

GENUS-LEVEL CHEMICAL DIFFERENTIATION OF VOLATILE PROFILES FROM DRIED LEAVES OF RIBES AND RUBUS REVEALED BY STANDARDIZED HYDRODISTILLATION–GC–MS ANALYSIS

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Leaf volatile profiles represent structured secondary metabolite systems with potential chemotaxonomic relevance. In this study, the volatile fractions obtained from dried leaves of *Ribes nigrum*, *Ribes rubrum*, *Rubus idaeus*, and *Rubus fruticosus* were comparatively analyzed under standardized hydrodistillation–GC–MS conditions to evaluate compositional differentiation at the genus level. A total of 142 volatile constituents were identified based on mass spectral matching (NIST23, Match Factor ≥ 90) and retention index data. Multivariate analysis of major constituents ($\geq 3\%$) revealed clear intergeneric separation, supported by hierarchical cluster analysis. Class-level statistical assessment demonstrated that *Rubus* samples contained significantly higher proportions of lipoxygenase (LOX)-derived C₆ and related aliphatic compounds than *Ribes* (Mann–Whitney U test, $p < 0.001$), whereas total monoterpene abundance did not differ significantly between genera. The results suggest that the observed compositional differentiation is primarily associated with the relative enrichment of LOX-associated volatiles in *Rubus* under the applied analytical conditions. The dataset additionally includes the first standardized report on the volatile composition of *Rubus fruticosus* leaves. Although based on a limited number of species, the consistency of multivariate and class-level patterns supports the consistency of the observed compositional differentiation.

Keywords: chemical differentiation, chemotaxonomy, leaf volatiles, *Ribes nigrum*, *Ribes rubrum*, *Rubus idaeus*, *Rubus fruticosus*

INTRODUCTION

Leaves of berry plants represent an underexplored source of volatile compounds, yet their chemical composition remains insufficiently characterized compared with that of fruits and buds. Black currant (*Ribes nigrum* L.) and red currant (*Ribes rubrum* L.) are the two main *Ribes* species (Grossulariaceae) that are cultivated worldwide for berry production (Zdunić et al., 2016). Similarly, red raspberries (*Rubus idaeus* L.) and blackberries (*Rubus fruticosus* L., Rosaceae) are highly demanded fruits (Paris et al., 2025). Due to their valued taste and aroma, as well as the content of bioactive substances, the fruits of all four species are widely used to produce juices, jams, syrups, jellies, herbal

teas, wine, etc. (Zia-Ul-Haq et al., 2014; Zdunić et al., 2016; Wajs-Bonikowska et al., 2017; Vinogradov et al., 2020; De Santis et al., 2022; Truong et al., 2025).

In addition to their nutritional importance, vegetative parts of *Ribes* and *Rubus* species have attracted interest as sources of bioactive and sensory compounds (De Santis et al., 2022; Čechovičienė et al., 2024). From a sustainability perspective, berry leaves represent an underutilized vegetative biomass with potential phytochemical value. In Estonian folk medicine, the leaves of *Ribes nigrum* and *Rubus idaeus* were mainly used to treat colds and coughs. In contrast, *Ribes rubrum*, which was widely grown in home gardens, was of limited importance in folk medicine, whereas *Rubus frutico-*

sus was regarded as a relatively little-known plant (Sõukand and Kalle, 2008).

