

Article

Impact of Cultivar and Season on the Flavor of Red, White, and Black Currants: Integrated Instrumental and Sensory Analysis

Eva Vítová ¹ , Pavel Diviš ^{1,*} , Jaromír Pořízka ¹  and Jana Zemanová ² 

¹ Institute of Food Science and Biotechnology, Faculty of Chemistry, Brno University of Technology, Purkyňova 118, 612 00 Brno, Czech Republic; vitova@fch.vut.cz (E.V.); porizka@fch.vut.cz (J.P.)

² Department of Food Technology, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1665/1, 613 00 Brno, Czech Republic; jana.zemanova@mendelu.cz

* Correspondence: divis@fch.vut.cz

Abstract: Currants are highly valued nutritionally and are traditionally grown in the Czech Republic. This study investigated 15 cultivars of red, white, and black currants to better understand their positive sensory properties and their relationship to consumer preference. Red and white cultivars, in particular, have received little attention from this perspective. Sensory quality, primarily flavor, was evaluated in conjunction with volatile compound profiling to identify the sensorially superior cultivars. The results confirmed clear differences between black currants and red/white variants. Red and white currants, belonging to the same species (*Ribes rubrum*), exhibited similar volatile compound content and composition, as well as similar sensory characteristics, distinguishing them significantly from black currants (*Ribes nigrum*). The flavor of black currants, characterized by strong astringency and distinct blackcurrant notes, was generally perceived less favorably by the evaluators. A total of 54 volatile compounds were identified across the analyzed cultivars. Alcohols (contributing flowery and fruity aromas), aldehydes (grassy aromas), and esters (fruity aromas) were the most abundant in most cultivars. Using the odor activity value (OAV) concept, 15 of these compounds were identified as likely contributors to currant flavor (OAV ≥ 1). Principal component analysis (PCA) identified the top cultivars within each variant: ‘Victoria’ (white), ‘Rubigo’ (red), and ‘Demon’ (black). These are proposed for potential practical applications.

Keywords: currants; flavor; aroma compounds; sensory analysis; solid phase microextraction; gas chromatography; mass spectrometry



Academic Editor: Alessandro Genovese

Received: 31 January 2025

Revised: 20 March 2025

Accepted: 2 May 2025

Published: 6 May 2025

Citation: Vítová, E.; Diviš, P.; Pořízka, J.; Zemanová, J. Impact of Cultivar and Season on the Flavor of Red, White, and Black Currants: Integrated Instrumental and Sensory Analysis. *Appl. Sci.* **2025**, *15*, 5156. <https://doi.org/10.3390/app15095156>

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1. Introduction

Currants are berry-bearing shrubs of the *Ribes* L. genus (*Grossulariaceae* family), with the most common species being *R. rubrum* L. (red, white, and pink currants) and *R. nigrum* L. (black currant) [1]. Red, white, and pink currants are similar in composition, belonging to the same species. Ripe red currants are bright red with a delicate tart flavor due to organic acids, while white currants are less acidic, sweeter, and have a unique flavor, typically ranging in color from white to yellowish or pinkish [2]. Black currants are dark blue due to anthocyanins, more astringent, and possess a distinct, strong aroma. They are rich in minerals, pectins, ascorbic acid, and, notably, polyphenolic compounds, which contribute significantly to astringency and are potent antioxidants [3–5].

While currants can be consumed fresh; their acidic, astringent flavor means the majority are commercially processed into products such as juices, wines, liqueurs, syrups, jams, and jellies [1].

The flavor compounds of black currants and their products have been extensively studied since the 1960s. Research has focused not only on characterizing aroma compounds [6,7] but also on the impact of various factors on the aroma profile, including growing conditions [8], cultivar [9,10], ripening stage [6,11], and processing conditions such as freezing [6], thermal treatment [12,13], enzymatic treatment [7], and storage [7,14].

Various methods assess volatile aroma compounds in fruits, differing mainly in extraction techniques. Early studies on currants and currant products used traditional solvent extraction [2,15,16]. However, this method has several drawbacks: It is time-consuming, requires large sample and solvent volumes, and target analytes can be affected or lost due to high temperatures or the solvents used. Furthermore, large solvent volumes complicate trace analysis and pose environmental pollution, health hazards to personnel, and increased waste treatment costs. Later studies employed solventless techniques such as solid-phase extraction [15], dynamic headspace [10,12,13], and vacuum-headspace extraction [6]. However, solid-phase microextraction (SPME) has become the most common technique [11,14,17,18] due to its simplicity, speed, versatility, and solvent-free nature, minimizing sample handling and volatile component loss. A drawback of SPME is that quantitative and accurate extraction can be challenging, as the extraction efficiency of each compound depends on the equilibrium between the liquid and gas phases and its affinity for the SPME fiber. Studies have shown qualitative and quantitative compositional differences depending on the isolation method, indicating that no universal method exists. For example, Varming et al. [16] found different compound compositions in black currants when comparing headspace and solvent extraction. Gas chromatography with flame ionization detection (GC-FID) or gas chromatography-mass spectrometry (GC-MS), sometimes coupled with olfactometry for aroma description [15,16], remains the standard approach for determining thermally labile volatile compounds and was used in most of the cited studies.

In contrast to the extensive research on the volatile compounds of black currants, sensory analysis of their quality has received significantly less attention. Boccorh et al. [15,19] and Brennan et al. [20] were among the first to identify typical black currant aroma descriptors. Subsequent studies have examined the impact of factors such as composition [21], processing [7,8,13], and storage [3–5] on black currant aroma/flavor. Most of these studies [3,4,7,20] focused on juice, the main commercial product.

Studies on red/white currants are scarce and primarily focus on taste-related compounds like sugars, acids, and phenolics [2,22] or on phenolics as potent antioxidants [23–25]. Fruit sensory quality encompasses physical characteristics (berry size, color, and firmness) and characteristics related to chemical composition (color, sweetness, sourness, and flavor). Flavor is particularly important to consumers, ultimately determining acceptability and purchase decisions. Ideal currants are firm, bright, and large, with the appropriate cultivar-specific color. Long shelf life with retained firmness and flavor is also desirable for the fresh fruit market [20].

To our knowledge, the sensory quality and related aroma profile of red/white currants have received little published research, with only a few exceptions [18,26]. Therefore, this study aimed to evaluate the sensory quality of selected red, white, and black currant cultivars harvested over two consecutive years (2020–2021) to identify the best cultivars for potential commercialization. Descriptive sensory profiling was combined with volatile compound profiling, as these compounds significantly contribute to overall currant acceptability.

2. Materials and Methods

2.1. Chemicals

All chemicals used as reference standards of volatile compounds (as listed in Supplementary Material Table S1), were of analytical grade purity, purchased from Merck (Darmstadt, Germany).

2.2. Currant Samples

Fifteen currant cultivars were analyzed: five white ('Blanka' (Bl), 'Jantar' (Jan), 'Orion' (Or), 'Primus' (Pr), and 'Victoria' (Vic)); five red ('Detvan' (Det), 'Jonkheer van Tets' (JVT), 'Rovada' (Rov), 'Rubigo' (Rub), and 'Tatran' (Tat)); and five black ('Ben Gairn' (BG), 'Ben Hope' (BH), 'Ceres' (Cer), 'Demon' (Dem), and 'Moravia' (Mor)). The studied cultivars are traditional cultivars historically grown in the Czech Republic. The currants were grown on experimental plots (50°22'29" N, 15°34'38" E, 321 m altitude) in collaboration with experts from Mendel University in Brno. The average annual temperature at the site was 9.1/7.8 °C, precipitation was 768/689 mm, and sunshine duration was 1760/1671 h in 2020/21, respectively. The berries were harvested at full maturity between July and August in two consecutive years (2020–2021), stored at 5 °C, and sensorially evaluated fresh within two days. All chemical analyses were performed within seven days.

