	ocimene	C10H16	0.27±0.07	0.13±0.06	0.12±0.03	
	9	terpinolene	C10H16	0.93±0.4	0.29±0.26	0.56±0.13	
	10	isolongifolene	C15H24	—	0.67±0.17	0.4±0.17	
	11	alloocimene	C10H16	0.48±0.32	0.73±0.16	—	
	12	1-Sclerene	C15H24	0.8±0.02	0.37±0.19	0.47±0.09	
	13	1,2,4-methenoazulene,decahydr	C15H24	—	0.50±0.16	—	
	14	δ-cadinene	C15H24O	—	0.44±0.21	0.38±0.08	
	15	cedrol	C15H26O	1.52±0.34	1.32±0.20	—	
	16	longifolene	C15H24	—	—	0.2±0.05	
	17	thujopsene	C15H24	—	—	0.21±0.07	
	18	[1S-(1α,4α,7α)]-1,2,3,4,5,6,7,8-	C15H24	0.24±0.21	—	—	
	19	α-caryophyllene	C15H24	0.11±0.03	—	—	
	20	Asulphene	C15H24	0.5±0.11	0.44±0.09	0.41±0.02	
	21	1-isopropyl-7-methyl-4-methylene-1,2,3,	C15H24	—	—	0.36±0.17	
	22	1,6-cyclodecadiene,1-methyl-5-methylene-	C15H24	—	—	0.25±0.03	
	23	(+)-α-Leaf ene (+) - β - Celene	C15H24	—	0.25±0.08	—	
	24	3,7,11-trimethyl-1,3,6,10-dodecane-tetrene	C15H24	—	0.38±0.3	—	
	25	(-)-γ-Cadinene	C15H24	—	1.06±0.13	0.16±0.05	
	26	naphthalene,1,2,3,4,4a,7-hexahydro-1	C15H24	—	0.18±0.15	2.01±0.23	
	27	(E)-3-hexene-1-alcohol	C6H12O	—	0.1±0.08	—	
	Alcohols	28	camphor	C10H16O	0.31±0.03	0.32±0.17	0.92±0.15
		29	2-Adhaline ketone	C10H16O	0.76±0.34	0.59±0.14	—
		30	linalool	C10H18O	0.45±0.10	0.27±0.23	0.2±0.03