The aroma and flavor profile of blackcurrant berries, and the juice made from them, has been the most extensively studied (Zia-Ul-Haq et al., 2014; Zdunić et al., 2016; Marsol-Vall et al., 2019; Wajs-Bonikowska et al., 2017; Vinogradov et al., 2020; De Santis et al., 2022; Kelanne et al., 2022; Truong et al., 2025). Due to their strong, specific odor, the volatile profiles (VP) of *Ribes nigrum* buds have also been thoroughly investigated (Le Quere and Latrasse, 1990; Garland et al., 2002; Oprea et al., 2008; Dvaranauskaitė et al., 2008, 2009; Mackèla et al., 2015). In contrast, the VP of *Ribes rubrum* berries (Jung, 2018; Yu et al., 2020; Eksi Karaagac et al., 2021; Vítová et al., 2025), as well as *Rubus idaeus* fruits (Yang et al., 2015, 2020; Diaconeasa et al., 2019; Truong et al., 2025) and *R. fruticosus* fruits (Padilla-Jimenez et al., 2019; Dewitte et al., 2021; Cadi et al., 2021; Čechovičienė et al., 2024) have been comparatively less analyzed than blackcurrant volatiles. Nevertheless, available studies indicate substantial variability related to cultivar, ripening stage, and analytical methodology. Several studies have also examined volatile compounds in the leaves of black currant (Orav et al., 2002; Kiliç et al., 2008; Stevic et al., 2010), red currant (Kendir et al., 2019), and raspberry (De Santis et al., 2022). However, to the best of our knowledge, no studies have yet addressed the volatile fraction of blackberry leaves.

Leaves represent an underutilized by-product of berry cultivation. From a sustainability perspective, berry leaves also represent a potentially valu-

able vegetative biomass. In the present study, leaves were selected because they represent chemically distinct vegetative material and may provide additional information on genus-level volatile organisation under standardized analytical conditions.

Previous studies have demonstrated the functional and sensory relevance of vegetative berry materials, supporting further investigation of their volatile composition in *Ribes* and *Rubus* spp. (Vinogradov et al., 2020; Raal, 2023; Raal et al., 2024). From a flavor and fragrance perspective, leaf volatiles often differ markedly from fruit volatiles, being dominated by terpenoids and green-leaf compounds rather than fruity esters; however, comparative data on the volatile composition of berry leaves remain limited. Leaf volatile fractions are typically characterized by terpenoids and lipoxygenase-derived C₆ compounds, which differ substantially from fruit-derived esters and sulfur-containing volatiles (Yang et al., 2015; Jung et al., 2017).

Therefore, the aim of this study was to characterize and comparatively evaluate the steam-distilled leaf volatile fractions of leaves from *Ribes nigrum*, *Ribes rubrum*, *Rubus idaeus*, and *Rubus fruticosus* (Table 1) using GC–MS-based analysis, with particular emphasis on interspecific differences and volatile compound classes relevant to aroma and flavor perception.

The present study evaluates whether standardized hydrodistillation–GC–MS profiling reveals statistically supported chemical differentiation at the genus level in leaf volatile compositions of *Ribes* and *Rubus*. To our knowledge, no previous study has systematically evaluated genus-

Table 1. Plant material collected from Estonia in July 2025 with the yield of volatile fractions

Plant material (leaves)	Collected from	Altitudes, m a.s.l.	Yield of volatile fraction, %
<i>Ribes nigrum</i> 1	Tartu (Tartu county)	~45	0.353±0.016
<i>Ribes nigrum</i> 2	Kuressaare (Saare county)	~8	0.131±0.006
<i>Ribes nigrum</i> 3	Suuremetsa village, Võru parish, Võru county	~80	0.202±0.009
<i>Ribes nigrum</i> 4	Uue-Kariste village, Mulgi parish, Viljandi county	~60	0.115±0.005
<i>Ribes rubrum</i>	Tartu (Tartu county)	~45	0.122±0.005
<i>Rubus idaeus</i>	Tartu (Tartu county)	~45	0.096±0.004
<i>Rubus fruticosus</i>	Tartu (Tartu county)	~45	0.110±0.005

Note: m a.s.l. – metres above sea level

level structuring of leaf volatile profiles in *Ribes* and *Rubus* under strictly standardized analytical conditions. We hypothesize that the two genera differ significantly in the relative contributions of major volatile chemical classes, resulting in consistent multivariate separation under identical analytical conditions. The objectives were (i) to characterize major volatile constituents under standardized conditions, (ii) to evaluate multivariate genus-level structuring, and (iii) to statistically assess differences in dominant chemical classes. The dataset additionally includes the first standardized report on the volatile composition of *Rubus fruticosus* leaves. This study moves beyond descriptive profiling by statistically validating genus-level compositional structuring.