2.3. HS-SPME-GC-FID/MS Determination of Volatile Compounds

Volatile compounds were analyzed using SPME-GC-FID/MS. Each sample was analyzed in duplicate ($n = 2$). For SPME extraction, 2 g of homogenized currant sample was placed in a 10 mL vial, combined with 20 µL of the internal standard propan-2-ol (220 µg/L in water), and analyzed immediately. SPME was performed in headspace (HS) mode using a 50/30 µm Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB/CAR/PDMS) fiber (Supelco, Bellefonte, PA, USA) under the following conditions: equilibrium time 10 min and extraction at 40 °C for 20 min.

GC-FID analyses were performed using a TRACETM GC (ThermoQuest, Milan, Italy) with a DB-WAX capillary column (30 m × 0.32 mm × 0.5 µm, J&W Scientific, Santa Clara, CA, USA) under the following conditions: injector temperature, 240 °C; splitless desorption, 10 min; and carrier gas, N₂ at a flow rate of 0.9 mL/min. The column temperature was programmed as follows: from 40 °C (held for 1 min) to 200 °C at a 5 °C/min gradient (held for 7 min). The FID temperature was 220 °C, with H₂ at 35 mL/min, air at 350 mL/min, and N₂ makeup gas at 30 mL/min.

GC-MS analyses were performed on a TraceTM 1310 GC system with a split/splitless injector coupled with an ISQTM LT Single Quadrupole and a TG-WaxMS capillary column (30 m × 0.25 mm × 0.5 µm, Thermo Fisher Scientific Inc., Waltham, MA, USA), using He as the carrier gas at a flow rate of 1 mL/min. The other GC conditions were as described above. The ion source temperature was 200 °C, and the MS was set in electron impact mode at 70 eV, scanning m/z 30–370 amu at a rate of 0.2 s.

Volatile compounds were identified by comparing mass spectra with the NIST/EPA/NIH library, Version 2.0 (Gaithersburg, MD, USA), and confirmed by comparing retention times with reference standards and experimental retention indices (RI^{exp}) with literature values from the NIST WebBook open-access database (RI^{lit}). RI^{exp} values were determined using a mixture of n-alkanes (Merck, Darmstadt, Germany) ranging from C₈ to C₂₀. Identified volatiles were semi-quantified using propan-2-ol as an internal standard, using Equation (1).

$$c = A_c / A_{is} \times c_{is} \quad (1)$$

where c represents relative concentration of analyte (µg/kg), c_{is} concentration of the internal standard (220 µg/L), A_c peak area of analyte, and A_{is} peak area of internal standard.

The method is based on the method described and validated in our previous study [27] with minor modifications.

2.4. Sensory Analysis

Sensory evaluations were conducted using generic descriptive analysis in a sensory laboratory equipped according to [28], under controlled conditions. The test panel consisted of 20 panelists ($n = 20$), both male (7) and female (13), all over 20 years of age, and remained consistent across both years of the study. Panelists were trained in general sensory analysis according to [29], using standard solutions of 0.5% sucrose (sweetness), 0.04% citric acid (sourness), and 0.2% aluminum sulfate (astringency).

Descriptor selection was based on preliminary evaluations by a panel of three experts [30], and was informed by the methodologies of Laaksonen et al. [3] and Boccorh et al. [19]. The specific “blackcurrant” note was defined using commercial blackcurrant concentrate and crushed blackcurrant berries. The descriptor “firmness/crispiness” was evaluated as a component of mouthfeel. The highest quality currant samples, as selected by the expert panel, were anchored to 100% on a 0–100% scale, representing “firm/crispy”, while 0% represented “soft”.

Prior to evaluating the experimental samples, assessors were familiarized with the attributes and scales. Approximately 20 g of each sample was served in randomly coded containers, and water was provided for palate cleansing between samples. Liking of flavor, odor, and overall acceptability were evaluated using a hedonic scale with verbal anchors ranging from “unacceptable” to “excellent”. Four flavor characteristics (sweet, acid/sour, astringent, and “blackcurrant”) and mouthfeel (firmness/crispiness) were evaluated on unstructured line scales (0–100%), with flavor characteristics ranging from “weak” to “very strong” and mouthfeel ranging from “soft” to “firm/crispy”. Samples were evaluated in three separate sessions, each with five samples representing different currant cultivars (red, white, and black). The entire evaluation was conducted over two days in each year, with each evaluator assessing all 15 samples.

2.5. Statistical Analysis

The results of the chemical analyses were analyzed using one-way analysis of variance (ANOVA) followed by Tukey’s HSD test. The results of the sensory analyses were evaluated using the Kruskal–Wallis test followed by the Nemenyi post hoc test. Principal component analysis (PCA) was used to confirm and visualize differences among samples (cultivars and year of production), with a significance level set at $p \leq 0.05$. All analyses were performed using Statistica 14 (StatSoft, Tulsa, OK, USA).

3. Results and Discussion

To select the most sensorially acceptable cultivars, we emphasized the sensory evaluation of flavor and odor, while also considering the firmness (mouthfeel) of the berries. Generic descriptive analysis, consistent with relevant studies [2–5], was applied for this purpose.

3.1. Comparison of Sensory Characteristics of Red, White, and Black Currants

As anticipated, comparisons between the red, white, and black variants revealed differences in sensory properties, particularly between black currants (*R. nigrum*) and red/white currants (*R. rubrum*). However, these differences were statistically significant only for astringency ($p < 0.05$), which was significantly higher in black currants, and for the characteristic “blackcurrant” note ($p < 0.05$). Differences in appearance and color were also observed, but these results are not included as the study focused on sensory characteristics. Texture, primarily determined by firmness, and sweetness are known to significantly influence currant acceptability. Therefore, firmness/crispiness was also evaluated. All

samples exhibited acceptable texture, with red/white currants demonstrating greater firmness and crispiness than black currants. All samples possessed a pleasant, mildly acidic, sweet flavor. Consistent with Schwarz and Hofmann [2], white currants were perceived as sweeter and received higher ratings, while red currants were perceived as more acidic. Acidity, attributed to organic acids, is a key determinant of red currant flavor. The flavor of black currants was somewhat diminished by their distinct, relatively strong aroma, which was not favorably perceived by the panelists. However, it is important to note that the observed differences between red, white, and black currants varied slightly across the two years of the study. The overall acceptability of individual cultivars fell within a relatively narrow range (44.3–72.1%), corresponding to medium to high acceptability. Black currants received slightly lower ratings. These results suggest that panelists did not exhibit a strong preference for any particular type/variant of currant, despite considerable differences in their properties (color, flavor, and odor). Astringency and the “blackcurrant” note can be considered the primary differentiating factors between red/white and black currants.

3.2. Effect of Cultivar on Sensory Properties of Currants

A comparison of individual cultivars within each of the three variants revealed significant differences ($p \leq 0.05$) in all evaluated properties, with the exception of astringency. Astringency was consistently low across all red and white cultivars, while being higher in all black cultivars. A detailed comparison of the sensory characteristics of individual cultivars within each variant is provided in Table 1, with the best (most acceptable) cultivars within each variant marked with an asterisk.

Sweetness in white cultivars (Table 1a) ranged from 32.5% to 52.4%, acidity ranged from 38.2% to 72.3%, and astringency was very low (19.1–34.7%). Among the white cultivars, ‘Victoria’ was evaluated as the most acceptable in both years (68.7% and 72.1%) due to its excellent flavor, very good odor, sweetness with minimal astringency, and firm, crispy texture. ‘Orion’ also had very good flavor, attributed to high sweetness and very low astringency, but its less crispy texture lowered its overall rating. ‘Jantar’ was considered the least acceptable (64.2% and 50.9%) due to its less appealing flavor, lower sweetness, and noticeable astringency. Its texture was also softer and less crispy. A distinct earthy off-flavor was detected in ‘Primus’, which was negatively perceived by the evaluators.

In red currants (Table 1b), all cultivars were mildly sweet (24.8–51.5%) and more acidic (39.3–69.6%), with low astringency (23.8–29.4%). This low astringency slightly contradicts Schwarz and Hofmann [2], who stated that both acidic and astringent tastes are key determinants of red currant flavor. Among the red cultivars, ‘Rubigo’ was evaluated as the most acceptable in both years (70.2% and 62.2%) due to its superior flavor, odor, and texture. ‘Tatran’ was the least acceptable (56.3% and 52.2%) due to its strong acid and astringent taste and a distinct earthy off-flavor.

