

# Analysis and Sensory Evaluation of Jostaberry (*Ribes x nidigrolaria* Bauer) Volatiles

Katrin Hempfling, Oxana Fastowski, Johanna Celik, and Karl-Heinz Engel\*

Lehrstuhl für Allgemeine Lebensmitteltechnologie, Technische Universität München, Maximus-von-Imhof-Forum 2, D-85350 Freising-Weihenstephan, Germany

**ABSTRACT:** Volatiles of jostaberries (*Ribes x nidigrolaria* Bauer)—a hybrid of black currant (*Ribes nigrum* L.) and gooseberry (*Ribes uva-crispa* L.)—were isolated via vacuum headspace extraction and analyzed by capillary gas chromatographic methods for the first time. (*E*)-Hex-2-enal, (*E*)-hex-2-en-1-ol, (*Z*)-hex-3-enal, (*Z*)-hex-3-en-1-ol, methyl butanoate, ethyl butanoate, 2-methylbut-3-en-2-ol, and 1,8-cineol turned out to be the most dominant volatiles. The variability of the volatile profile was shown by the analysis of jostaberries harvested from different locations in Southern Germany and in different years. In addition to ripe jostaberries, underripe berries were also investigated and changes in the volatile profile were followed during the ripening process. By using sensory analysis, key aroma compounds were elucidated. An aroma model prepared by mixing most odor active compounds ((*Z*)-hex-3-enal, 1,8-cineol, ethyl butanoate, (*E*)-hex-2-enal, (*E*)-hex-3-enal, hexanal, pent-1-en-3-one, methyl butanoate, ethyl hexanoate, and oct-1-en-3-one) in their naturally occurring concentrations showed an overall aroma very similar to that of fresh jostaberries.

**KEYWORDS:** *Ribes x nidigrolaria* Bauer, jostaberry, volatiles, aroma, reconstitution

## INTRODUCTION

Jostaberry (*Ribes x nidigrolaria* Bauer) is a hybrid of black currant (*Ribes nigrum* L.) and gooseberry (*Ribes uva-crispa* L.). Both gooseberries and black currants suffered from American powdery mildew or rather leaf spot and white pine blister rust.<sup>1</sup> Therefore, the aim of the first hybridization experiments conducted already in 1929 was the creation of a new species of soft fruit, exhibiting higher resistance to yield- and quality-reducing diseases.<sup>1,2</sup> Jostaberries turned out to be extremely profitable in terms of yield and to exceed the vigor of the parent species. The plants are as hardy as those of gooseberries but have the benefit of having no thorns. At full ripeness, the fruits are dark colored and their size is between those of gooseberries and black currants.<sup>1</sup> Early jostaberry hybrids were not suitable for mechanical harvesting and the commercial production remained limited. Therefore, attempts have been made to breed varieties that can be harvested easily and mechanically.<sup>3</sup> Jostaberries are not only suitable for fresh consumption but also for the production of jams and beverages.<sup>4</sup> Official data on the cultivation of jostaberries are not available; obviously, they still represent a niche product.

Thus far, analytical investigations of jostaberries have been focused on ingredients exhibiting antioxidative properties. First studies date already from 1985; especially during the past decade, this aspect has been studied in depth.<sup>5–9</sup> The phenol content, the antioxidant activity and the concentrations of anthocyanins in jostaberries are between those of gooseberries and black currants. Major anthocyanins of jostaberries were reported to reflect those of both parent species.<sup>8</sup> Another benefit of jostaberries is the high vitamin C content, which reaches nearly the levels in black currants.<sup>1</sup>

Already in 1978 Bauer noted that jostaberries combine both the aroma of gooseberries and the typical notes of black currants.<sup>1</sup> However, flavor compounds of jostaberries have not

been studied thus far. Therefore, the objectives of the present study were (i) to identify and to quantify volatile jostaberry constituents, (ii) to demonstrate the degree of variability in the volatile composition, and (iii) to assess the contributions of single compounds to the overall aroma by gas chromatography-olfactometry (GC-O).

## MATERIALS AND METHODS

**Fruits.** Jostaberries (cultivars not known) were harvested (hand-picked) at different locations in Southern Germany in three seasons. 2010: Freising (19 July); 2011: Oberrottwil (30 June), Lindau (3 July), Deutenkofen (4 July and 11 July), Hangenham (4 July), Freising (13 July); 2012: Deutenkofen (2 July (2 batches)), Freising (16 July). Except for one batch harvested in the underripe state (Deutenkofen on 2 July, 2012), all other fruits were picked at the ripe state. The degree of ripeness was evaluated according to color and firmness. Underripe jostaberries are very hard and their color ranges only from green to light-red, whereas ripe jostaberries are considerably softer and nearly black. Black currants analyzed in this study were purchased at a local market in Freising, Germany (20 June, 2011); they were declared to originate from Oberkirch, a location in Southern Germany. All berries were analyzed within two days after harvest and purchase, respectively. Until analysis, they were stored at 4 °C.

**Chemicals.** Authentic reference chemicals were purchased from commercial sources (Aldrich, Steinheim, Germany; Merck, Darmstadt, Germany) or provided by *Frey+Lau GmbH* (Henstedt-Ulzburg, Germany). Heptan-2-ol was purchased from Fluka (Steinheim, Germany), sodium sulfate from Merck (Darmstadt, Germany) and citric acid, hydrochloric acid and sodium hydroxide from Sigma-Aldrich (Steinheim, Germany). All chemicals used were of analytical grade. The solvents diethyl ether (Honeywell Burdick & Jackson, Seelze,

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Table 1. Volatile Compounds Isolated by Means of VHS from Ripe Jostaberries Harvested in 2011 at Three Locations in Southern Germany<sup>a</sup>