MATERIALS AND METHODS

PLANT MATERIAL

The research material consisted of leaves of berry shrubs, collected from four growing sites for *Ribes nigrum* and from one growing site for each of *Ribes rubrum*, *Rubus idaeus*, and *Rubus fruticosus* (Table 1). The plant material was collected in July 2025 in Estonia and dried for 10 days at room temperature, protected from sunlight. Leaves were collected during the fruiting period to ensure comparable developmental stages among all studied taxa under field conditions. Prior to hydrodistillation of the volatile fractions, the research material was stored in a dry room in paper bags. The voucher specimen is stored at the Institute of Pharmacy, University of Tartu.

DISTILLATION OF VOLATILE FRACTIONS

The extraction of volatile fractions from the leaves of all studied species was performed using a steam distillation apparatus according to the European Pharmacopoeia (European Pharmacopoeia, 11th ed.; Council of Europe: Strasbourg, 2022). A total of 30 g of dried, crushed leaves (1–3 mm) was distilled with 400 mL of water for 3 h. For GC-MS analysis, the volatile fractions were diluted with hexane. The yields of volatile fractions were determined by the pharmacopoeial method using 0.5 mL of xylene for distillation (European Pharmacopoeia, 11th ed.; Council of Europe: Strasbourg, 2022). The yields of volatile fractions were determined according to the European Pharmacopoeia

poeia method using three parallel distillations. Based on these replicate measurements performed under identical conditions, the average standard deviation of volatile fraction yields was approximately 4.5%. Although steam distillation may affect the abundance of highly volatile compounds, it provides a robust and reproducible basis for comparative profiling under identical conditions.

GC-MS ANALYSIS

The volatile fractions of *Ribes* and *Rubus* species were subjected to GC-MS analysis on a capillary column HP-5ms UI column (30 m length, 0.25 mm inner diameter, 0.25 μ m film thickness) using split mode (5:1) on an Agilent 6890/5973 GC-MS system (Agilent Technologies, Santa Clara, CA, USA) with the temperature range 50–280 °C and the carrier gas (He) flow was kept constant 1 mL/min throughout the whole analysis. The oven was held at 50 °C for 2 minutes, followed by a ramp of 4 °C/min to a final temperature of 280 °C, which was maintained for 5 minutes. The MSD was operated in EI mode at 70 eV, scanning across the mass range of 29–400 m/z with a delay time of 4 minutes and a scan speed of 3.8 scans per second. Data acquisition and processing were performed using MSD ChemStation software (D.02.00.275, Agilent Technologies, Santa Clara, CA, USA). The obtained compounds were identified using NIST23 library with Match Factor $\geq$ 90 and by retention indexes (relative to n-alkanes C8 – C30) or by comparison with reference compounds. Relative peak areas were calculated from three technical replicate GC-MS analyses of the same volatile fraction sample without correction factors.

STATISTICAL ANALYSIS

Relative abundances (%) were calculated by normalizing peak areas to the total chromatographic area of each sample. Multivariate structuring of major volatile constituents ($\geq$ 3%) was explored using principal component analysis (PCA). Hierarchical cluster analysis (HCA) was performed using Ward's linkage and Euclidean distance. To assess intergeneric differences in dominant chemical classes, compounds were grouped into major structural categories (e.g., monoterpenes and lipoxygenase (LOX)-derived C₆ aliphatics), and their relative contributions (%) were calculated for each sample. Differences between *Ribes* and

Rubus were evaluated using the two-sided Mann–Whitney U test, with $p < 0.05$ considered statistically significant. The Mann–Whitney U test was applied to compare relative abundance patterns among analyzed samples rather than independent biological populations.

RESULTS AND DISCUSSION

YIELD OF VOLATILE FRACTIONS

Ribes nigrum leaves were distinguished from other species by higher volatile fraction yields (up to 0.35%; Table 1). In previous studies, depending on the *R. nigrum* variety, the essential oil yield of buds was 1.28–1.77% (Oprea et al., 2008), and, depending on the harvesting period, 0.60–1.76% in buds, and 0.12% in leaves (Dvaranauskaite et al., 2009). The yields of volatile fractions from berries, buds, and leaves of *Ribes nigrum* grown in Estonia were 0.003%, 0.21%, and 0.14%, respectively (Orav et al., 2002). Overall, quantitative data on the yields of volatile fractions from different organs of *Ribes* and *Rubus* spp. are scarce, and when reported, the yields are generally low.