	31	2-Tsalol	C10H18O	—	—	0.80±0.25
	32	α -terpineol	C10H18O	2.83±0.97	1.89±1.79	1.92±0.43
	33	mentha camphor	C10H20O	—	0.17±0.06	0.36±0.01
	34	caryophyllic acid	C10H12O2	0.46±0.27	0.48±0.23	—
	35	methyl benzenecarboxylate	C8H8O2	—	0.25±0.15	0.36±0.19
Esters	36	2,2,6-trimethyl-1,4-cyclohexadione	C9H14O2	0.16±0.06	—	—
	37	menthyl salicylate	C8H8O3	0.3±0.08	0.42±0.35	0.55±0.24
	38	Sweet leaf acetone	C13H22O	0.32±0.02	0.44±0.16	0.16±0.08
	39	DDSA	C16H26O3	—	0.33±0.33	—
	40	methyl hexadecanoate	C17H34O2	0.62±0.22	0.53±0.21	0.2±0.10
	41	dibutyl phthalate	C16H22O4	—	0.11±0.04	—
Ketone	42	4,6,6-trimethyldihuan [3.1.1]Geng-3-ene-2-ketone	C10H14O	3.51±0.73	1.16±0.35	1.89±0.34
	43	trans-2-Octenal	C8H14O	1.43±0.45	1.01±0.98	0.88±0.20
	44	Adiphenylacetone	C10H12O	1.62±0.16	0.62±0.1	0.34±0.1
	45	dodecane	C12H26	0.9±0.37	2.71±0.51	—
	46	8-methyl-hepene	C18H38	—	0.6±0.55	0.52±0.15
	47	n-tridecane	C13H28	—	0.19±0.14	0.23±0.16
	48	tetradecane	C14H30	1.95±0.57	—	0.27±0.04
	49	2,6,10,14-tetramethyltetradecane	C21H44	—	0.21±0.16	—
Alkane	50	3-methylpentadecane	C16H34	—	0.72±0.35	0.15±0.02
	51	hexadecane	C16H34	0.31±0.08	0.17±0.08	0.12±0.04
	52	dioctylmethane	C17H36	—	—	0.6±0.02
	53	2,6,10,14-tetramethylpentadecane	C19H40	0.57±0.30	0.57±0.05	0.48±0.03
	54	2,6-diisopropyl naphthalene	C16H20	0.43±0.25	0.23±0.08	—
	55	octadecane	C18H38	—	—	0.16±0.05
	56	phytane	C20H42	—	0.33±0.20	—
	57	1,13-Tetradecadiene	C14H26	1.56±0.08	0.23±0.20	0.27±0.03
	58	nonadecane	C19H40	0.52±0.47	0.21±0.1	0.19±0.04
	59	eicosane	C20H42	—	0.16±0.03	0.15±0.09
	60	n-heneicosane	C21H44	0.53±0.26	0.26±0.07	0.16±0.02
	Aromatic hydrocarbons	61	ethyl benzene	C8H10	—	0.26±0.05
62		p-xylene	C8H10	1.19±0.78	0.75±0.32	2.1±0.04
63		m-xylene	C8H10	0.43±0.03	0.4±0.17	1.27±0.19
64		Interethyl toluene	C9H12	0.57±0.05	—	—
65		mesitylene	C9H12	1.05±0.53	0.52±0.12	0.80±0.55
66		Diethyl benzene	C10H14	3.51±1.54	2.5±0.33	0.85±0.52
67		Neighborhood isopropyl toluene	C10H14	—	—	1.35±0.30
68		(3E) -4,8-dimethyl non-1,3,7-triene	C11H18	0.91±0.32	0.46±0.15	0.56±0.02
69		(3E, 5E) -2,6-dimethyl-1,3,5,7-Octatetraene	C10H14	—	1.21±0.10	1.44±0.67
70		5-ethyl-3,5-dimethylbenzene	C10H14	—	—	0.80±0.45

	71	naphthalene	C10H8	—	0.37±0.13	—
	72	2-Methylnaphthalene	C11H10	0.6±0.28	—	—
	73	1,4-diacetylbenzene	C10H10O2	—	0.44±0.26	—
	74	bicyclo[3.1.1]hept-2-ene,2,6-dimethyl	C12H12	3.10±0.34	—	—
	75	2,3,6-trimethyl naphthalene	C13H14	—	—	0.13±0.01
	76	naphthalene,1,4,6-trimethyl-benzene,1,3-dimethyl-5-(phenylmethyl)-1,1'-biphenyl,3-(1-methylethyl)-	C13H14	0.78±0.44	0.95±0.29	0.43±0.13
	77	benzophenone	C15H16	—	—	0.22±0.02
	78	2,2',5,5'-tetramethylyl biphenyl	C16H18	—	—	0.62±0.07
	80	naphthalene,1,2,3-trimethyl-4-(1E)-	C16H18	1.82±0.68	—	—
	81	aldehyde C-9	C9H18O	0.34±0.06	0.3±0.10	0.21±0.11
	82	3-ethylbenzaldehyde	C9H10O	0.12±0.05	1.12±0.18	0.09±0.01
Aldehydes	83	Diformaldehyde	C8H6O2	0.17±0.14	0.31±0.20	—
	84	4-ethylbenzaldehyde	C9H10O	0.83±0.23	0.46±0.17	0.34±0.12
	85	capraldehyde	C10H20O	1.45±0.21	0.50±0.26	0.21±0.14
Acids	86	dibutyl succinate	C12H22O4	0.3±0.21	—	—
	87	2-Methyl methoxybenzoate	C9H10O3	0.28±0.19	—	—

Note: "-" is not detected.

Differential VOC emitted

As illustrated in Figure 1, the relative concentrations of 87 detected VOCs in three types of cloves were organized into a 9×87 matrix. Principal Component Analysis (PCA) was subsequently conducted using the Meiwei cloud platform (L. Eriksson *et al.*, 2006). The

contribution rates of PC1 and PC2 were determined to be 42.58% and 30.7%, respectively. The cumulative contribution rate of the extracted principal components reached 73.28%. The results indicate that the 9 samples are distinctly distributed across four quadrants without any overlap, thereby confirming significant differences among the samples.