compounds	RI <sup>b</sup>	Lindau <sup>c</sup>	Deutenkofen <sup>e</sup>	Hangenham <sup>e</sup>	remark
		[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	
<i>C<sub>6</sub>-components</i>					
(E)-hex-2-enal	1211	6027 ± 439	5793 ± 857	5176 ± 507	fg,h
(E)-hex-2-en-1-ol	1406	1663 ± 159	1745 ± 920	1547 ± 634	fg,i
(Z)-hex-3-enal	1138	798 ± 125	2299 ± 426	1454 ± 916	fg,i
(Z)-hex-3-en-1-ol	1384	712 ± 143	491 ± 93	502 ± 185	fg,i
(E)-hex-3-enal	1133	164 ± 48	275 ± 80	246 ± 20	fg,i
hexanal	1075	144 ± 23	128 ± 81	140 ± 21	fg,i
hexan-1-ol*	1355	170 ± 53 (a)	48 ± 18 (b)	118 ± 47 (a,b)	fg,i
(E)-hex-3-en-1-ol	1364	78 ± 7	52 ± 20	57 ± 17	fi
(Z)-hex-2-enal	1194	45 ± 10	66 ± 25	39 ± 7	jk
(Z)-hex-2-en-1-ol	1417	5 ± 1	5 ± 2	7 ± 4	fi
hex-5-enal**	1127	n.q. <sup>f</sup> (b)	4 ± 1 (a)	4 ± 1 (a)	jk
<i>esters</i>					
methyl butanoate**	975	3664 ± 905 (b)	1851 ± 448 (c)	5409 ± 621 (a)	fg,i
ethyl butanoate***	1034	633 ± 112 (b)	445 ± 86 (b)	1698 ± 176 (a)	fg,i
methyl (E)-but-2-enoate*	1096	139 ± 27 (a)	92 ± 16 (b)	108 ± 6 (a,b)	fg,i
ethyl (E)-but-2-enoate***	1158	24 ± 5 (b)	24 ± 4 (b)	77 ± 9 (a)	fg,i
methyl hexanoate***	1184	63 ± 4 (a)	19 ± 2 (b)	74 ± 10 (a)	fg,h
methyl benzoate	1613	48 ± 5	62 ± 5	48 ± 9	fg,i
ethyl hexanoate***	1232	13 ± 5 (a,b)	n.q. (b)	26 ± 8 (a)	fg,h
ethyl benzoate	1659	13 ± 11	22 ± 1	24 ± 4	fg,i
hexyl acetate***	1263	3 ± 2 (b)	4 ± 1 (b)	23 ± 5 (a)	fh
methyl octanoate*	1387	20 ± 6 (a,b)	11 ± 2 (b)	23 ± 0 (a)	fh
benzyl acetate	1725	9 ± 1	10 ± 4	14 ± 4	fi
butyl acetate*	1061	5 ± 1 (b)	4 ± 3 (b)	11 ± 3 (a)	fi
ethyl octanoate**	1436	3 ± 2 (b)	2 ± 2 (b)	11 ± 2 (a)	fh
(E)-hex-2-enyl acetate	1332	8 ± 2	16 ± 8	9 ± 4	fi
2-methylbut-3-en-2-yl acetate	1251	n.d. <sup>g</sup>	7 ± 3	8 ± 3	fk,i
methyl salicylate	1743	13 ± 5	12 ± 1	8 ± 2	fh
methyl decanoate***	1588	n.q. (b)	n.q. (b)	6 ± 2 (a)	fh
2-methylpropyl acetate***	1005	n.d. (b)	n.d. (b)	5 ± 1 (a)	fn
ethyl salicylate*	1783	n.q. (b)	2 ± 1 (a,b)	3 ± 1 (a)	fi
ethyl propanoate	945	n.q.	n.q.	n.q.	fi
3-methylbutyl acetate	1110	n.d.	n.q.	n.q.	fi
octyl acetate	1463	n.d.	n.d.	n.q.	fi
chrysanthenyl acetate	1802	n.d.	n.q.	n.d.	jk
linalyl acetate	1552	n.q.	n.d.	n.q.	fi
ethyl decanoate	1635	n.q.	n.d.	n.q.	fi
<i>alcohols</i>					
2-methylbut-3-en-2-ol**	1041	1182 ± 197 (b)	1051 ± 287 (b)	1995 ± 144 (a)	fg,i
2-methylpropan-1-ol**	1084	33 ± 7 (b)	26 ± 6 (b)	117 ± 32 (a)	fg,i
(Z)-pent-2-en-1-ol	1322	30 ± 2	37 ± 5	39 ± 3	fi
butan-1-ol**	1142	15 ± 2 (b)	8 ± 3 (b)	38 ± 10 (a)	fi
(R)-oct-1-en-3-ol***	1452	35 ± 9 (b)	134 ± 27 (a)	25 ± 4 (b)	fg,i,o
pent-1-en-3-ol	1160	24 ± 3	23 ± 3	24 ± 3	fh
octan-1-ol	1560	9 ± 4	12 ± 3	14 ± 2	fh
(Z)-hexa-3,5-dien-1-ol**	1507	12 ± 3 (a)	n.d. (b)	10 ± 2 (a)	jk
pentan-1-ol**	1252	n.q. (b)	6 ± 1 (a)	9 ± 2 (a)	fi
benzylalcohol*	1871	4 ± 1 (b)	5 ± 0 (a,b)	7 ± 1 (a)	fi
(E)-pent-2-en-1-ol**	1315	n.q.(b)	16 ± 6 (a)	7 ± 1 (b)	jk
ethanol**	931	7 ± 2 (a)	12 ± 5 (a)	n.d. (b)	fi
pentan-2-ol	1123	3 ± 3	n.q.	3 ± 3	fi
nonan-1-ol	1646	n.q.	n.q.	n.q.	fi
2-ethylhexan-1-ol	1492	n.d.	n.q.	n.q.	fi
2-phenylethan-1-ol	1906	n.d.	n.q.	n.q.	fi
(E)-hexa-3,5-dien-1-ol	1504	n.q.	n.d.	n.d.	jk