VOLATILE PROFILES OF *RIBES* AND *RUBUS* SPP.

A total of 142 volatile compounds were identified in four *Ribes* and *Rubus* spp. VPs (Table S1). In *Ribes nigrum*, the major volatile constituents were cymene, α -phellandrene, α -sabinene, γ -terpinene, and terpinen-4-ol, which only partially overlap with the results of other studies (Le Quere and Latrasse, 1990; Orav et al., 2002; Kiliç et al., 2008; Stevic et al., 2010). These differences may reflect variation in extraction methodology, plant developmental stage, geographical origin, and the use of dried versus fresh plant material. The volatile composition of *R. nigrum* leaves from four growing sites was qualitatively consistent but showed marked quantitative differences, mainly affecting monoterpene hydrocarbons and their oxygenated derivatives. This site-dependent variation altered the relative balance of major monoterpenes, suggesting quantitative modulation of the dominant monoterpenes without altering the qualitative composition.

Ribes rubrum was dominated by α -pinene, bornyl acetate, neral, citral, and geraniol, which does not match the previous result (Kendir et al., 2019). Unlike the fruit aroma of *R. nigrum*, which is largely

defined by low-threshold sulfur compounds and methoxypyrazines, the leaf volatiles characterized by steam distillation and GC–MS were dominated by monoterpenes and oxygenated terpenoids, reflecting a distinct volatile profile within the limits of the applied methodology (Jung et al., 2017; Jung, 2018). For *Rubus idaeus*, 2-heptanone was the dominant component, consistent with earlier studies, while differences in minor constituents may reflect methodological or material-related factors (De Santis et al., 2022; Table S1).

Principal component analysis based on major volatile constituents representing $\geq 3\%$ relative abundance confirmed clear genus-level differentiation between *Ribes* and *Rubus* species. The separation was driven primarily by monoterpene-dominated profiles in *Ribes* and by higher proportions of fatty acids and oxygenated sesquiterpenes in *Rubus*, highlighting distinct compositional patterns in the distribution of major volatile constituents between the two genera (Figure 1).

The dendrogram (Figure 2) demonstrates clear genus-level separation, with *Ribes nigrum* and *R. rubrum* clustering together and *Rubus idaeus* and *R. fruticosus* forming a distinct cluster, supporting consistent chemical differentiation between the genera.

Distinct qualitative and quantitative differences were observed in the VP of *Ribes* and *Rubus* species (Table S1). Heatmap analysis revealed clear genus-specific patterns in relative com-

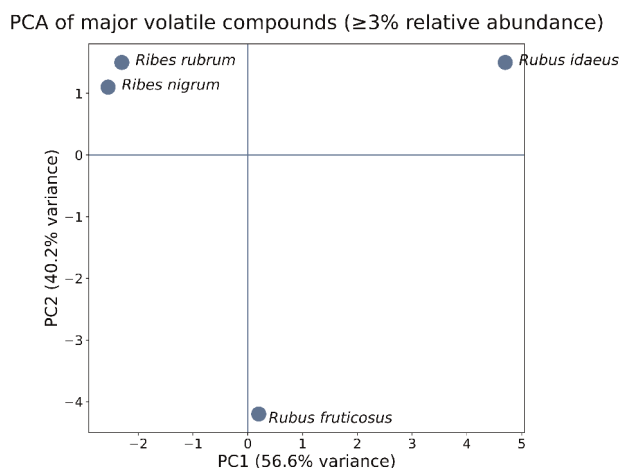


Figure 1. Principal component analysis of major volatile compounds ($\geq 3\%$ relative abundance) in *Ribes* and *Rubus* species. PC1 (56.6%) and PC2 (40.2%) together explained 96.8% of the total variance. *Ribes nigrum* and *R. rubrum* were clearly separated from *R. idaeus* and *R. fruticosus*.