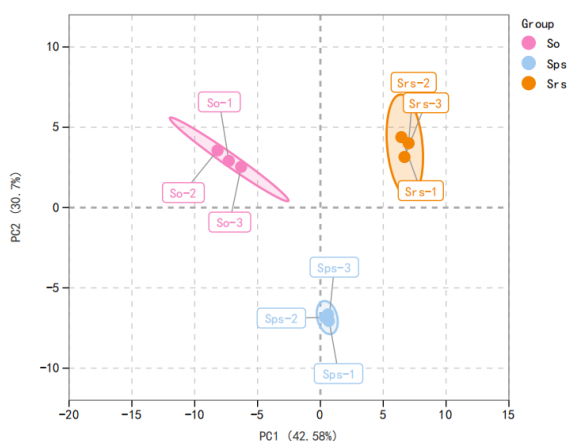


Figure 1 Principal component analysis of VOCs emitted from three lilac flowers

VOCs analysis of different floral components (including lilac flowers, Martin flowers, and others) revealed that terpene compounds constituted the largest proportion among all detected VOCs, both in terms of species diversity and relative content. Consequently, it was hypothesized that terpenes are the primary contributors to the volatile organic compounds emitted by lilac flowers and represent one of the key components responsible for their aroma. As shown in Figure 2, significant differences were observed between lilac flower groups in terms of terpenes, aromatic hydrocarbons, and seven other compounds. Additionally, alcohol compounds exhibited significant differences compared to esters and acids; ester compounds differed

significantly from ketones and alkanes; ketones and alkanes showed significant differences relative to aldehydes and acids. Furthermore, terpenes demonstrated significant differences with the seven other compounds, while no significant differences were noted between alcohols, esters, ketones, and aldehydes when compared to six compounds excluding terpenes. Significant differences were also identified between alkanes, aromatic hydrocarbons, and acids. Overall, significant variations were found among terpenes, aromatic hydrocarbons, and the seven other compounds, as well as between alcohols and esters, aldehydes and acids, ketones and acids, and alkanes and acids.

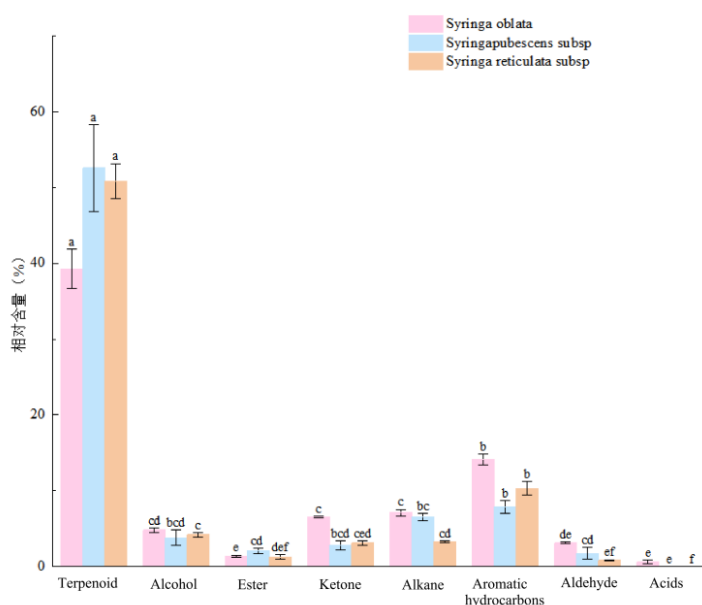


Figure 2 Relative content of VOCs species emitted by the three *Syringa* flowers

Note: Different lowercase letters above the column indicated significant difference between groups ($P < 0.05$).

According to Venn figure (Chen W *et al.*, 2014), after GC-MS analysis of VOCs volatilized by three kinds of lilac flowers, there were 34 kinds of VOCs components in the samples of lilac flowers, lilac flowers and Martin flowers.