Table 1. continued

compounds	RI <sup>b</sup>	Lindau <sup>c</sup>	Deutenkofen <sup>c</sup>	Hangenham <sup>c</sup>	remark
		[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	
<i>terpenes/terpene alcohols</i>					
1,8-cineol	1200	647 $\pm$ 115	536 $\pm$ 50	557 $\pm$ 84	f,g,h
terpinen-4-ol <sup>*</sup>	1592	101 $\pm$ 39 (a)	47 $\pm$ 6 (a,b)	34 $\pm$ 4 (b)	f,g,i
$\alpha$ -terpineol	1685	26 $\pm$ 12	22 $\pm$ 3	15 $\pm$ 3	f,g,h,p
$\beta$ -pinene	1093	6 $\pm$ 3	7 $\pm$ 2	8 $\pm$ 2	f,h
2-hydroxy-1,8-cineol <sup>**</sup>	1721	3 $\pm$ 1 (b)	4 $\pm$ 0 (a)	4 $\pm$ 1 (a)	f,k,q
$\gamma$ -terpinene	1238	4 $\pm$ 2	6 $\pm$ 1	4 $\pm$ 1	f,i
sabinene <sup>**</sup>	1106	n.d. (b)	4 $\pm$ 1 (a)	2 $\pm$ 2 (a,b)	f,i
2-hydroxy-1,8-cineol <sup>*</sup>	1859	4 $\pm$ 0 (a)	2 $\pm$ 2 (a,b)	n.q. (b)	f,k,q
terpinolene <sup>***</sup>	1272	n.q. (b)	13 $\pm$ 2 (a)	n.q. (b)	f,g,i
limonene <sup>**</sup>	1196	n.q.(b)	3 $\pm$ 1 (a)	n.d. (b)	f,g,i
<i>p</i> -mentha-1,4-dien-7-ol <sup>***</sup>	2053	n.d. (b)	3 $\pm$ 0 (a)	n.d. (b)	j,k
<i>p</i> -cymene <sup>***</sup>	1255	n.d.(b)	3 $\pm$ 0 (a)	n.q. (b)	f,i
camphene	1051	n.q.	n.q.	n.q.	f,i
$\alpha$ -pinene	1013	n.d.	n.q.	n.q.	f,g,i
myrcene	1165	n.d.	n.d.	n.q.	f,g,i
menthol	1644	n.d.	n.q.	n.q.	f,i
camphor	1499	n.d.	n.d.	n.q.	f,i
borneol	1686	n.q.	n.d.	n.d.	f,i
<i>aldehydes</i>					
( <i>E</i> )-pent-2-enal	1120	22 $\pm$ 4	36 $\pm$ 10	25 $\pm$ 4	f,i
nonanal <sup>**</sup>	1391	n.q. (b)	9 $\pm$ 3 (a)	5 $\pm$ 0 (a)	f,h
prop-2-enal <sup>**</sup>	843	n.q. (b)	14 $\pm$ 7 (a)	n.d. (b)	f,i
propanal <sup>**</sup>	801	n.q. (b)	7 $\pm$ 3 (a)	n.d. (b)	f,i
benzaldehyde	1516	n.q.	n.q.	n.q.	f,n
( <i>E,E</i> )-hepta-2,4-dienal	1475	n.d.	n.q.	n.q.	f,i
2-methylbutanal	909	n.q.	n.d.	n.d.	f,i
3-methylbutanal	912	n.q.	n.d.	n.d.	f,i
( <i>E</i> )-hept-2-enal	1317	n.d.	n.q.	n.d.	f,g,i
<i>ketones</i>					
pent-1-en-3-one <sup>**</sup>	1009	20 $\pm$ 4 (b)	62 $\pm$ 6 (a)	49 $\pm$ 9 (a)	f,h
octan-3-one	1254	n.q.	2 $\pm$ 2	2 $\pm$ 2	f,h
acetophenone	1640	n.d.	n.q.	n.q.	f,g,i
oct-1-en-3-one	1296	n.d.	n.q.	n.d.	f,h
menthone	1457	n.d.	n.d.	n.q.	f,i
( <i>Z</i> )-geranylacetone	1859	n.q.	n.d.	n.d.	f,i
<i>others</i>					
C5-compounds	963	32 $\pm$ 4	27 $\pm$ 10	36 $\pm$ 6	f,k,r
isoeugenol	2315	4 $\pm$ 4	n.d.	n.d.	f,i
( <i>E</i> )-linalool oxide	1428	n.d.	n.d.	n.q.	j,k

<sup>a</sup>Correlation analysis was carried out by ANOVA. Levels of significance:  $p = 0-0.001$ : highly significant (\*\*\*) ,  $p = 0.001-0.01$ : very significant (\*\*),  $p = 0.01-0.05$ : significant (\*); statistically significant differences (Tukey's HSC) are indicated by different characters (a,b and c). <sup>c</sup>Material harvested on 03 July, 2011. <sup>d</sup>Material harvested on 04 July, 2011. <sup>b</sup>Linear retention indices. <sup>d</sup>Data from triplicate experiments for each batch: mean  $\pm$  standard deviation. <sup>f</sup>Identification based on comparison of mass spectral and GC data with those of authentic reference compounds. <sup>g</sup>Recovery considered. <sup>h</sup>Reference compound from Aldrich, Steinheim, Germany. <sup>i</sup>Reference compound provided by Frey+Lau GmbH, Henstedt-Ulzburg, Germany. <sup>j</sup>Tentatively identified by comparison of mass spectral data with those from database. <sup>k</sup>Quantitation without response factor. <sup>l</sup>Not quantifiable: concentration below limit of quantitation (1.7  $\mu\text{g}/\text{kg}$ ). <sup>m</sup>Not detectable: concentration below limit of identification (0.6  $\mu\text{g}/\text{kg}$ ). <sup>n</sup>Reference compound from Merck, Darmstadt, Germany. <sup>o</sup>The enantiomer was identified by comparison of the retention time with an authentic reference on (2,3-di-*O*-acetyl-6-*O*-*tert*-butyldimethylsilyl)- $\beta$ -cyclodextrin as chiral stationary phase. <sup>p</sup>The ratio of enantiomers was identified by comparison of retention times with an authentic reference on (2,3-di-*O*-acetyl-6-*O*-*tert*-butyldimethylsilyl)- $\beta$ -cyclodextrin as chiral stationary phase and comparison to literature data: <sup>34</sup> 65% (S): 35% (R). <sup>q</sup>Compound was synthesized according to ref 35. <sup>r</sup>Coelution of propyl acetate, pentan-2-one, pentan-3-one and pentanal.

Germany) and *n*-pentane (AppliChem., Darmstadt, Germany) were distilled before use.

**Isolation of Volatiles by Vacuum Headspace Extraction (VHS).** Before analysis, stored fruits were brought to room temperature (approximately 2 h). After removal of the peduncles, 500 g of jostaberries were homogenized (Moulinex Turbo blender) with 400 mL water for 30 s. After the addition of 150  $\mu\text{g}$  of heptan-2-ol as internal standard (1 mL of a 1:10-diluted stock solution of 0.150 g

heptan-2-ol/100 mL water), the homogenate was transferred into a 2 L round-bottom flask and the blender was rinsed with 150 mL of water. The flask was placed into a water bath (35 °C) and the isolation was carried out for 2 h at a vacuum of 1–10 mbar (Leybold-Hereus pump, typ D4A). The aqueous distillate was condensed in three cooling traps. The first two were cooled by a water–ice mixture and the third by liquid nitrogen. After thawing, the distillates were pooled and extracted (3  $\times$  50 mL) using a mixture of diethyl ether and