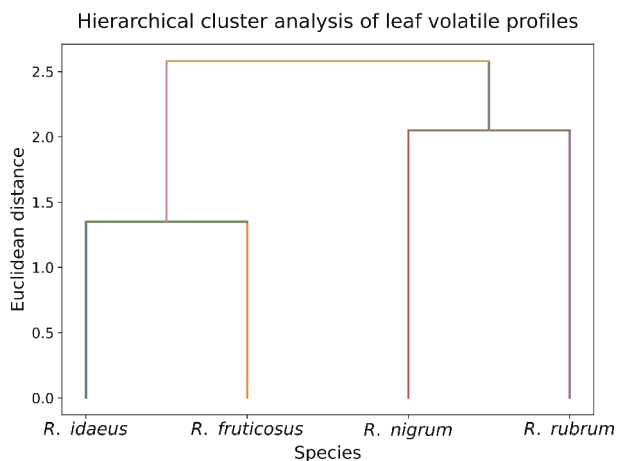


Figure 2. Hierarchical cluster analysis (Ward's linkage, Euclidean distance) based on major leaf volatile constituents ($\geq 3\%$ relative abundance; mean values). The dendrogram demonstrates clear genus-level separation between *Ribes* and *Rubus* species.

pound abundance (Figure 3). *Ribes* spp. were characterized by higher proportions of monoterpenes and oxygenated monoterpenes, whereas *Rubus* spp. showed increased levels of aliphatic aldehydes, alcohols, fatty acids, and selected oxygenated sesquiterpenes. Several compounds were abundant in *Ribes* but absent or detected only at trace levels in *Rubus*. Although not all individual compounds differed significantly among the species, the overall VP exhibited consistent genus- and species-specific characteristics. *Rubus idaeus* showed high proportions of aliphatic alcohols and oxygenated sesquiterpenes, whereas *Rubus fruticosus* was characterized by monoterpene alcohols and citral-related compounds.

Class-level analysis showed no significant intergeneric differences in total monoterpene abundance (Figure 4; Mann–Whitney U test, $p = 0.494$). In contrast, LOX-derived C_6 and related aliphatic compounds were significantly more abundant in *Rubus* than in *Ribes* (Figure 5; $p < 0.001$). Thus, genus-level differentiation is primarily associated with enrichment of LOX-derived volatiles in *Rubus*.

The pronounced contribution of LOX-derived volatiles in *Rubus* may reflect differences in metabolic allocation within fatty acid-derived pathways in leaf tissues. In contrast, although monoterpenes remain prominent constituents in *Ribes*, their overall proportion does not alone explain the observed multivariate genus-level separation. LOX-derived green-leaf volatiles are commonly associated with rapid stress and herbivory signalling in plants, whereas terpenoid-rich volatile fractions

are often linked to constitutive or inducible defence functions (Hatanaka, 1993; Turlings et al., 1995). The observed compositional divergence may therefore reflect different ecological roles of volatile metabolism in the studied genera.

The selected compounds include volatiles with reported low odor thresholds and established relevance to chemical composition rather than abundance alone. Selected compounds with reported low odor thresholds were considered to facilitate comparison of potentially aroma-active constituents (Table 2) (Yang et al., 2015; Burdock, 2016; Jung et al., 2017; Pagès-Hélary and Cayot, 2024; Truong et al., 2025; Acree and Arn; Leffingwell and Leffingwell). The subset of selected key odorants (Table 2) further illustrates the compositional divergence between the genera. Although not all compounds differed quantitatively to the same extent, the distribution of functionally relevant volatiles reflects the contrasting enrichment patterns identified in the statistical analysis. *Ribes* samples were characterized by higher relative contributions of several monoterpenoid and phenolic constituents (e.g., p-cymene, thymol, carvacrol), whereas *Rubus* samples showed greater representation of LOX-associated green-leaf volatiles and related aliphatic compounds. These patterns further support the compositional differentiation observed between the two genera.

The dominance of monoterpenes such as α -phellandrene, cymene and γ -terpinene suggests a fresh, terpenic and citrus-like aroma character for *Ribes* species, whereas higher proportions of fatty acids, aldehydes and oxygenated sesquiterpenes in *Rubus* species are associated with green, fatty and woody nuances.