The overall acceptability of black cultivars (Table 1c) varied considerably (44.3–68.3%). ‘Demon’ (68.3% and 68.1%) and ‘Moravia’ (64.9% and 66.6%) were considered the best in both years, with a pleasantly sweet flavor, very good odor, and a balanced, characteristic “blackcurrant” note, although their texture was less crispy. ‘Ben Gairn’ had the lowest acceptability (46.4% and 44.3%), likely due to its less appealing flavor with an atypical rancid off-flavor that masked the characteristic “blackcurrant” note. This may indicate increased sensitivity of this cultivar and its specific storage requirements.

These results are difficult to compare with existing literature due to the scarcity of studies on the sensory quality of fresh currants. Most studies focus on juices, a commercially significant product. However, the sensory characteristics (flavor and aroma) of fresh berries and processed juice can differ significantly due to processing interventions such as heat [13] or enzyme treatment [7] and sucrose addition [20], which can substantially alter the flavor.

Table 1. (a). Comparison of sensory characteristics of single cultivars within white currants; (b) comparison of sensory characteristics of single cultivars within red currants; (c) comparison of sensory characteristics of single cultivars within black currants.

(a)							
Sensory Characteristics		Year	Currant Cultivars/Rating in %				
			White				
			Bl	Jan *	Or	Pr	Vic **
Flavor characteristics	Flavor	2020	64.1 ^{aA} ± 9.3	55.9 ^{aA} ± 8.8	77.1 ^{bA} ± 11.2	63.4 ^{aA} ± 10.2	77.9 ^{bA} ± 7.2
		2021	65.7 ^{aA} ± 5.6	63.8 ^{aA} ± 9.9	70.8 ^{aA} ± 7.9	65.1 ^{aA} ± 10.2	71.7 ^{aA} ± 9.5
	Odor	2020	50.6 ^{aA} ± 10.5	51.1 ^{aA} ± 10.4	65.1 ^{bA} ± 10.6	42.4 ^{aA} ± 8.7	64.9 ^{bA} ± 8.4
		2021	64.3 ^{aB} ± 6.2	54.3 ^{bA} ± 10.5	64.5 ^{aA} ± 8.3	47.6 ^{aA} ± 9.5	73.7 ^{cA} ± 9.4
	Sweet	2020	32.5 ^{aA} ± 9.5	34.5 ^{aA} ± 9.9	49.5 ^{bA} ± 8.8	49.7 ^{Ab} ± 10.4	52.4 ^{bA} ± 10.9
		2021	47.2 ^{abB} ± 7.5	37.8 ^{bA} ± 8.0	45.3 ^{abA} ± 8.5	49.2 ^{aA} ± 9.1	50.8 ^{aA} ± 9.6
	Acid	2020	72.3 ^{aA} ± 10.7	63.1 ^{abA} ± 9.2	49.1 ^{bA} ± 9.8	48.4 ^{bA} ± 9.3	53.6 ^{abA} ± 10.3
		2021	50.3 ^{aA} ± 10.1	49.2 ^{aA} ± 6.5	57.4 ^{aA} ± 9.2	38.2 ^{bA} ± 9.1	45.1 ^{abA} ± 11.7
	Astringent	2020	34.7 ^{aA} ± 10.0	34.2 ^{abA} ± 10.3	19.1 ^{cA} ± 6.6	22.6 ^{bcA} ± 7.1	20.6 ^{bcA} ± 10.1
		2021	33.9 ^{aA} ± 7.5	34.1 ^{aA} ± 8.9	24.5 ^{aA} ± 11.8	32.4 ^{aA} ± 8.9	20.9 ^{aA} ± 7.4
	Blackcurrant	2020	nd	nd	nd	nd	nd
		2021	nd	nd	nd	nd	nd
	Firmness/crispiness	2020	66.0 ^{aA} ± 9.5	49.4 ^{bA} ± 7.8	50.7 ^{bA} ± 10.2	49.7 ^{bA} ± 9.3	66.2 ^{aA} ± 9.1
		2021	49.1 ^{aB} ± 10.0	49.6 ^{abA} ± 10.6	48.4 ^{aA} ± 10.5	58.3 ^{bcA} ± 11.2	62.4 ^{cA} ± 9.7
	Overall acceptability	2020	65.0 ^{aA} ± 10.0	64.2 ^{aA} ± 7.6	65.3 ^{aA} ± 10.1	65.7 ^{aA} ± 9.9	68.7 ^{aA} ± 9.4
		2021	66.0 ^{abA} ± 5.4	50.9 ^{cA} ± 11.5	66.3 ^{abA} ± 6.8	62.2 ^{aA} ± 8.1	72.1 ^{bA} ± 7.9
(b)							
Sensory Characteristics		Year	Currant Cultivars/Rating in %				
			Red				
			Det	JVT	Rov	Rub **	Tat *
Flavor characteristics	Flavor	2020	63.7 ^{abA} ± 8.4	49.8 ^{cA} ± 7.7	67.3 ^{abA} ± 9.0	69.6 ^{bA} ± 8.9	58.5 ^{acA} ± 11.9
		2021	46.6 ^{aB} ± 10.9	62.4 ^{bcA} ± 9.5	54.4 ^{abB} ± 10.3	64.4 ^{cA} ± 8.4	53.1 ^{abA} ± 10.0
	Odor	2020	58.7 ^{acA} ± 8.4	46.2 ^{bA} ± 7.7	54.9 ^{abcA} ± 8.5	62.2 ^{cA} ± 9.6	52.8 ^{abA} ± 9.7
		2021	39.6 ^{aB} ± 8.8	56.2 ^{bA} ± 9.8	45.8 ^{aA} ± 8.3	59.2 ^{bA} ± 9.3	42.6 ^{aA} ± 8.2
	Sweet	2020	31.5 ^{aA} ± 7.3	46.5 ^{bA} ± 8.4	24.8 ^{aA} ± 8.5	51.5 ^{bA} ± 9.0	33.7 ^{aA} ± 9.8
		2021	40.2 ^{acA} ± 8.5	26.8 ^{bB} ± 10.0	41.3 ^{aB} ± 9.5	45.6 ^{aA} ± 10.4	33.1 ^{bcA} ± 6.5
	Acid	2020	60.7 ^{abA} ± 9.5	39.3 ^{cA} ± 7.8	64.8 ^{abA} ± 9.0	57.9 ^{aA} ± 9.9	69.6 ^{bA} ± 9.9
		2021	48.7 ^{aA} ± 10.1	66.9 ^{cB} ± 10.8	54.9 ^{abA} ± 9.5	46.8 ^{aA} ± 11.0	60.4 ^{bcA} ± 8.8
	Astringent	2020	23.8 ^{aA} ± 7.4	29.4 ^{aA} ± 7.9	27.1 ^{aA} ± 9.4	26.5 ^{aA} ± 9.9	27.9 ^{aA} ± 10.8
		2021	27.7 ^{aA} ± 9.2	25.2 ^{aA} ± 11.1	26.9 ^{aA} ± 10.5	28.6 ^{aA} ± 10.2	29.1 ^{aA} ± 11.7
	Blackcurrant	2020	nd	nd	nd	nd	nd
		2021	nd	nd	nd	nd	nd
	Firmness/crispiness	2020	53.6 ^{aA} ± 6.6	39.3 ^{cA} ± 6.9	57.6 ^{abA} ± 9.6	62.3 ^{bA} ± 8.8	55.3 ^{abA} ± 9.4
		2021	53.9 ^{aA} ± 8.8	47.2 ^{aA} ± 10.8	56.3 ^{aA} ± 9.5	65.7 ^{bA} ± 11.6	48.9 ^{aA} ± 10.4
	Overall acceptability	2020	67.1 ^{aA} ± 7.6	57.9 ^{bA} ± 5.4	66.3 ^{aA} ± 8.5	70.2 ^{aA} ± 8.4	56.3 ^{bA} ± 10.7
		2021	50.7 ^{aB} ± 11.4	58.8 ^{abA} ± 5.6	53.3 ^{bA} ± 9.3	62.2 ^{bA} ± 7.1	52.2 ^{aA} ± 10.7
(c)							
Sensory Characteristics		Year	Currant Cultivars/Rating in %				
			Black				
			BG *	BH	Cer	Dem **	Mor
Flavor characteristics	Flavor	2020	51.6 ^{aA} ± 10.4	53.5 ^{aA} ± 8.6	49.9 ^{aA} ± 10.3	64.8 ^{bA} ± 11.4	59.6 ^{abA} ± 9.4
		2021	45.5 ^{aA} ± 9.2	55.6 ^{abA} ± 11.7	54.8 ^{abA} ± 9.2	63.2 ^{bA} ± 10.1	60.2 ^{bA} ± 8.1
	Odor	2020	59.2 ^{acA} ± 10.6	67.9 ^{bcA} ± 7.4	56.9 ^{aA} ± 11.2	70.3 ^{bA} ± 8.4	74.4 ^{bA} ± 6.9
		2021	58.1 ^{aA} ± 11.5	68.6 ^{bcA} ± 9.7	63.2 ^{abA} ± 10.6	74.3 ^{cA} ± 8.4	71.9 ^{bcA} ± 8.8
	Sweet	2020	37.2 ^{abA} ± 7.9	35.0 ^{acA} ± 9.3	25.5 ^{cA} ± 7.6	39.6 ^{abA} ± 10.0	44.9 ^{bA} ± 10.9
		2021	39.1 ^{abA} ± 10.4	39.9 ^{aA} ± 10.0	30.3 ^{bA} ± 8.7	44.9 ^{aA} ± 9.9	45.1 ^{aA} ± 9.7
	Acid	2020	49.1 ^{aA} ± 10.4	63.7 ^{bA} ± 7.8	65.1 ^{bA} ± 10.0	51.6 ^{aA} ± 9.9	53.2 ^{aA} ± 7.5
		2021	43.7 ^{aA} ± 9.8	71.3 ^{cA} ± 9.5	67.4 ^{cA} ± 9.9	50.5 ^{abA} ± 10.3	55.2 ^{bA} ± 9.9
	Astringent	2020	52.1 ^{aA} ± 10.5	51.3 ^{aA} ± 10.1	52.6 ^{aA} ± 10.6	51.9 ^{aA} ± 9.4	52.3 ^{aA} ± 10.8
		2021	51.4 ^{aA} ± 10.8	52.0 ^{aA} ± 11.2	58.1 ^{aA} ± 10.1	52.1 ^{aA} ± 9.8	53.7 ^{aA} ± 10.3
	Blackcurrant	2020	44.8 ^{aA} ± 9.9	54.9 ^{abA} ± 9.4	52.4 ^{abA} ± 8.2	55.7 ^{bA} ± 11.2	56.2 ^{bA} ± 11.4
		2021	37.5 ^{aA} ± 5.4	55.5 ^{bA} ± 9.1	52.8 ^{bA} ± 8.4	59.5 ^{bA} ± 9.6	59.4 ^{bA} ± 8.4
	Firmness/crispiness	2020	45.6 ^{aA} ± 9.9	53.2 ^{aA} ± 10.1	49.8 ^{aA} ± 9.9	51.7 ^{aA} ± 9.3	47.2 ^{aA} ± 10.6
		2021	51.1 ^{acA} ± 10.3	58.5 ^{aA} ± 10.2	42.7 ^{acA} ± 8.3	43.1 ^{acA} ± 6.5	39.5 ^{aA} ± 9.4
	Overall acceptability	2020	46.4 ^{aA} ± 10.3	62.0 ^{bcA} ± 7.2	57.5 ^{bA} ± 10.9	68.3 ^{cA} ± 8.3	64.9 ^{bcA} ± 8.0
		2021	44.3 ^{aA} ± 10.5	62.2 ^{bA} ± 9.5	60.7 ^{bA} ± 10.1	68.1 ^{bA} ± 8.8	66.6 ^{bA} ± 6.7