**Table 2. Concentrations of Major Volatiles Isolated by Means of VHS from Ripe Jostaberries Harvested at the Location Freising in Different Years<sup>a</sup>**

compounds	Freising		
	2010 (July 19) [ $\mu\text{g}/\text{kg}$ ]	2011 (July 13) [ $\mu\text{g}/\text{kg}$ ]	2012 (July 16) [ $\mu\text{g}/\text{kg}$ ]
( <i>E</i> )-hex-2-enal	8066 $\pm$ 109	9613 $\pm$ 819	11473 $\pm$ 2730
( <i>Z</i> )-hex-3-enal	652 $\pm$ 142	565 $\pm$ 226	322 $\pm$ 198
( <i>E</i> )-hex-2-en-1-ol	862 $\pm$ 325	525 $\pm$ 180	438 $\pm$ 151
hexanal*	158 $\pm$ 33 (b)	365 $\pm$ 75 (a)	330 $\pm$ 114 (a,b)
( <i>Z</i> )-hex-3-en-1-ol***	223 $\pm$ 19(a)	186 $\pm$ 11 (a)	127 $\pm$ 13 (b)
( <i>E</i> )-hex-3-enal	149 $\pm$ 74	233 $\pm$ 22	160 $\pm$ 30
( <i>Z</i> )-hex-2-enal**	68 $\pm$ 16 (a)	45 $\pm$ 4 (a,b)	30 $\pm$ 3 (b)
hexan-1-ol	45 $\pm$ 10	43 $\pm$ 10	35 $\pm$ 3
( <i>E</i> )-hex-3-en-1-ol*	34 $\pm$ 14 (a)	25 $\pm$ 3 (a,b)	8 $\pm$ 7 (b)
<b>total:</b>	<b>10256</b>	<b>11601</b>	<b>12921</b>
methyl butanoate***	695 $\pm$ 225 (b)	2330 $\pm$ 291 (a)	2000 $\pm$ 287 (a)
ethyl butanoate***	46 $\pm$ 20 (c)	348 $\pm$ 66 (b)	596 $\pm$ 149 (a)
methyl ( <i>E</i> )-but-2-enoate*	90 $\pm$ 4 (b)	125 $\pm$ 15 (a,b)	151 $\pm$ 31(a)
methyl benzoate***	160 $\pm$ 16 (a)	13 $\pm$ 3 (b)	34 $\pm$ 10 (b)
methyl hexanoate***	23 $\pm$ 5 (b)	40 $\pm$ 3 (a)	24 $\pm$ 1 (b)
ethyl ( <i>E</i> )-but-2-enoate***	4 $\pm$ 1(c)	22 $\pm$ 4 (b)	62 $\pm$ 9 (a)
<b>total:</b>	<b>1018</b>	<b>2879</b>	<b>2867</b>
2-methylbut-3-en-2-ol*	586 $\pm$ 74 (b)	1670 $\pm$ 548 (a)	1378 $\pm$ 197 (a,b)
1,8-cineol	453 $\pm$ 97	308 $\pm$ 51	484 $\pm$ 80
pent-1-en-3-one*	28 $\pm$ 2 (b)	57 $\pm$ 10 (a)	49 $\pm$ 12 (a,b)
( <i>R</i> )-oct-1-en-3-ol***	5 $\pm$ 1 (b)	68 $\pm$ 16 (a)	10 $\pm$ 3 (b)
( <i>E</i> )-pent-2-enal	29 $\pm$ 3	30 $\pm$ 7	22 $\pm$ 3
( <i>Z</i> )-pent-2-en-1-ol**	22 $\pm$ 1(b)	27 $\pm$ 3 (a)	18 $\pm$ 1 (b)
pent-1-en-3-ol***	8 $\pm$ 2 (b)	21 $\pm$ 3 (a)	17 $\pm$ 1 (a)
terpinen-4-ol*	22 $\pm$ 6 (a)	14 $\pm$ 5 (a,b)	10 $\pm$ 2 (b)
<b>total:</b>	<b>1153</b>	<b>2195</b>	<b>1988</b>
<b>sum total:</b>	<b>12427</b>	<b>16675</b>	<b>17776</b>

<sup>a</sup>All compounds with concentrations  $\geq 20 \mu\text{g}/\text{kg}$  in at least one of the analyzed batches are considered. Correlation analysis was carried out by ANOVA. Levels of significance:  $p = 0-0.001$ : highly significant (\*\*\*),  $p = 0.001-0.01$ : very significant (\*\*),  $p = 0.01-0.05$ : significant (\*); statistically significant differences (Tukey's HSC) are indicated by different characters (a, b and c).

*n*-pentane (1:1; v:v). After drying with sodium sulfate, the extract was concentrated to 1 mL using a Vigreux column and to a final volume of 0.5 mL under a gentle nitrogen flow. All VHS-isolations were carried out in triplicate and the extracts were analyzed by HRGC-FID as well as by HRGC-MS.

**Capillary Gas Chromatography (HRGC-FID).** The separations were performed on a Carlo Erba Mega II 8575 series gas chromatograph (Thermo Fisher Scientific, Dreieich, Germany) equipped with a split/splitless injector (215 °C, split ratio 1:10), a flame ionization detector (FID) and a flame photometric detector (FPD) operating at 235 °C. The column used was a 60 m  $\times$  0.32 mm (i.d.) fused silica capillary column coated with DB-Wax (0.25  $\mu\text{m}$  film thickness; J&W Scientific). The oven temperature was programmed from 40 °C (5 min hold) at 4 °C/min to 240 °C (25 min hold). The carrier gas used was hydrogen at a constant inlet pressure of 110 kPa. Data acquisition was done via Chromcard software (Thermo Fisher Scientific). Retention indices were calculated on the basis of the analysis of *n*-alkanes (C<sub>8</sub>–C<sub>32</sub>) under the same conditions.

**Quantitation.** FID response factors were determined with solutions of authentic compounds relative to the internal standard (0.1  $\mu\text{g}/\mu\text{L}$  in diethyl ether). Recovery rates were determined in triplicate from aqueous solutions and buffer solutions (hydrochloric acid–sodium citrate buffer, pH 3.5) for acids, respectively (100  $\mu\text{L}$  stock solution (3 mg reference and 3 mg heptan-2-ol in 1 mL ethanol), were isolated from 1 L of water or buffer by means of VHS). Recovery rates were determined for main representatives of the different compound classes: methyl butanoate (63  $\pm$  18%), ethyl butanoate (76  $\pm$  8%),

methyl (*E*)-but-2-enoate (82  $\pm$  5%), ethyl (*E*)-but-2-enoate (87  $\pm$  3%), methyl hexanoate (76  $\pm$  6%), methyl benzoate (87  $\pm$  13%), (*E*)-hex-2-en-1-ol (77  $\pm$  7%), (*Z*)-hex-3-en-1-ol (76  $\pm$  5%), hexanol (82  $\pm$  2%), hexanal (86  $\pm$  4%), (*E*)-hex-2-enal (85  $\pm$  6%), (*E*)-hex-3-enal (29  $\pm$  7%), (*Z*)-hex-3-enal (30  $\pm$  10%), oct-1-en-3-ol (101  $\pm$  0%), 2-methylbut-3-en-2-ol (40  $\pm$  15%), 1,8-cineol (86  $\pm$  14%), terpinen-4-ol (83  $\pm$  8%), and acetophenone (92  $\pm$  4%). Recovery rates of acids, such as acetic acid, propanoic acid, butanoic acid, (*E*)-hex-2-enoic acid, (*E*)-hex-3-enoic acid, dimethylmalonic acid and cinnamic acid were less than 13%; therefore, members of this class of substances were not quantified. The limits of detection and the limits of quantitation were determined for octanal, (*E*)-oct-2-enal, ethyl hexanoate, methyl 3-hydroxybutanoate and pent-1-en-3-ol as representatives.<sup>10</sup> Four concentrations in the range from 625 to 6250 ng/mL were analyzed in triplicate, and by determining a calibration curve, the limits of detection and the limits of quantitation were calculated (assumption: recovery rate and response factor = 1).