Within the limits of the applied analytical approach, the leaf VP of *Ribes* and *Rubus* differed markedly, with *Ribes* leaves dominated by isoprenoid-derived mono- and oxygenated terpenoids, whereas *Rubus* leaves showed a stronger contribution of lipoxygenase (LOX) derived C_6 compounds (Hatanaka, 1993; Dudareva et al., 2006). This contrast reflects distinct compositional patterns associated with terpenoid-dominated versus lipoxygenase-derived volatile fractions.

Several aroma-active compounds identified in the leaves, including monoterpenoids and phenolic volatiles such as thymol, carvacrol, eugenol, and methyl salicylate, are commonly reported in medicinal and aromatic plants (Raal, 2025). Although biological activity was not evaluated in the present study, the detected volatile constitu-

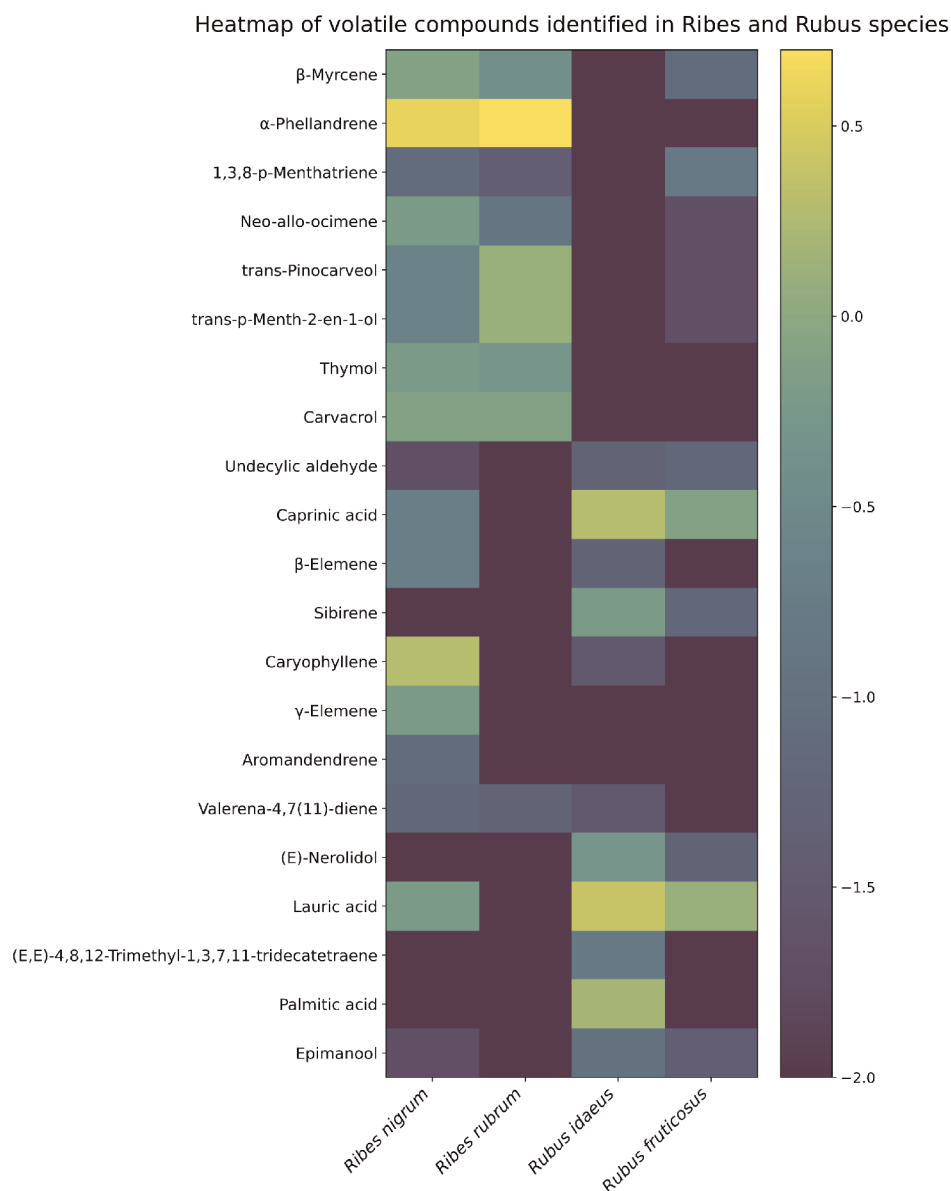


Figure 3. Heatmap of volatile compounds identified in four plant species. The color intensity represents the relative content of individual compounds (mean values, %, log₁₀-transformed as log₁₀(x + 0.01)). Rows correspond to identified volatile compounds and columns to plant species. Darker colors indicate higher relative abundance, whereas light colors indicate low or non-detectable levels. Monoterpenes predominated in *Ribes* spp., whereas fatty acids and related aliphatic compounds were more characteristic of *Rubus* spp.

ents demonstrate the chemical diversity of berry leaf volatile fractions and may support future studies addressing their biological relevance.