Note: Sample (cultivar) labeling: Bl—'Blanka', Jan—'Jantar', Or—'Orion', Pr—'Primus', Vic—'Victoria'; Det—'Detvan', JVT—'Jonkheer van Tets', Rov—'Rovada', Rub—'Rubigo', Tat—'Tatran'; BG—'Ben Gairm', BH—'Ben Hope', Cer—'Ceres', Dem—'Demon', Mor—'Moravia'; different letters in the same row indicate significant differences (Kruskal–Wallis test, $p \leq 0.05$) between cultivars and different capital letters in the same column indicate significant differences between 20/21 season; nd—not detected. * the worst cultivar; ** the best cultivar.

Descriptor selection in this study was inspired by the work of Boccorh et al. [15,19] and Brennan et al. [20], who first identified basic aroma descriptors for black currant juices, including sweet, acidic, and astringent tastes and fruity, grassy, citrus, caramel, and “blackcurrant” aromas. These attributes were also used in other studies on black currant juices [3–5,21], sometimes with additional descriptors such as “catty”, “minty”, and “earthy”. The only study focusing on fresh black currant berries, by Jung et al. [6], provided a brief evaluation of their aroma profile based on GC-olfactometry. No detailed sensory evaluation of red and white currants has been performed to date. The work of Schwarz and Hofmann [2], who evaluated an extract from fresh mashed red currant berries and described phenolics as key astringent compounds using sensory analysis, is a relevant exception.

The main objective of this study was to compare currant cultivars, as cultivar is a key factor affecting fruit flavor, along with post-harvest processing and storage. Studies comparing currant cultivars [6] or juices produced from different cultivars [3,4,20] are very scarce. Nevertheless, in accordance with our results, they all confirm differences in sensory characteristics, especially flavor. No scientific studies specifically addressing the cultivars analyzed in this study were found, although Jung [26] conducted a brief evaluation involving ‘Rovada’, but its aroma profile was not described in detail. Some brief information can be found in growers’ manuals, which generally describe currants as having a firm texture and juicy flavor, with white and black currants being sweet and red currants being sweet tart, although each variety should have its unique flavor profile and texture.

3.3. Volatile Compounds Identified in Currant Samples Using HS-SPME-GC-FID/MS Method

Fruit flavor is closely related to the content and composition of volatile (aroma) compounds, which can be measured instrumentally. Therefore, the sensory evaluation was supplemented by volatile compound analysis. This approach has been particularly understudied in red and white currants.

A total of 54 volatile compounds were identified in the 15 analyzed currant cultivars using HS-SPME-GC-FID/MS. They were classified into six groups based on their chemical characteristics: alcohols (14), aldehydes (11), esters (12), terpenes and terpenoids (14), ketones (2), and an acid (1). An overview, indicating their presence in each variant (red/white/black), is provided in Supplementary Material Table S1. All these compounds, except ethyl heptanoate, have been previously found in black currants by numerous authors [6,7,10,12–14,17] and are known to be aroma-active. However, as shown in Table S1, their aroma descriptions from the open-access PubChem database can vary significantly depending on factors such as their concentration in sample, the sensitivity of the evaluator, etc.

The volatile profile of black currants has been investigated for several decades, with over 200 aroma compounds identified. Most authors report alcohols, esters, terpenes, and terpenoids as major components [9,12,13,16,17]. This study also found aldehydes to be a substantial group.

Alcohols were the most abundant compounds identified in all samples. Several metabolic pathways are involved in their biosynthesis. Six primary alcohols—ethanol, butan-1-ol, pentan-1-ol, hexan-1-ol, octan-1-ol, and nonan-1-ol—were identified. These are formed by enzymatic reduction of corresponding aldehydes by alcohol dehydrogenases. Free ethanol is a product of fermentation and is found in very small quantities in fruit; however, bound in esters, it is a common component of fruit aroma [31]. Other short-chain (<C₁₈) primary alcohols contribute to the characteristic flavors of fruits, but according to Liu et al. [17], they do not significantly contribute to currant aroma in their free form. They are less important than their aldehyde homologs due to higher odor thresholds [31].