**Gas Chromatography–Mass Spectrometry (GC–MS).** Mass spectral data were obtained on a gas chromatograph–mass spectrometer (GC 8000<sup>TOP</sup> with a Voyager GC–MS, Thermo Fisher Scientific) equipped with a split/splitless injector (220 °C, split ratio 1:50). The separation was performed on a 30 m  $\times$  0.25 mm (i.d.) fused silica capillary column coated with DB-WaxEtr (0.5  $\mu\text{m}$  film thickness; J&W Scientific). The oven temperature was programmed from 40 °C (5 min hold) at 4 °C/min to 240 °C (25 min hold). The carrier gas used was helium at a constant inlet pressure of 75 kPa. Ionization was set at 70 eV, source temperature at 200 °C, and interface temperature

Table 3. Concentrations of Volatiles in Underripe and Ripe Jostaberries<sup>a</sup>

compounds	underripe		ripe		compounds	underripe		ripe	
	[ $\mu\text{g}/\text{kg}$ ] <sup>b</sup>		[ $\mu\text{g}/\text{kg}$ ] <sup>b</sup>			[ $\mu\text{g}/\text{kg}$ ] <sup>b</sup>		[ $\mu\text{g}/\text{kg}$ ] <sup>b</sup>	
<i>C<sub>6</sub>-compounds</i>					<i>alcohols</i>				
( <i>E</i> )-hex-2-enal***	2133 ± 1282	13583 ± 1393	( <i>Z</i> )-pent-2-en-1-ol	30 ± 0	28 ± 1				
( <i>Z</i> )-hex-3-enal **	17891 ± 2653	6006 ± 852	pent-1-en-3-ol	29 ± 3	28 ± 2				
hexanal***	211 ± 13	486 ± 36	2-methylpropan-1-ol*	n.q.	9 ± 5				
( <i>E</i> )-hex-2-en-1-ol*	260 ± 34	381 ± 31	( <i>E</i> )-pent-2-en-1-ol	4 ± 0	4 ± 0				
( <i>E</i> )-hex-3-enal**	621 ± 105	318 ± 34	ethan-1-ol	n.d.	4 ± 3				
( <i>Z</i> )-hex-3-en-1-ol***	1042 ± 112	264 ± 20	benzylalkohol	n.d.	n.q.				
( <i>Z</i> )-hex-2-enal	22 ± 12	44 ± 10	pentan-2-ol	n.q.	n.d.				
hexan-1-ol	28 ± 3	25 ± 4	octan-1-ol**	14 ± 4	n.d.				
( <i>E</i> )-hex-3-en-1-ol**	27 ± 6	10 ± 1	<b>total</b>	<b>319</b>	<b>1116</b>				
<b>total</b>	<b>22237</b>	<b>21117</b>	<i>terpenes</i>						
<i>esters</i>					1,8-cineol				
methyl butanoate**	398 ± 92	2019 ± 527	terpinen-4-ol	8 ± 1	7 ± 1				
ethyl butanoate**	9 ± 5	123 ± 34	sabinene	6 ± 2	5 ± 1				
methyl ( <i>E</i> )-but-2-enoate***	n.d. <sup>c</sup>	110 ± 18	$\alpha$ -terpineol	2 ± 2	3 ± 0				
methyl benzoate**	15 ± 2	109 ± 23	$\beta$ -pinene	2 ± 2	n.d.				
methyl hexanoate	10 ± 9	28 ± 9	terpinolene	n.d.	n.q.				
methyl octanoate	25 ± 6	17 ± 3	$\gamma$ -terpinene	n.q.	n.d.				
ethyl decanoate***	n.d.	10 ± 2	<b>total</b>	<b>378</b>	<b>454</b>				
methyl decanoate***	n.d.	9 ± 2	<i>ketones</i>						
benzyl acetate***	n.d.	7 ± 0	pent-1-en-3-one	64 ± 4	69 ± 13				
ethyl ( <i>E</i> )-but-2-enoate***	n.d.	7 ± 1	oct-1-en-3-one*	20 ± 9	n.d.				
methyl salicylate	4 ± 1	5 ± 1	<b>total</b>	<b>84</b>	<b>69</b>				
( <i>E</i> )-hex-2-enyl acetate	4 ± 3	3 ± 3	<i>aldehydes</i>						
hexyl acetate	n.q. <sup>d</sup>	n.q.	( <i>E</i> )-pent-2-enal	31 ± 5	27 ± 5				
ethyl hexanoate	n.d.	n.q.	nonanal**	5 ± 2	n.q.				
3-methylbut-2-enyl acetate	n.q.	n.d.	( <i>Z</i> )-pent-2-enal***	21 ± 1	n.d.				
<b>total</b>	<b>466</b>	<b>2447</b>	<b>total</b>	<b>38</b>	<b>27</b>				
<i>alcohols</i>					<i>others</i>				
2-methylbut-3-en-2-ol**	94 ± 23	1011 ± 328	C5-compounds <sup>e</sup>	12 ± 2	10 ± 2				
( <i>R</i> )-oct-1-en-3-ol*	148 ± 47	32 ± 7	heptadienal isomer	6 ± 0	6 ± 1				
			<b>total</b>	<b>18</b>	<b>16</b>				

<sup>a</sup>Data relate to material from Deutenkofen; underripe and ripe berries were harvested on the same day: 02 July, 2012. Correlation analysis was carried out by ANOVA. Levels of significance:  $p = 0-0.001$ : highly significant (\*\*\*),  $p = 0.001-0.01$ : very significant (\*\*),  $p = 0.01-0.05$ : significant (\*). <sup>b</sup>Triplicate analysis of underripe and ripe fruits: mean  $\pm$  standard deviation. <sup>c</sup>Not detectable: concentration below limit of identification (0.6  $\mu\text{g}/\text{kg}$ ). <sup>d</sup>Not quantifiable: concentration below limit of quantitation (1.7  $\mu\text{g}/\text{kg}$ ). <sup>e</sup>Coelution of propyl acetate, pentan-2-one, pentan-3-one and pentanal.

at 240 °C. Data acquisition was done via Xcalibur software, version 1.4 (Thermo Fisher Scientific).