The VOCs of lilac flowers, lilac flowers, and wild Martin flowers contain 10, 11 and 12 kinds of unique VOCs components respectively. The

specific components of lilac flowers are α -caryophyllene, m-ethyltoluene and 2-methylnaphthalene. The specific components of lilac flowers were (+) - α -robinene, (E) -3-hexene-1-ol, DDSA, dibutyl phthalate, phytane, ethyl benzene, naphthalene, etc. The unique components of the flower are m-xylene, o-isopropyl toluene and poikilene.

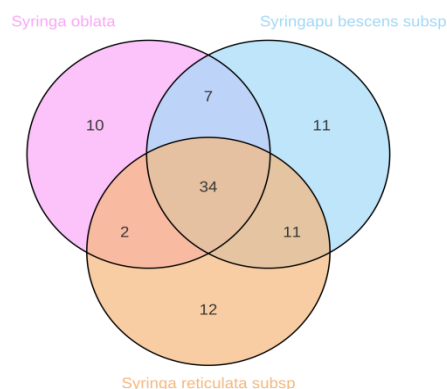


Figure 3 Venn diagram of VOCs emitted from 3 species of lilac flowers

OPLS analysis of VOCs volatilized from 3 kinds of lilac flowers

In order to better explain the difference between the VOCs components of three kinds of lilac flowers, OPLS-DA model (Thevenot et al,2015) was used to analyze the GC-MS relative content data of each sample, and the data were normalized and dimensionality reduced by supervised discriminant statistics. To realize visualization and discriminant predictive analysis of complex data results (DUDAREVA N et al.,2003).

As can be seen from FIG. 3 (a), VOCs emitted by three kinds of lilac flowers are clearly separated on the score chart. The R^2x value of the model is 0.632, the R^2y value is 0.998, and the Q^2 prediction index is 0.968, indicating that the differentiation prediction accuracy of VOCs emitted by three kinds of lilac flowers is as high as 96.8%. This result fully demonstrated that there were significant differences in VOCs of each component of the three lilac flowers. In order to verify the stability and fitting results of the established OPLS-DA model, 200 response

displacement tests were performed on the relative content data of VOCs emitted by three kinds of lilac flowers. the variable important in the projection (VIP) method was used to screen out the significant contribution of VOCs emitted by 3 kinds of lilac flowers. VOCs with VIP values greater than 1 mean that they contribute more to the differentiation between the sample groups, indicating more significant differences between the groups (GOUINGUENE SP et al,2002). According to the results in Figure 3 (c), 33 VOCs with VIP value greater than 1 were found, of which 10 were terpenes, including α -caryophyllene, 3-ethenylcyclooctene, lolene, Asulphene, etc. 4 alcohol compounds, including (E) -3-hexene-1-ol, linalool, camphor, etc.; 2 kinds of ester compounds, methyl benzoate and dibutyl phthalate; 1 ketone compound, which is p-ethyl acetophenone; 6 alkanes, including 1, 13-tetradecane diene, eicosane, octadecane, etc. 9 kinds of aromatic hydrocarbon compounds, including p-diethylbenzene, m-ethyl toluene, o-isopropyl toluene, etc. 1 type of aldehyde, capric aldehyde.

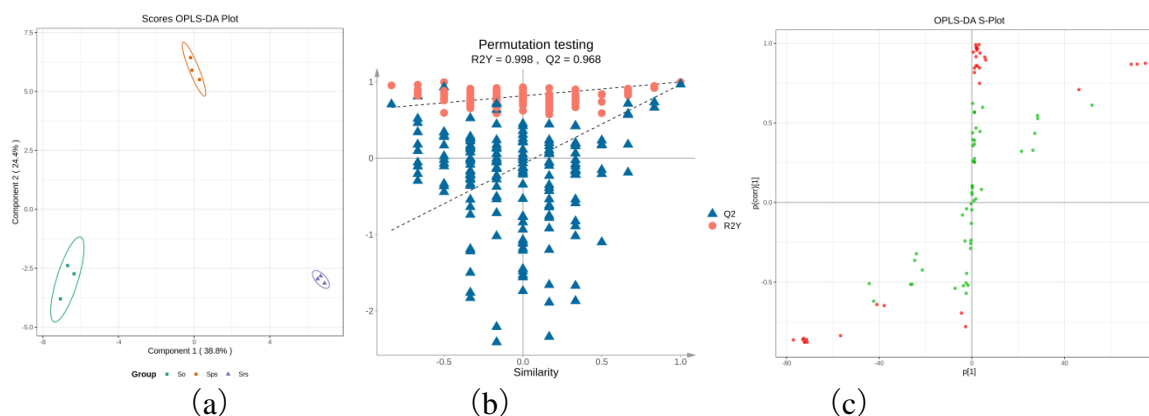


Figure 4 For the VOCs emitted by 3 species of lilac flowers, OPLS-DA model score plot (a), permutation test (b),S-plot graph(c)