Among these, only hexan-1-ol, generated from linoleic acid as part of the C₆ group, was recognized as an important contributor to black currant aroma [6]. The identified secondary alcohols, butan-2-ol and pentan-2-ol, are assumed to be formed by enzymatic reduction of corresponding methyl ketones. The branched-chain alcohols, 2-methylpropan-1-ol and 3-methylbutan-1-ol, are derived from amino acids (Leu, Ile) [31]. Among these, 3-methylbutan-1-ol, along with the unsaturated C₆ alcohols (E)-2-hexen-1-ol and the isomers (E)- and (Z)-3-hexen-1-ol, was previously recognized as a key component of black currant aroma [13,16]. These are formed from the unsaturated linoleic and linolenic acids via the lipoxygenase pathway after plant tissue disruption [6]. 1-Octen-3-ol, known in cheese for its typical mushroom aroma, has also been isolated from plants and, surprisingly, identified as a key component of black currant aroma, contributing a floral note [12].

Five straight-chain aldehydes—ethanal, hexanal, octanal, nonanal, and decanal—were identified. They are formed via β -oxidation of unsaturated fatty acids; saccharides (glucose, fructose, and sucrose) or amino acids can also be precursors [31]. Octanal and nonanal were previously recognized as key aroma components of black currants [12–14,16,17]. Three unsaturated aldehydes—(E)-2-hexenal, (Z)-3-hexenal, and (E)-2-octenal—were identified. These, along with their corresponding unsaturated alcohols, are generated from the oxidative degradation of linolenic and linoleic acids by the lipoxygenase pathway [6]. (E)-2-hexenal was previously recognized as a key component of black currants [12]. These C₆ and C₈ compounds are important contributors to the characteristic flavors of many fruits [31], but their profile can be rapidly altered by isomerization or reduction; accordingly, Jung et al. [6] identified the constitutional isomer (E)-3-hexenal. The branched-chain aldehydes 2-methylbutanal and 3-methylbutanal are formed from amino acids, similar to the corresponding alcohols. Benzaldehyde, derived from the shikimate pathway via phenylalanine [31], has been identified as a key component of black currants [14,17].

Esters are one of the largest groups of volatile constituents in nearly all fruits, contributing to their fruity flavor; they are also important in black currant berries [6,12,17]. They can be formed by different reactions: esterification, alcoholysis, acidolysis, or transesterification. These reactions can occur spontaneously or be catalyzed by esterases and lipases [14]. Fatty acids, particularly those with 2, 4, and 6 carbon straight chains, play a major role in ester synthesis, while the source of alcohols and aldehydes for ester synthesis in fruit is not fully understood [31]. Acetic acid and ethanol are most often bound in esters, and Jung [26] also mentions butanoic acid esters as quantitatively important. Four acetates (methyl, ethyl, butyl, and octyl acetate) and five ethyl esters (ethyl butanoate, propanoate, hexanoate, heptanoate, and decanoate) were identified in the samples. Ethyl butanoate and hexanoate were previously recognized as key components of black currants [13,14,16]. Based on GC-olfactometry, Varming et al. [16] consider the following esters as the top five most potent compounds in black currant juice aroma: methyl acetate, ethyl propanoate, methyl butanoate, ethyl butanoate, and ethyl hexanoate.

Terpenes and their oxygenated derivatives are important volatile compounds in nearly all fruit types, including black currants [8], and their contribution to fruit aroma is well established. Many are stored in plants as glycosides, released by glycosidase activity during maturation. Consequently, they are reported to be indicators of fruit freshness, maturity, botanical and geographical origin, quality, and authenticity [7]. They are derived from saccharides through the metabolic intermediate mevalonic acid, which provides the basic structural isoprene unit; many others are formed through transformation of the initial products by oxidation, dehydrogenation, acylation, and other reactions [31]. There has been particular interest in terpenes in recent years, mainly because of the biological activity shown by some [11]. Consistent with the literature [7,9], terpenes were numerous in the samples. Eight monoterpenes (β -pinene, sabinene, limonene, δ -3-carene, α -terpinene, γ -

terpinene, terpinolene, and β -phellandrene) and five monoterpenoids (linalool, α -terpineol, terpinen-4-ol, β -damascenone, and rose oxide) were identified. Terpenoids are known for their strong flavor and represent the characteristic black currant flavor, while sesquiterpenes are not considered contributors to black currant aroma. The only sesquiterpene found in this study was β -caryophyllene. Limonene, β -phellandrene, linalool, α -terpineol, β -damascenone, and rose oxide are known as key aroma components of black currants [12,13].

Although most ketones have relatively high flavor thresholds, some, such as the alkan-2-ones, are still important to flavor. They are formed by β -oxidation and decarboxylation of fatty acids, and short-chain (C_5 – C_{11}) alkan-2-ones are highly potent flavor molecules found in numerous plants. They are also assumed to be precursors of aroma-active secondary alcohols [31]. Only heptan-2-one was identified in the samples, consistent with Jung et al. [6]. 1-Octen-3-one, along with the corresponding alcohol 1-octen-3-ol, is derived from linoleic acid. These are important components of cheese aroma (with a typical mushroom note) but also occur naturally in some plants and have, surprisingly, been identified as key components of black currant aroma [6,12,13].

Carboxylic acids are important components of plant foods. Acids up to C_{10} play a significant role in aroma, not only directly but also as precursors to other aromatic substances (esters, lactones, etc.). Only acetic acid was identified in the samples; it is formed by sugar degradation (glucose, fructose, and sucrose) and, along with malic and citric acids, is a major contributor to fruit sourness [31].

Sulfur compounds should also be mentioned. Although present at very low concentrations, they are known to contribute to the characteristic flavor of black currants [15,19]. They were not detected in the samples, likely because their concentrations were below the detection limit of the method used. Their thermal lability might be another reason for their absence.

In contrast to black currants, there are very few studies on red/white currants. Yu et al. [18] investigated the chemical composition of various berry fruits (e.g., sea buckthorn, blueberry), including red currants. They identified 18 volatile compounds, of which only the esters methyl, ethyl, and octyl acetate were consistent with our findings. The only more comprehensive study is that of Jung [26], who studied volatile constituents of fresh red and white currants in greater detail. Using liquid–liquid extraction, they identified a total of 139 compounds in red currants and 92 in white currants. The major classes were C_6 compounds (i.e., C_6 alcohols and aldehydes) and acids, with (Z)-3-hexen-1-ol, (Z)-3-hexenal, (E)-2-hexenal, 1-octen-3-one, acetic acid, linalool, and β -damascenone identified as key components of red currant aroma. With the exception of (Z)-3-hexenal, all of these were also identified in our samples of red/white currants, although not in all varieties (see Table S1).

In total, 40, 39, and 54 volatile compounds were identified in red, white, and black currants, respectively (see Table S1). As expected, and consistent with Jung [26], the red and white currants were quite similar in terms of identified compounds, as they belong to the same species, *R. rubrum*, while black currants had the most substances, mainly from the group of terpenoids. Of all identified terpenes, sabinene, δ -3-carene, and rose oxide have not yet been identified in red/white currants and could, therefore, be tentatively considered specific to black currants. Alcohols, aldehydes, and esters were the most numerous in all currant variants (red/white/black). In contrast to black currants, terpenes and terpenoids constituted only a minor compound class in the red variants, which is also consistent with Jung [26].

Regarding the individual cultivars within the red/white/black variants, they were similar in terms of identified compounds (see below). Typical HS-SPME-GC-FID chromatograms of compounds identified in selected representatives (the sensorially most

acceptable) of red/white/black cultivars are depicted in Figure 1, showing clear differences in the volatile composition between black and red/white currants.