**Gas Chromatography-Olfactometry.** The GC-system consisted of a Carlo Erba Strumentazione 4200 gas chromatograph equipped with a FID (230 °C) and a sniffing port (230 °C), using a deactivated capillary column (30 cm) and a split/splitless injector (220 °C, split ratio 1:10). Volatiles were separated on a 60 m  $\times$  0.32 mm (i.d.) fused silica capillary column (injection volume 1  $\mu\text{L}$ ) coated with DB-Wax (0.25  $\mu\text{m}$  film thickness; J&W Scientific). The oven temperature was programmed from 55 °C (10 min hold) at 4°/min to 240 °C (25 min hold). The carrier gas used was hydrogen at a constant inlet pressure of 110 kPa. The GC-effluent was split 1:1 among FID and sniffing port; no humidified air or nitrogen was used.

**Statistical Analysis.** XLSTAT (Addinsoft, Version 2008.4.01) was used for statistical tests (confidence interval for all tests: 95%). Correlation analyses were carried out with ANOVA. Levels of significance:  $p = 0-0.001$ : highly significant (\*\*\*),  $p = 0.001-0.01$ : very significant (\*\*),  $p = 0.01-0.05$ : significant (\*). Statistically significant differences were identified by Tukey's HSC.

**Aroma Extract Dilution Analysis (AEDA).** Three extracts (500  $\mu\text{L}$  each) obtained by VHS from ripe jostaberries (date of harvest: 30 June, 2011; location: Oberrotweil) were combined and gently concentrated to 0.5 mL under nitrogen flow. The concentrated extract was diluted gradually with the solvent mixture of diethyl ether and

*n*-pentane (v:v; 1:1) and analyzed by GC-O until no odor was detectable anymore. AEDA was done by one panelist by sniffing of the whole chromatogram (in triplicate for the concentrated extract and once for the subsequent dilutions); at the higher dilution steps, the sensorial assessment was limited to the odor-active areas remaining in the chromatogram.

**Determination of Odor Thresholds.** Odor thresholds were determined by a panel (at least 10 participants) in a triangle-test using the "forced choice" technique. The compounds were dissolved in water and the solutions were assessed in glasses covered with lids.

**Reconstitution Experiments.** Reconstitution models were prepared based on the concentrations of aroma-active compounds determined in the batch of fresh jostaberries from the location Oberrotweil (30 June, 2011), extracts of which have been used for AEDA: (*Z*)-hex-3-enal (955  $\mu\text{g}/\text{kg}$ ), 1,8-cineol (447  $\mu\text{g}/\text{kg}$ ), ethyl butanoate (712  $\mu\text{g}/\text{kg}$ ), (*E*)-hex-2-enal ( $\mu\text{g}/\text{kg}$ ), hexanal (134  $\mu\text{g}/\text{kg}$ ), pent-1-en-3-one (18  $\mu\text{g}/\text{kg}$ ), methyl butanoate (2725  $\mu\text{g}/\text{kg}$ ), ethyl hexanoate (10  $\mu\text{g}/\text{kg}$ ), (*E*)-hex-3-enal (116  $\mu\text{g}/\text{kg}$ ) and oct-1-en-3-one (0.01  $\mu\text{g}/\text{kg}$ ). Appropriate amounts of stock solutions of the odorants were dissolved using an aqueous solution of oxalic acid (40 mg/L), malic acid (3.5 g/L), ascorbic acid (1.5 g/L), citric acid (25 g/L), glucose (30 g/L), fructose (35 g/L) and sucrose (20 g/L).

**Aroma Profile Tests.** Samples (15 mL) were placed into glasses with lids and were orthonasally evaluated by a sensory panel of at least

Table 4. Concentrations and Sensory Data of Key Odorants of Jostaberries

odorant	RI <sup>a</sup>	odor quality <sup>b</sup>	FD factor <sup>c</sup>	threshold		[μg/kg] <sup>d</sup>	OAV <sup>e</sup>
				[μg/L in water]	remark		
(Z)-hex-3-enal	1138	grassy	32	0.6	f	1476	2460
1,8-cineol	1200	eucalyptus	512	2	f	499	250
ethyl butanoate	1034	pineapple-like	4096	2.5	f	539	216
(E)-hex-2-enal	1211	apple-like	32	77	f	8139	106
hexanal	1075	fatty-green	256	4	f	230	58
pent-1-en-3-one	1009	musty, pungent	16	1	f	45	45
methyl butanoate	975	fruity, cheesy	128	63	f	2526	40
ethyl hexanoate	1232	green, fruity	32	1.4	f	8	6
(E)-hex-3-enal	1133	green	32	160	g	206	1
nonanal	1391	waxy	16	1	h	n.q. <sup>i</sup>	
3-methylbut-2-enyl acetate	1251	musty, green	64			2	
(Z)-octa-1,5-dien-3-ol <sup>j</sup>	1490	mushroom-like	256	0.1	k	n.d. <sup>l</sup>	
propan-2-thiol	801	sulfurous	64	0.001	m	n.d.	
oct-1-en-3-one	1296	mushroom-like	64	0.005	n	n.d.	
ethyl acetate	886	fruity	32	5	o	n.c. <sup>p</sup>	
methyl (E)-but-2-enoate	1096	fruity, pungent	2048	124	f	117	<1
(E)-pent-2-enal	1120	green, pungent	128	1500	q	27	<1
hexan-1-ol	1355	pungent, green	1024	500	r	75	<1
(E)-hex-3-en-1-ol	1364	geranium-like	64	1000	s	39	<1
2-methylpropanoic acid	1562	musty	64	10	t	n.q.	<1
linalyl acetate	1552	sweet, herbal	32	24	f	n.q.	<1
2-methylpropyl acetate	968	green, fresh	16	441	u	n.q.	<1
2-methylpropan-1-ol	1084	cheesy, alcoholic	16	75000	s	27	<1
(E)-linalool oxide	1428	earthy, musty	16	100	v	n.q.	<1

<sup>a</sup>Linear retention indices on a DB-Wax-column (see Materials and Methods). <sup>b</sup>Assessed at AEDA. <sup>c</sup>GC-O and AEDA were performed by one panelist using a concentrated VHS extract corresponding to 1.5 kg of jostaberries obtained from Oberrotweil on 30 June, 2011. <sup>d</sup>Concentrations calculated from 9 batches of ripe jostaberries (listed in Materials and Methods). <sup>e</sup>Odor activity value, calculated by division of individual, averaged concentration and odor threshold. <sup>f</sup>Determined in triangle test. <sup>g</sup>Reference 36. <sup>h</sup>Reference 37. <sup>i</sup>Not quantifiable: concentration below limit of quantitation (1.7 μg/kg). <sup>j</sup>Identification by comparison of mass spectrum and odor description with literature<sup>25</sup> and by comparison of the linear retention index using a mushroom extract (linolenic acid added at homogenization analogous to ref 25) and literature data.<sup>38</sup> <sup>k</sup>Reference 39. <sup>l</sup>not detectable: concentration below limit of detection (0.6 μg/kg). <sup>m</sup>Reference 40. <sup>n</sup>Reference 41. <sup>o</sup>Reference 42. <sup>p</sup>Not calculable: recovery too poor (see Materials and Methods). <sup>q</sup>Reference 43. <sup>r</sup>Reference 44. <sup>s</sup>Reference 45. <sup>t</sup>Reference 46. <sup>u</sup>Reference 47. <sup>v</sup>Reference 48.