Differences in the leaf VP of *Ribes* and *Rubus* species likely reflect distinct ecological strategies, with *Ribes* leaves characterized by terpenoid-based profiles and *Rubus* leaves by a stronger contribution of LOX-derived green-leaf volatiles (Turlings et al., 1995; Heil, 2008).

The observed differentiation between *Ribes* and *Rubus* leaf volatile profiles may reflect differences in metabolic organisation associated with terpenoid- and LOX-derived volatile pathways. Because only a limited number of species per genus were analyzed and only *Ribes nigrum* was represented by multiple sampling sites, the observed structuring should be interpreted cautiously and may partly reflect species-, genotype,

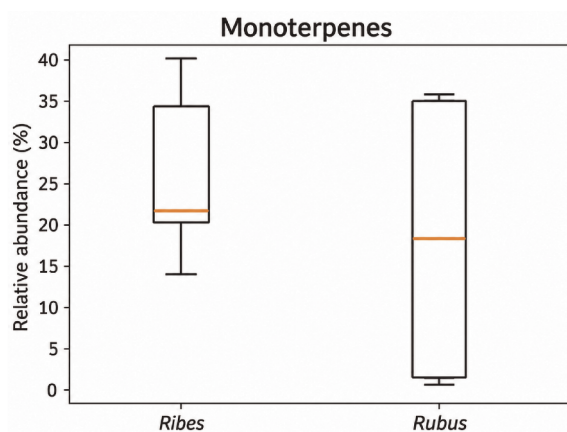


Figure 4. Relative abundance (%) of monoterpenes in individual leaf samples of *Ribes* (*R. nigrum*, *R. rubrum*) and *Rubus* (*R. idaeus*, *R. fruticosus*). No statistically significant intergeneric differences were observed (Mann–Whitney U test, $U = 51.0$, $p = 0.494$).

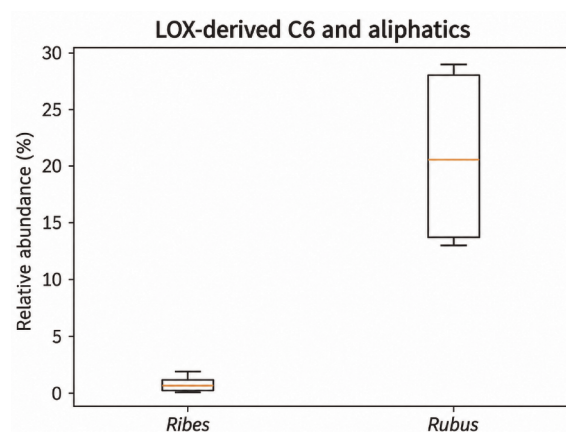


Figure 5. Relative abundance (%) of LOX-derived C₆ and related aliphatic compounds in individual leaf samples of *Ribes* and *Rubus*. *Rubus* samples exhibited significantly higher proportions compared to *Ribes* (Mann–Whitney U test, $U = 0.0$, $p = 5.16 \times 10^{-5}$).

Table 2. Selected volatile compounds identified in leaves of *Ribes* and *Rubus* spp.