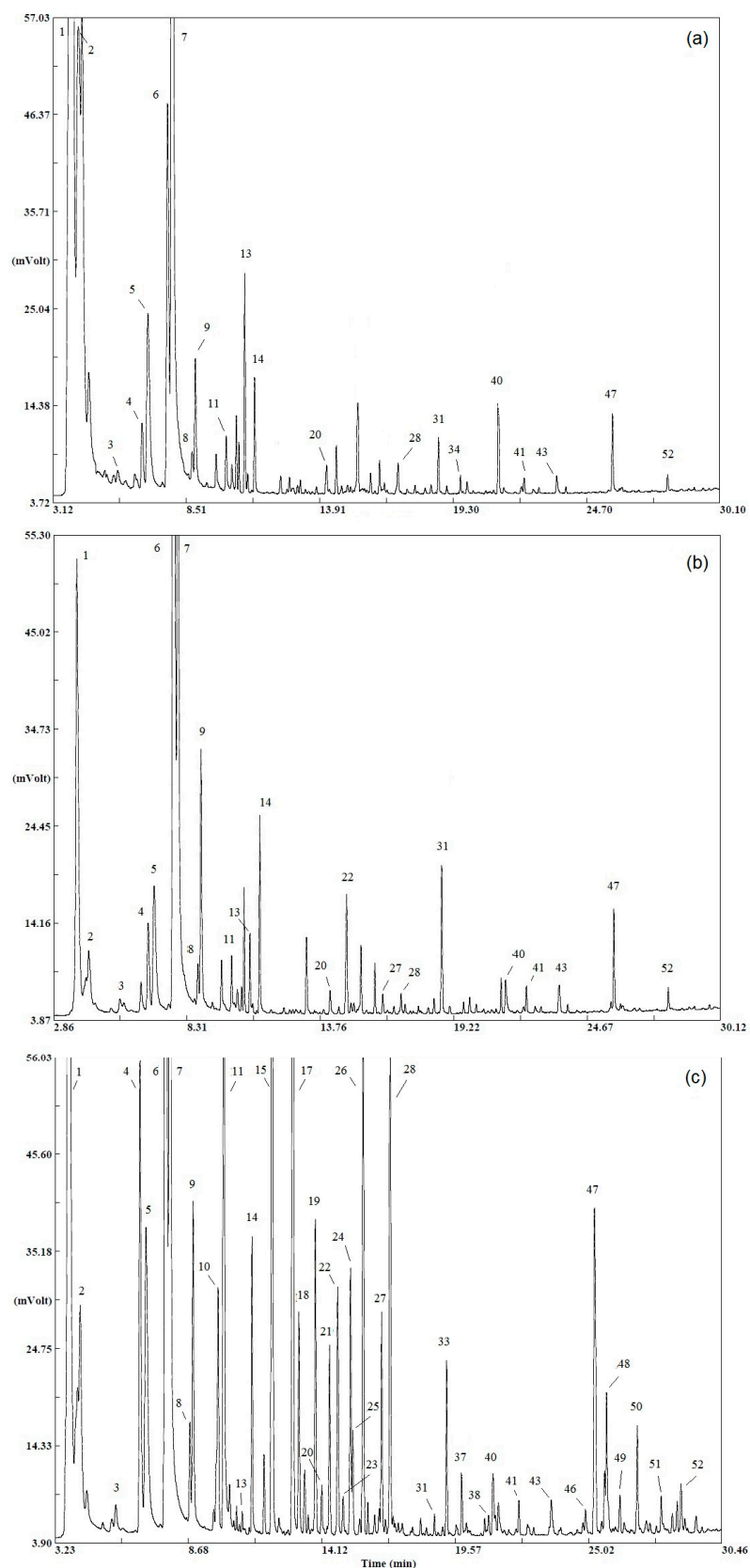


Figure 1. Example of HS-SPME-GC-FID chromatograms of compounds identified in selected red/white/black currant cultivars ((a) white Victoria, (b) red Rubigo, and (c) black Demon). For peak identification, see Table S1 in Supplementary Material).

3.4. Effect of Cultivar on Volatile Composition of Currants

As confirmed by many authors, fruit volatile profiles can be influenced by various pre-harvest (e.g., cultural practices) and post-harvest (e.g., processing, storage) factors [31]. Considering that the tested currants were cultivated under the same conditions, harvested at full ripeness, and analyzed fresh, the cultivar is the main factor influencing their variability. However, very few publications compare currant cultivars. We can mention studies by Jung et al. [6], Marsol-Vall et al. [7], Kampuss et al. [10], and Liu et al. [17], who compared several black currant cultivars (none of which overlapped with ours) and confirmed the significant effect of cultivar on aroma compound composition. Only Ruiz del Castillo and Dobson [11] analyzed differences in the terpene composition of ‘Ben Hope’, a well-established cultivar grown in the UK, describing the terpene fraction as largely associated with the distinctive black currant aroma. In the case of red currants, Jung [26] analyzed ‘Jonkheer van Tets’, ‘Rovada’, and ‘Tatran’—cultivars also included in our study. Many studies do not mention cultivars at all, meaning that most of the cultivars we analyzed have not yet been the subject of published research.

The variance in the content of compounds identified in red/white/black currants is provided in Supplementary Material Table S2. Consistent with previous studies, alcohols, aldehydes, and esters were the major classes of volatile compounds and quantitatively predominated in nearly all varieties. In contrast, Jung et al. [6] also found terpenes to be predominant in several black currant cultivars.

Despite the similar number of compounds identified, significant differences in the proportions of most volatiles were observed between cultivars within both the red/white and black currant groups (see Table S2). This is consistent with the findings of other authors [7,9], who also found differences between cultivars in the quantitative rather than the qualitative composition of compounds.

A comparison of volatile compounds in single cultivars within red/white/black currant variants is provided in Supplementary Material Table S3.

Comparing individual compound classes, alcohols ranged from 11.5% to 48.5% in red/white currants and were less abundant in black currants (9.2–37.4%). The following alcohols were present in all cultivars (concentration range in parentheses): ethanol (87.6–1090.2 µg/kg), butan-1-ol (0–53.2 µg/kg), pentan-1-ol (0–14.4 µg/kg), hexan-1-ol (4.7–45.8 µg/kg), butan-2-ol (3.4–98.2 µg/kg), and 1-octen-3-ol (0–38.5 µg/kg), with ethanol quantitatively predominating. The differences between cultivars were significant for all detected alcohols except (E)-3-hexen-1-ol ($p = 0.33$). This compound was found in minimal concentrations (0–6.2 µg/kg) and only in eight red and black cultivars (see Table S3). Consistent with Jung [26], it was not present in white currants. (E)- and (Z)-3-hexen-1-ol, in contrast to Jung [26], where these compounds were found to be predominant in black currants, were present only in small quantities (<6.6 µg/kg) in our samples.

Aldehydes ranged from 15.1% to 30.2% in red/white cultivars and from 21.1% to 37.4% in black cultivars, with ethanal predominating in nearly all cultivars. Ethanal (19.6–455.7 µg/kg), hexanal (18.9–85.6 µg/kg), 2-methylbutanal (13.7–231.1 µg/kg), 3-methylbutanal (37.3–266.6 µg/kg), octanal (3.3–136.6 µg/kg), and nonanal (0–17.9 µg/kg) were present in all cultivars. Liu et al. [17] found that hexanal, nonanal, and (E)-2-octenal to significantly contribute to the overall aroma of black currants. These compounds were also predominantly present in our black cultivars. Significant differences were found between cultivars for all detected aldehydes except decanal ($p = 0.09$). In contrast to Liu et al. [17], who considered this compound a significant contributor to black currant aroma, it was found in minimal concentrations (0–6.4 µg/kg) in 10 red and black cultivars.