10 assessors. Descriptors used were determined in preliminary evaluations on the basis of the odor properties of reference compounds dissolved in water at concentrations 100 times above their odor thresholds. The following combinations of reference odorants and odor descriptions (given in parentheses) were used: ethyl butanoate (pineapple-like), methyl benzoate (sweet), (E)-hex-2-enal (apple-like), (Z)-hex-3-enal (grassy), hexanal (fatty-green), 1,8-cineol (eucalyptus-like), acetic acid (sour) and pent-1-en-3-one (musty-pungent). Assessors were asked to rate each descriptor in the samples presented on a seven point scale from 0 (not detectable) to 3 (strong). The sensory evaluation of the jostaberries was performed with the cut fruit within 30 s. For each descriptor, a new, intact berry was used.

## RESULTS AND DISCUSSION

**Analysis of the Volatile Profile of Jostaberries.** Volatile constituents of jostaberries were isolated via vacuum headspace extraction (VHS). This gentle method allows the isolation of volatiles without thermal treatment, has proven to be suitable for generating extracts exhibiting the aroma of fresh fruits and has recently been employed to isolate the volatiles from gooseberries.<sup>11–14</sup> The volatile compounds identified and quantified in VHS-extracts from jostaberries by means of HRGC-FID and HRGC-MS are presented in Table 1. C<sub>6</sub>-components and esters turned out to be the major compound classes. C<sub>6</sub>-components represent secondary flavor compounds, formed enzymatically from linoleic and linolenic acid, respectively, after disruption of the cell structure. They are important for plants

defense strategies and pest resistance and are widely used as flavoring substances because of their fresh, green odors.<sup>15,16</sup> The main C<sub>6</sub>-constituent was identified as (E)-hex-2-enal, known as quantitatively dominating C<sub>6</sub>-compound in other fruits, such as kiwis and nectarines.<sup>17,18</sup> In jostaberries the corresponding alcohol (E)-hex-2-en-1-ol as well as the positional isomers (Z)-hex-3-enal and (Z)-hex-3-en-1-ol were also detected in fairly high concentrations. The ester profile of jostaberries is mainly characterized by short-chain methyl and ethyl esters. Methyl butanoate constituting up to 87% of the total esters and up to 27% of the total volatiles, represents by far the main ester. In addition to C<sub>6</sub>-compounds and esters, 1,8-cineol and 2-methylbut-3-en-2-ol are also present at high concentrations. 1,8-Cineol, also known as eucalyptol, accounts for up to 89% of the essential oil of *Eucalyptus globulus*.<sup>19</sup> Due to its characteristic fresh, camphor-like odor, there are numerous applications for the flavoring of foods, beverages, cosmetics and in the fragrance industry.<sup>19,20</sup> 2-Methylbut-3-en-2-ol is known as a volatile compound of the creosotebush as well as of honey and matsutake-mushrooms.<sup>21–23</sup>

**Impact Factors on the Volatile Composition of Jostaberries.** The data in Table 1 represent the concentrations of volatile constituents in ripe jostaberries, all harvested at the ripe state at three locations in Southern Germany in 2011. Although the geographical distances are relatively small (at most 260 km), the data indicate that for the selected growing sites

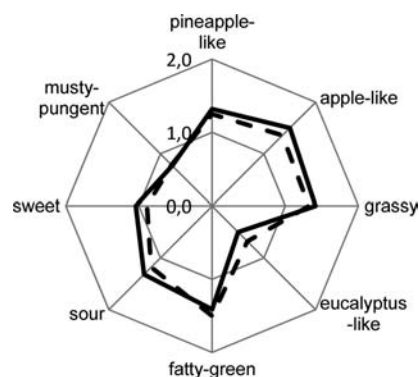
the factor location has only a minor impact on the volatile composition. Except for variations observed for individual substances, for example, methyl and ethyl butanoate or (*R*)-oct-1-en-3-ol, the quantitative distributions of most constituents and of the compound classes are quite comparable. It is noteworthy that in all three batches at least 91% of the total volatiles are represented by only eight components: (*E*)-hex-2-enal, (*E*)-hex-2-en-1-ol, (*Z*)-hex-3-enal, (*Z*)-hex-3-en-1-ol, methyl butanoate, ethyl butanoate, 2-methylbut-3-en-2-ol and 1,8-cineol.

In addition, ripe jostaberries harvested at the same location (Freising) in different years were investigated (Table 2). The total amounts of volatiles, the distributions of compound classes and the contents of most constituents were quite comparable in 2011 and 2012. The material harvested in 2010 exhibited a profile of  $C_6$ -compounds similar to those of 2011 and 2012; however, the contents of methyl and ethyl butanoate and of 2-methylbut-3-en-2-ol were significantly lower.

Finally, the impact of the state of ripeness was assessed by investigating not only ripe but also underripe jostaberries (Table 3). The total of  $C_6$ -compounds remained nearly constant, but the distribution of single compounds changed considerably. While the  $C_6$ -profile of underripe jostaberries is dominated by (*Z*)-hex-3-enal, ripe jostaberries are characterized by (*E*)-hex-2-enal as the main component. Also, the concentrations of (*E*)-hex-3-enal and (*Z*)-hex-3-en-1-ol, being generated via isomerization and reduction from (*Z*)-hex-3-enal, decreased during the ripening process, whereas (*E*)-hex-2-en-1-ol was more abundant in ripe jostaberries. In addition, the concentration of hexanal, an oxidation product of linoleic acid, increased during the ripening process of the fruit. The most obvious changes during the ripening process were observed for the totals of esters (from 466 to 2447  $\mu\text{g}/\text{kg}$ ) and alcohols (from 319 to 1116  $\mu\text{g}/\text{kg}$ ). The increase of esters was caused by rising concentrations of almost every ester-compound, but most clearly for methyl butanoate (from 398 to 2019  $\mu\text{g}/\text{kg}$ ). The alcohols showed different trends: the concentrations of (*Z*)-/(*E*)-pent-2-en-1-ol and pent-1-en-3-ol remained constant, whereas the contents of (*R*)-oct-1-en-3-ol and octan-1-ol decreased and those of 2-methylbut-3-en-2-ol and 2-methylpropan-1-ol increased significantly. 2-Methylbut-3-en-2-ol emitted from pine needles has been shown to be biosynthesized enzymatically from dimethylallyl diphosphate.<sup>24</sup> Next to the decreasing amount of (*R*)-oct-1-en-3-ol also the concentration of oct-1-en-3-one declined during the ripening-process. Both compounds are generated enzymatically from unsaturated fatty acids and are characterized by a mushroom-like odor.<sup>25,26</sup>