In order to more directly and clearly reveal the contribution rate of different VOCs to the samples of each component of the three lilac flowers, $P < 0.05$ and $VIP > 1$ were selected as the screening conditions, and the relative content of 33 different VOCs identified was used to draw a clustering heat map (Jeon JE *et al.*, 2020), as shown in Figure 4. By analyzing the change of VOCs relative content from high to low in the cluster heat map (color changed from blue to orange), 14 VOCs with significant content in the VOCs samples of lilac flowers were identified, including 8 terpenes, 2 aromatic hydrocarbons, 1 alkanes, ketones, alcohols and aldehydes. In the VOCs samples of lilac flowers, there were 8 VOCs, 1 terpenes, 1 alcohols, 2 alkanes and 2 esters. There were 16 kinds of VOCs, 5 kinds of terpenes, 5 kinds of aromatic hydrocarbons, 3 kinds of alkanes, 2 kinds of alcohols and 1 kind of esters in the VOCs samples. The metabolites of *m*-ethyltoluene, α -

caryophyllene, Alpha-pinene, octadecane, 1, 13-tetracylandiene, cedryl, *p*-diethylbenzene, 3e-4, 8-dimethyl nonon-1,3, 7-triene, *p*-ethylacetophenone, 1-caryophyllene, basil, linallinol, capric aldehyde and balsamene were up-regulated in the VOCs samples of lilac flowers. Metabolites such as dibutyl phthalate, *e*-3-hexene-1-ol, eicosane, delta-juniperene, heptadecane, methyl benzoate were up-regulated in VOCs samples of lilac flowers. Camphor, delta-cidene, longifolene, *n*-tridecane, heptadecane, tetracecane, menthol, methyl benzoate, *m*-xylene, *o*-isopropyl toluene, lohamber, 2, 2,5, 5-tetramethylbiphenyl, 2, 3, 6-trimethylnaphthalene, 3-ethenylcyclooctene, 1-benzyl-3,5-dimethylbenzene, 1,6-dimethyl-1,2,3,4,4A,7-hexahydronaphthalene and other metabolites were upregulated in the VOCs samples.

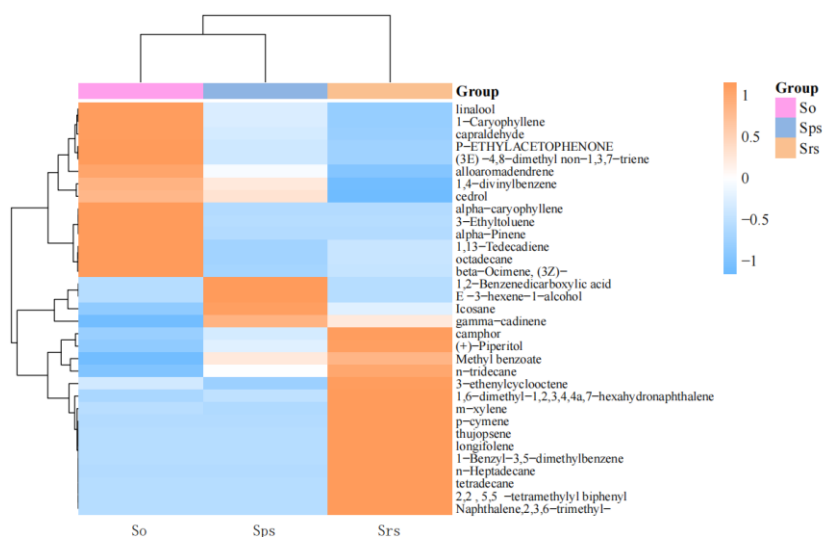


Figure 5 Heatmap of differential VOCs clustering emitted by the three *Syringa* flowers

Further analysis of KEGG metabolic pathways showed that these different VOCs were mainly derived from sesquiterpenoid biosynthesis, limonene and pinene degradation pathways, and terpenoid and steroid biosynthesis. The activity and regulation patterns of these metabolic

pathways are different among different lilac species, which may be related to their adaptation strategies to different ecological environments, providing a new perspective for understanding the environmental adaptation mechanism of lilac in cold and arid regions.