Esters ranged from 26.3% to 57.0% in red/white cultivars and from 23.5% to 43.4% in black cultivars, with ethyl propanoate significantly predominating in all cultivars. In

contrast to Jung [26], a quantitative preponderance of ethyl esters compared to methyl esters was observed. Nearly all identified esters were present in all cultivars: methyl acetate (0–104.2 µg/kg), ethyl acetate (4.9–38.3 µg/kg), butyl acetate (4.9–112.6 µg/kg), ethyl propanoate (80.9–859.0 µg/kg), methyl butanoate (4.7–57.9 µg/kg), ethyl butanoate (8.7–149.2 µg/kg), and octyl acetate (0–13.2 µg/kg). Consistent with Jung [26], they varied considerably depending on the cultivar, except for ethyl decanoate ($p = 0.09$), which was present in a range of 4.0–34.6 µg/kg, while published studies have found it only in traces in black currants (see Table S2). Consistent with our results, Liu et al. [17] and Jung [26] state that black currant berry profiles are dominated by short-chain esters, mentioning methyl and ethyl butanoate as the main ones, which also significantly prevailed in our black cultivars over the red ones. Harb et al. [14] also found high amounts of hexyl esters, which were not present in our samples.

Terpenes and terpenoids, the largest group of plant secondary metabolites, are not present in abundant levels in fruits [17]. They were more typical and abundant in black cultivars (6.0–20.4%) compared to red/white cultivars (1.8–10.6%). Consistent with our results, Jung [26] and Ruiz del Castillo and Dobson [9] observed large variations in the proportions of most terpenes and terpenoids. β -Pinene (0–46.6 µg/kg), linalool (3.5–74.5 µg/kg), and β -damascenone (3.0–11.5 µg/kg) were present in all cultivars. Marsol-Vall et al. [7], consistent with our results, stated that monoterpenoids are the most abundant among terpenoids, with limonene, δ -3-carene, and γ -terpinene prevailing. Liu et al. [17] also mentioned β -damascenone, but it was only present in small quantities in our samples.

Ketones, consistent with the study by Liu et al. [17], showed low levels (<4%) in all cultivars, as did acids.

Comparing our results with the literature is difficult because relatively few studies analyze fresh berries. More often, different products are analyzed [8,13], and the aromatic profile is then influenced by technological operations such as homogenization, juice extraction, or heat treatment. Moreover, only some studies report exact quantities (µg/kg) [6,17,26]; others express results as relative percentages [9,12]. For clarity, Table S2 shows the concentration range of each compound reported in the literature. As can be seen, the variability of individual compounds between studies is quite large, as in our case, but all coincide on the presence of significant differences between cultivars, mainly in compound content.

Regarding red/white cultivars, the quantitative representation of chemical groups was as follows: esters > alcohols > aldehydes > terpenes > ketones > acids. As mentioned previously, these have been scarcely investigated, and a direct comparison of red/white versus black currants has not yet been published. Jung [26] is one of the few who analyzed red currants and compared them to black currants. In contrast to our results, they found a high concentration of acetic acid as a distinctive feature of red currants; however, they did not find any esters, while Yu et al. [18] found esters to make up more than 40% of the aroma profile of *R. rubrum*. Similarly, in our study, esters were quantitatively the most important group, constituting 30.8–57.0% in white cultivars and 26.3–49.7% in red cultivars. As in the case of black currants, C_6 compounds formed a significant group, with (E)-2-hexenal predominating, and relatively low concentrations of terpenes were found (<10%). Comparing red versus white currants, the aroma composition was very similar, as also concluded by Jung [26].

3.5. Integrated Evaluation of Instrumental and Sensory Data Using PCA Analysis

To better visualize the differences between samples (black vs. red vs. white cultivars and the 2020 vs. 2021 seasons) and the relationships between instrumental (volatile composition) and sensory characteristics, all acquired results were subjected to PCA. PCA

was performed using the averaged ratings ($n = 20$) of all sensory characteristics and the averaged peak area ($n = 2$) of identified chemical groups of volatile compounds. The results for the first two principal components (PCs) are shown in Figure 2. The first three PCs cumulatively explained more than 70% of the total dataset variability.

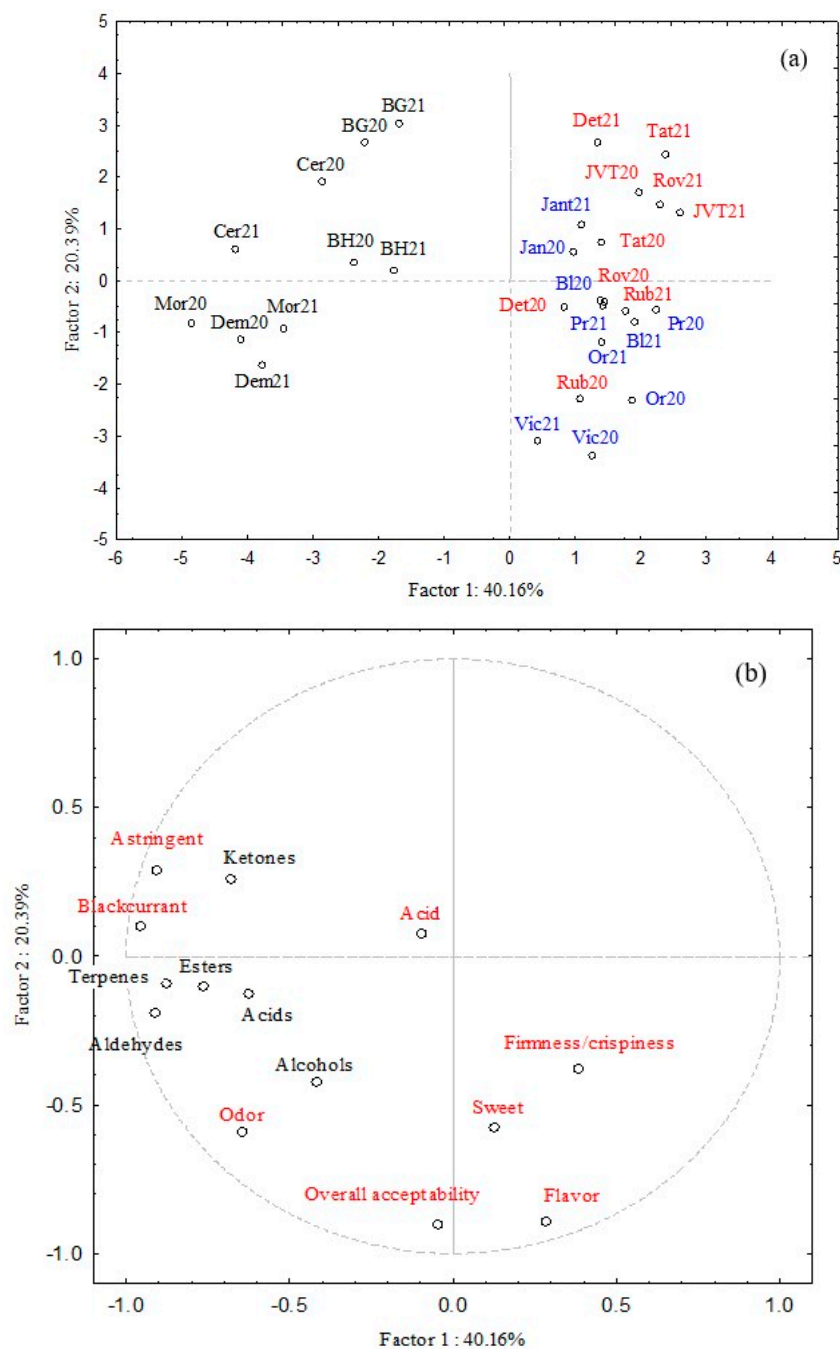


Figure 2. Projection of samples (currant cultivars) (a) and of the variables (groups of volatile compounds and sensory properties) (b) on factor plane obtained with first two PCs. For sample labeling, see Section 2.

Figure 2a demonstrates a distinct separation between samples, although seasonal variability (2020 vs. 2021) is less prominent. While individual cultivars cluster closely, they remain clearly differentiated. Principal component 2 (PC2) effectively distinguishes between the two years for all studied cultivars. The influence of season (2020 vs. 2021) on the aroma profile of currants is further illustrated in Supplementary Material Figure S1

(based on peak area). This figure also highlights the significantly higher total content of compounds, particularly terpenoids, in black currants.