Compound	<i>Ribes nigrum</i>	<i>Ribes rubrum</i>	<i>Rubus idaeus</i>	<i>Rubus fruticosus</i>	Aroma description
2-Hexenal	0.37±0.02	0.86±0.03	1.35±0.06	1.79±0.18	Green, fresh-cut grass, leafy
(E)-2-Hexenol	0.17±0.01	0.43±0.01	0.15±0.01	0.07±0.00	Green, herbaceous
1-Hexanol	0.04±0.00	0.06±0.00	0.15±0.01	0.19±0.01	Green, woody, herbal
Heptanal	0.02±0.00	0.03±0.00	2.16±0.04	2.29±0.06	Green, fatty, citrus-peel
2-Heptanol	0.01±0.00	0.01±0.00	23.93±0.48	8.05±0.15	Earthy, mushroom-like
Benzaldehyde	0.06±0.00	0.16±0.01	0.21±0.01	0.55±0.01	Almond, sweet, nutty
Linalool	0.47±0.01	0.22±0.00	0.24±0.00	10.61±0.16	Floral, sweet, citrus
Nonanal	0.14±0.00	0.06±0.00	1.27±0.08	1.57±0.04	Citrus, green, fatty
Methyl salicylate	0.60±0.02	0.52±0.01	3.66±0.04	1.29±0.02	Wintergreen, sweet, medicinal
Safranal	2.24±0.08	1.14±0.03	0.14±0.00	0.32±0.01	Warm, hay-like, saffron
Geraniol	2.37±1.62	2.95±0.02	0.52±0.01	21.34±0.16	Floral, rose-like
Citral (neral + geranial)	2.22±0.21	3.01±0.03	0.27±0.02	3.64±0.02	Lemon, citrus, fresh
Thymol	0.64±0.01	0.43±0.01	0.00±0.00	0.00±0.00	Herbal, thyme-like, phenolic
Carvacrol	0.86±0.01	0.76±0.01	0.00±0.00	0.00±0.00	Spicy, oregano-like
Eugenol	0.17±0.00	0.14±0.00	0.14±0.00	0.12±0.00	Clove-like, spicy
β-Caryophyllene	1.89±0.04	0.00±0.00	0.02±0.00	0.00±0.00	Woody, spicy
(E)-β-Damascenone	0.48±0.01	0.34±0.00	0.69±0.02	1.15±0.03	Fruity, floral, honey-like
trans-β-Ionone (I/II)	1.47±0.04	1.55±0.03	0.49±0.02	1.04±0.01	Violet-like, floral, woody
trans-Geranylacetone	0.67±0.02	0.95±0.02	0.96±0.05	0.54±0.01	Floral, green, fruity
p-Cymene	10.27±0.16	1.12±0.01	0.02±0.00	0.01±0.00	Aromatic, herbal, slightly spicy

Note: The table lists selected volatile compounds with reported low odour thresholds and known aroma relevance. Relative contents (% , mean ± SD) are presented to facilitate interspecific comparison.

or environment-related variation in addition to genus-level differentiation. Nevertheless, the consistency of the multivariate and class-level patterns obtained under standardized analytical conditions supports the relevance of the observed compositional separation.

CONCLUSIONS

This study reveals consistent compositional differentiation of leaf volatile profiles between the genera *Ribes* and *Rubus* under standardized hydrodistillation–GC–MS conditions.

The observed differentiation was primarily associated with enrichment of LOX-derived aliphatic compounds in *Rubus* under the applied analytical conditions. These findings highlight the chemotaxonomic relevance of volatile compositional patterns in berry-producing genera and provide the first standardized report on the leaf volatile composition of *Rubus fruticosus*. Taken together, these results support the potential chemotaxonomic value of leaf volatile profiles when analyzed under standardized conditions.

Future studies should include a larger number of species, seasonal sampling, and complementary ecological or biochemical analyses to further evaluate the chemotaxonomic relevance of leaf volatile profiles in berry-producing genera.

AUTHORS' CONTRIBUTIONS

Ain Raal: conceptualization, methodology, investigation, software, supervision, writing, editing. Rasmus Lodi: investigation, software, formal analysis. Oleh Koshovyi: conceptualization, investigation, supervision, writing, editing.

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