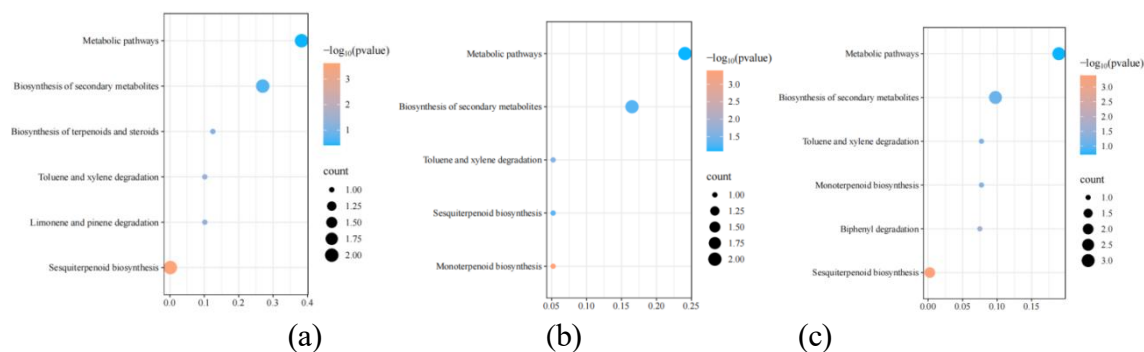


Figure 6 KEGG enrichment map of lilac *oblata* VOCs (a), KEGG enrichment map of lilac *pubescens* subsp VOCs (b), KEGG enrichment map of lilac *reticulata* subspVOCs (c)

Discussion

Volatile Organic Compounds (VOCs) emitted by the fresh flowers of three species of lilac in the frigid and arid regions of China. In order to study the VOCs of different fresh *Syringa* flowers, the VOCs of the fresh flowers of lilac *oblata*, *Syringapu bescens* subsp and *Syringa reticulata* subsp., were collected and analyzed by the dynamic headspace method and gas chromatography-mass spectrometry (GC-MS). The analysis showed that terpenoids and aromatic hydrocarbons were the most abundant compounds among the volatile components. Terpenoids had the highest content in the VOCs emitted by the fresh flowers of the three species of lilac, followed by aromatic hydrocarbons. As for acids, they were not detected in the VOCs emitted by the fresh flowers of the other two species of lilac except for *S. oblata*. Therefore, it is speculated that the proportion and relative content of the components vary among different varieties. The reasons for the differences in species may be multifaceted. Different plant varieties have their own distinct genetic backgrounds and physiological characteristics. For instance, there are differences in the regulatory mechanisms of different *Syringa* species during processes such as photosynthesis, respiration, and secondary metabolism. These differences affect the activities of various enzymes in the internal metabolic pathways (POTT M B *et al*, 2004; GERSHENZON J *et al*, 2000; DEGENHARDT J *et al*, 2009), which in turn lead to differences in the types of synthesized VOCs and their relative emitted contents. Moreover, the experimental tree species grow in the special environment of the frigid and arid regions. In order to adapt to

different ecological environments, attract specific pollinators, and resist specific pests and diseases, through long-term natural selection, they have evolved different VOCs emitted patterns to better survive and reproduce in the ecosystem (GOUNGUENE S P *et al*, 2002; LICHTENTHALER H K *et al*, 1999). For example, *S. oblata* may attract a wider variety of pollinating insects by releasing a relatively large amount and a rich variety of alcohols, terpenoids and other substances (DEGENHARDT J *et al*, 2009). *Syringa reticulata* var. *amurensis* forms a unique aroma with terpenoids and aromatic hydrocarbons, and conducts information exchange and ecological interaction with other organisms in its distribution area (Guenther A *et al*, 1995; TOWNSEND B J *et al*, 2005).