Limited research exists on the effect of season on aroma compounds in currants, and the impact of season on sensory properties, has not been extensively investigated. Marsol-Vall et al. [7] and Boccorh et al. [15,19] reported significant environmental effects, with temperature and radiation identified as key factors. Conversely, Jung et al. [6,26] observed consistent levels of selected compounds in black currants across two years. In this study, Kruskal–Wallis and ANOVA analyses revealed significant differences ($p \leq 0.05$), primarily in flavor and odor (see Table 1). Notably, the previously identified best cultivars ('Victoria', 'Rubigo', and 'Demon') did not exhibit significant differences in sensory properties, indicating their stability and resilience to varying climatic conditions. However, almost all cultivars showed significant differences in aroma composition, especially in alcohol content (see Table S3), confirming the substantial influence of environmental factors. Pinpointing specific effects remains challenging due to compound-specific variations. Climatic conditions for the harvest years (2020/2021) are summarized in Supplementary Material Figure S2 for reference.

Although 2020 was generally warmer than 2021 in the Czech Republic, temperatures during the currant ripening period (typically June to August) were comparable, with a maximum difference of approximately 3 °C.

The effect of currant type (red/white/black) is evident (see Figure 2a), with two distinct clusters. All black currant cultivars are located in the left part of the plot, correlating negatively with PC1. The second cluster, correlating positively with PC1, includes red and white cultivars, indicating their similarity in composition and sensory properties. The red and white cultivar clusters partially overlap, but separation can be observed along PC2. Most red cultivars are located in the upper part, correlating positively with PC2, except for 'Rubigo', which was sensorially evaluated as the most acceptable and is, thus, clearly separated from other red cultivars.

White cultivars are at the bottom, correlating with flavor, firmness, and overall acceptability. 'Jantar' is the only exception, being considered the least acceptable of the white cultivars. This suggests that white currants were sensorially preferred over red currants, likely due to their sweeter taste, better flavor, and texture, particularly their firmness/crispiness.

PCA also confirmed the distinctly different composition of black currant cultivars, which (unlike red/white cultivars) show a strong correlation with aldehydes, ketones, acids, esters, and terpenes. They are also characterized by their astringent and "blackcurrant" flavor notes [13,15,19], which were strongly correlated with each other. However, these properties correlated negatively with overall flavor, indicating that they are generally perceived negatively by consumers. The flavor of black currants is generally less preferred than that of red/white cultivars. As expected, flavor contributed most significantly to the overall acceptability of the samples. Sweetness correlated negatively with acidity and astringency (see Figure 2b), which, consequently, contributed negatively to sample acceptability. It can be inferred that assessors/consumers prefer sweeter, less acidic currants.

To estimate which compounds contribute to sample flavor, odor activity values (OAVs)—the ratio of a compound's concentration to its odor threshold—were calculated. Because currant berries primarily consist of water, odor thresholds in water, obtained from the literature, were used.

In black currants, the following compounds had OAVs ≥ 1 (exact values in parentheses) and were, therefore, considered to contribute to their aroma (aroma descriptions are provided in Table S1): β -damascenone (1520) > 1-octen-3-one (298) > δ -3-carene (55) > 3-methylbutan-1-ol (30) > (Z)-3-hexenal (17) > ethyl butanoate (12) $\approx$ ethyl hex-

anoate (12) $\approx$ rose oxide (12) > hexanal (9) > ethyl propanoate (8) > 1-octen-3-ol (6) > octanal (5) > nonanal (4) > ethyl heptanoate (2) $\approx$ (E)-2-octenal (2). The remaining compounds with OAVs < 1 likely make minor or no contributions. This is comparable with Jung [26], who, based on the OAV concept, detected the C₆ compounds hexanal, (Z)-3-hexenal, (E)-2-hexenal, and (Z)-3-hexenol; the short-chain esters ethyl butanoate and methyl butanoate; and the terpenes 1,8-cineole, α -pinene, rose oxide, 1-octen-3-one, and 1-octen-3-ol as odor-active compounds. Of these, β -damascenone, 3-methylbutan-1-ol, octanal, nonanal, ethyl propanoate, and ethyl hexanoate were also recognized as key components in other studies on black currant berries [12,13,16,17].

In red/white currants, the following compounds showed OAVs $\geq$ 1: β -damascenone (>1000) > 1-octen-3-one (>100) > ethyl propanoate (11) > ethyl hexanoate (5–6) > octanal (5) $\approx$ hexanal (5) > ethyl butanoate (4–5) > 1-octen-3-ol (4) $\approx$ nonanal (4). Consistent with our results, the only study dealing with OAV values in red currants [26] identified β -damascenone and 1-octen-3-one as odor-active. However, (E)-2-hexenal and acetic acid, which they found to be important, were detected in concentrations that were too low in our samples, and (Z)-3-hexenal was not detected in our cultivars at all. As shown, β -damascenone (0.002 $\mu\text{g/L}$) and 1-octen-3-one (0.005 $\mu\text{g/L}$), compounds with low odor thresholds, had the highest OAVs in all currant variants. According to Liu et al. [17], fruity, floral, and sweet notes are the major aroma features in currants, to which, according to our results, mainly terpenes and esters with high OAVs likely contribute.

4. Conclusions

This study comprehensively evaluated the sensory and volatile profiles of red, white, and black currant cultivars, revealing significant differences between and within these groups. Sensory analysis highlighted the distinct characteristics of black currants, particularly their higher astringency and unique “blackcurrant” aroma, which, while differentiating, did not translate to higher overall acceptability compared to red and white currants. White currants were generally favored, likely due to their superior sweetness and texture, while red currants were characterized by higher acidity.

Instrumental analysis using HS-SPME-GC-FID/MS identified a wide range of volatile compounds, demonstrating that cultivar significantly influences aroma composition. Black currants exhibited a greater diversity of compounds, especially terpenoids, while red and white currants showed similarities consistent with their shared species. OAV calculations identified key aroma contributors, with β -damascenone being a dominant compound across all cultivars.

PCA analysis effectively integrated sensory and instrumental data, confirming the clear separation of black currants from red and white currants and highlighting the subtle differences between individual cultivars and harvest years. The analysis underscored the importance of sweetness and texture in consumer preference and identified astringency and the “blackcurrant” note as primary differentiating factors.

Based on these comprehensive results, the cultivars ‘Victoria’ (white), ‘Rubigo’ (red), and ‘Demon’ (black) were identified as possessing the best sensory characteristics, making them prime candidates for potential practical applications. However, it is important to acknowledge that further investigation with a larger sample size would be necessary to draw more robust conclusions and establish definitive links between chemical composition, sensory properties, and consumer acceptability. This expanded research would enhance the understanding of these relationships and facilitate more informed decisions regarding cultivar selection and utilization.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app15095156/s1>. Table S1: Volatile compounds identified in white/red/black currant cultivars using HS-SPME-GC-FID/MS method; Table S2: Content of volatile compounds identified in white/red/black currant cultivars in both years (2020 vs. 2021); Table S3: Comparison of volatile compounds of single cultivars within white (a), red (b), and black (c) currants. Figure S1. Comparison of chemical groups of compounds in red/white/black currants (seasonal variability 2020 vs. 2021); Figure S2. Temperature (°C), precipitation (mm), and sunshine (h) during the cultivation of currants (data from the Czech Hydrometeorological Institute).

Author Contributions: Conceptualization, writing—original draft preparation, methodology, E.V.; investigation, data curation, J.P. and J.Z.; writing—review and editing, formal analysis, supervision, P.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by project of Internal grants of Brno University of Technology (Standard project of specific research No. FCH-S-24-8597).

Institutional Review Board Statement: Ethical review and approval were waived for this study, because the evaluation posed no (or negligible) risk to participants. The subject of sensory evaluation was safe natural material (fresh currant fruits). Experiments were performed in accordance with the “IFST Guidelines for Ethical and Professional Practices for the Sensory Analysis of Foods” and with relevant institutional guidelines approved by the internal review board. All evaluators, aged 20–30, participated voluntarily and provided informed consent to participate in the study.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to institutional policies.

Conflicts of Interest: The authors declare no conflicts of interest.

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