**Screening of the Sensory Contributions of Aroma Compounds.** The extracts obtained by VHS were reminiscent of fresh jostaberries and exhibited fresh, green as well as black currant-like odor notes. A pooled and concentrated extract of 1.5 kg jostaberries was used for AEDA. A total of 58 odor-active compounds were detected; those with flavor dilution factors (FD)  $\geq 16$  are listed in Table 4. Particularly, lipid oxidation products and short chain esters turned out to be among the potent odorants. As a second step the odor activity values (OAV), that is, the ratios of concentrations and odor thresholds of the individual substances, were calculated. Considering that odor thresholds cited in literature vary strongly, odor thresholds for substances with a great impact on the aroma of jostaberries, as indicated by the FD-factors, were determined by an own panel. (*Z*)-Hex-3-enal had by far the greatest impact on the aroma of jostaberries, followed by 1,8-cineol and ethyl butanoate. For a total of nine compounds OAVs  $\geq 1$  could be

calculated; these were used as basis for the subsequent recombination experiments. Considering the low odor threshold of oct-1-en-3-one (0.005  $\mu\text{g}/\text{L}$ ) and of the structurally related (*Z*)-octa-1,5-dien-3-ol (0.1  $\mu\text{g}/\text{L}$ ), the contribution of a mushroom-note to the overall flavor of jostaberries seemed probable; therefore, oct-1-en-3-one was also included in the model. Since its concentration in the investigated ripe jostaberries was below the limits of detection and quantitation, respectively, an amount corresponding to twice the odor threshold concentration was used. In order to imitate a berry-like matrix, recombinates were prepared in an aqueous solution of sugars and organic acids, naturally contained in the berries. According to the panelists the recombine was reminiscent of jostaberry, combining a mild black currant note with a green gooseberry-like aroma. The aroma profile was in good agreement with that of fresh jostaberries (Figure 1).



**Figure 1.** Comparison of the aroma profiles of the jostaberry reconstitution model (continuous line) and the original fruit (broken line).

**Comparison of Major Volatiles of Jostaberries, Gooseberries and Black Currants.** Considering that jostaberry is a hybrid of black currant and gooseberry, it seemed reasonable to have a preliminary screening of the contribution of the pools of volatiles in these starting materials to those present in jostaberries. As a first attempt, the eight compounds shown to constitute at least 91% of the total volatiles in the

**Table 5.** Concentrations of Main Volatiles in Jostaberries Compared to Those in Gooseberries and Black Currants

	jostaberries <sup>a</sup>	gooseberries <sup>b</sup>	black currants <sup>c</sup>
	[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>	[ $\mu\text{g}/\text{kg}$ ] <sup>d</sup>
<i>C<sub>6</sub>-components</i>			
( <i>E</i> )-hex-2-enal	9613 $\pm$ 819	509 $\pm$ 157	2227 $\pm$ 404
( <i>Z</i> )-hex-3-enal	565 $\pm$ 226	1128 $\pm$ 81	461 $\pm$ 99
( <i>E</i> )-hex-2-en-1-ol	525 $\pm$ 180	66 $\pm$ 8	257 $\pm$ 1
( <i>Z</i> )-hex-3-en-1-ol	186 $\pm$ 11	71 $\pm$ 11	152 $\pm$ 35
<i>hemi-/ monoterpene alcohols</i>			
2-methylbut-3-en-2-ol	1670 $\pm$ 548	n.d. <sup>e</sup>	238 $\pm$ 124
1,8-cineol	308 $\pm$ 51	n.d.	71 $\pm$ 20
<i>esters</i>			
methyl butanoate	2330 $\pm$ 291	1276 $\pm$ 137	1774 $\pm$ 1090
ethyl butanoate	348 $\pm$ 66	47 $\pm$ 35	1773 $\pm$ 1523

<sup>a</sup>Harvested on 13 July, 2011 in Freising. <sup>b</sup>Data correlate to gooseberries var. Achilles (25 August, 2010).<sup>14</sup> <sup>c</sup>Obtained from a local market on 20 June, 2011. <sup>d</sup>Data from triplicate experiments for each batch: mean  $\pm$  standard deviation. <sup>e</sup>Not detectable: concentration below limit of identification (0.6  $\mu\text{g}/\text{kg}$ ).

batches of gooseberries analyzed in this study were selected for comparison (Table 5). The literature data available on the volatile profiles of black currants refer to frozen fruits.<sup>27–33</sup> Taking into account the known influence of freezing on the generation of C<sub>6</sub>-components, these data were not considered suitable as basis for a comparison. Therefore, volatiles were isolated from a batch of fresh black currants via VHS in the same way as performed for jostaberries and gooseberries.<sup>14</sup> For gooseberries, a batch of var. Achilles, exhibiting a spectrum of volatiles close to the mean distribution determined in this fruit, was selected for comparison.<sup>14</sup>

As shown in Table 5, the C<sub>6</sub>-profile of jostaberries exhibits characteristics similar to those of black currants: (*E*)-hex-2-enal represents the main C<sub>6</sub>-component, followed by (*E*)-hex-2-en-1-ol and (*Z*)-hex-3-enal. The prominent role observed for (*Z*)-hex-3-enal in the spectrum of C<sub>6</sub>-components in gooseberries is not reflected in jostaberries. 2-Methylbut-3-en-2-ol and 1,8-cineol are examples of volatiles being highly abundant in jostaberries but not detected in the investigated gooseberries.<sup>14</sup> Apparently, the genetic information for biosynthesis of these compounds in jostaberry exclusively stems from black currant. On the other hand, the pronounced preponderance of methyl butanoate compared to ethyl butanoate observed in gooseberries is also reflected in jostaberries, whereas in the investigated batches of black currants the concentrations were almost identical. Of course, these comparisons have to be considered preliminary and would have to be extended for a broader spectrum of constituents and fruit batches.

## AUTHOR INFORMATION

### Corresponding Author

\*Tel: +49 8161 714250. Fax: +49 8161 714259. E-mail: k.h.engel@wzw.tum.de.

### Notes

The authors declare no competing financial interest.

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