There are significant differences in the relative contents of Volatile Organic Compounds (VOCs) emitted by the fresh flowers of three species of lilac in the frigid and arid regions of China, and such differences have important ecological adaptation significance. *S. oblata* Lindl. mainly consists of α -caryophyllene, ocimene and linalool. *Syringa pubescens* Turcz. var. *microphylla* (Diels) M. C. Chang *et* X. L. Chen is characterized by δ -cadinene, heptadecane and methyl benzoate. While *Syringa reticulata* (Blume) H. Hara var. *amurensis* (Rupr.) J. S. Pringle mainly emits *m*-xylene, *o*-cymene and thujopsene. These different composition patterns of VOCs reflect the adaptive evolution of different *Syringa* varieties to specific ecological environments.

Through the analysis of the relative content data of GC-MS of each sample by the one-way analysis of variance (ANOVA) and the orthogonal partial least squares discriminant analysis (OPLS-

DA) model, it was found that VOCs with a variable importance in the projection (VIP) value greater than 1 mean that they have a high contribution rate in the discrimination among sample groups. A total of 33 kinds of differential VOCs with VIP > 1 were screened out, among which there were 10 kinds of terpenoid compounds, including α -caryophyllene, ocimene, aromadendrene, etc. This difference may be the result of different reproductive strategies adopted by the three species of lilac. In the frigid and arid regions, the types and quantities of pollinating insects are limited. *Syringa* attracts specific pollinators by releasing specific combinations of VOCs to improve the pollination efficiency. For example, the high content of linalool in *S. oblata* Lindl. has a strong floral fragrance and has a strong attraction to bees and butterflies; while methyl benzoate in *Syringa pubescens* Turcz. var. *microphylla* (Diels) M. C. Chang et X. L. Chen may attract different types of pollinating insects. This differentiation in the composition of VOCs may be an important mechanism for *Syringa* to reduce reproductive competition and improve fitness in the frigid and arid environment (TOWNSEND B J et al, 2005). In addition, previous studies have found that a large number of volatile terpenoids have antimicrobial activities. In *Gossypium hirsutum*, gossypol, a derivative of cadinene, can defend against pests and diseases (HUANG M et al, 2012), and β -caryophyllene plays an important role in the defense against pathogens in *Arabidopsis thaliana* (LIN Fuping et al, 2012).

Based on the differences in the emitted characteristics of VOCs from the flowers of the three species of lilac, more reasonable plant configurations can be carried out. In urban landscape design, functional configurations can be made according to the characteristics of the main VOCs emitted by different lilac species: linalool emitted by *S. oblata* has a sedative and soothing effect and is suitable for being configured in leisure areas; δ -cadinene emitted by *Syringapu bescens* subsp. has a refreshing and invigorating effect and is suitable for being arranged in activity areas; the characteristic VOCs emitted by *Syringa reticulata* subsp. can be used to create a specific landscape atmosphere. According to the data in the landscape industry, from 2020 to 2023, the demand for landscape plants adapted to the frigid and arid climate in northern cities of China

increased by 32%. As an excellent tree species resistant to cold and drought, *Syringa* has great application potential (CHEN Xia et al, 2015).

Conclusion

This study systematically analyzed the VOC composition and differential distribution of three *Syringa* species in cold and arid regions of China using metabolomics approaches. A total of 87 VOCs were identified, with significant differences observed in the types and relative contents of VOCs emitted by *S. oblata*, *Syringapu bescens* subsp., and *Syringa reticulata* subsp. The main components of VOCs emitted by *S. oblata* were 1-caryophyllene, ocimene, and linalool; those emitted by *Syringapu bescens* subsp. were δ -cadinene, heptadecane, and methyl benzoate; and those emitted by *Syringa reticulata* subsp. were m-xylene, o-cymene, and thujopsene. These differences reflect the adaptive evolution of lilac species to different microenvironments in cold and arid regions, resulting from long-term plant-environment interactions. The findings provide new insights into the environmental adaptation mechanisms of plant volatile secondary metabolites and offer scientific guidance for the rational configuration of landscape plants and the development of lilac resources.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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