

Influence of Eggs on the Aroma Composition of a Sponge Cake and on the Aroma Release in Model Studies on Flavored Sponge Cakes

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The use of solvent-assisted flavor evaporation extraction (SAFE) and purge and trap in Tenax allowed the identification of more than 100 volatile compounds in a sponge cake (SC-e). Gas chromatography–olfactometry (GC-O) of the SAFE extracts of crumb and crust were achieved in order to determine the most potent odorants of SC-e. The change in the traditional dough formulation of SC-e in which eggs were substituted by baking powder (SC-b) as the leavening agent produced important changes in some key aroma compounds. The release curves of some aroma compounds—some of them generated during baking and others added in the dough—were followed by cumulative headspace analysis. In the flavored SC-b, the aroma release curves showed a plateau after 15 min of purge, while the release increased proportionally with the purge time in the flavored SC-e. In general, except for some of the aroma compounds with the highest log *P* values, the rate of release of most of the added and generated aroma compounds was significantly influenced by the changes in the cake formulation. The higher rates of release found for the aroma compounds in SC-b could contribute to explain its rapid exhaustion of aroma compounds in the purge and trap experiments and might lead to poorer sensorial characteristics of this cake during storage.

KEYWORDS: Aroma compounds; sponge cake; dough formulation; SAFE, GC-O; cumulative headspace analysis; aroma release

INTRODUCTION

The flavor of bakery products is the result of the aroma compounds produced by enzymatic, fermentative, and thermal reactions during baking and the aroma compounds deliberately added to the products to obtain baked goods with specific aromatic characteristics.

The Maillard reactions occurring during the baking process are the main chemical events responsible for the generation of compounds with low odor thresholds associated with the roasty-pleasant aromatic notes in bakery products. These notes are highly desirable and intimately associated in consumer's minds with a delicious, high-grade product (1–3).

Previous studies of these aromatic compounds in baked products have mainly focused on bread and bread-making steps (4–10) and second on cookies (11). To our knowledge, no study on the odorants formed during baking of sponge cakes has been published.

Different factors such as the selection of raw materials (1, 5, 7, 12), the modification of the making process (9, 10) or of the fermentation conditions (13, 14), or even the addition of enzymes and additives (15) are used to modify the aroma

Table 1. Dough Formulation and Water Content before and after Baking^a

ingredients (g/100 g dough)	SC-e	SC-b
wheat flour	25.12	27.87
sucrose	25.12	27.87
pasteurized whole eggs liquid	45.73	
palm oil	4.01	4.45
salt	0.49	0.55
baking powder		1.10
mineral water		38.12
% water in the dough ^b	35.09 ± 0.01	40.04 ± 0.21
% water in the baked cakes ^b	30.37 ± 0.92	34.76 ± 0.30

^a SC-e, sponge cake formulated with eggs; SC-b, sponge cake formulated with baking powder. ^b Expressed as g/100 g of dry matter.

composition of bakery products. In addition, many aroma compounds initially present in the dough and generated during baking could be lost by evaporation during baking. Flavoring of bakery goods is then widely employed to compensate for this aroma loss (16–19) or to produce products with special aromatic characteristics (20). Flavoring must take into account the fact that the original aromatic formulation used to flavor the baked goods must be somewhat resistant to temperature. Even in this case, it would be modified during processing

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Table 2. Volatile Composition in the Traditional Homemade Dough and Sponge Cake with Eggs (Dough-e and SC-e, Respectively) and in the Sponge Cake Formulated with Baking Powder (SC-b) Using Solvent-Assisted Flavor Evaporation and Purge and Trap in Tenax

RI-exp ^a	RI-ref ^b	compounds	identification ^c	dough-e	SC-e	SC-p
876	912	3-methylbutanal	A, B		×	
962	970	butane-2,3-dione (diacetyl) ^e	A, B		×	×
1035	1028	ethyl butanoate ^e	A, B		×	×
1056	1054	pentane-2,3-dione	A, B		×	×
1065	1071	dimethyldisulphide	A, B		×	×
1077	1084	hexanal	A, B	×	×	×
1142		1,2-dimethylbenzene ^d	B		×	×
1154	1145	butan-1-ol ^d	A, B		×	×
1184		heptan-2-one	B	×	×	×
1185	1174	heptanal	A, B	×	×	×
1195	1201	limonene ^d	A, B	×	×	×
1209		pyrazine	B		×	×
1230	1240	2-pentylfuran	A, B	×	×	×
1240	1220	ethyl hexanoate	A, B	×	×	×
1244	1243	(Z)-hept-4-enal ^e	A, B			×
1258	1255	pentan-1-ol	A, B	×	×	×
1260		2-methyl-dihydro-(2H)-furan-3-one ^d	B		×	×
1264	1240	2-methylpyrazine	A, B		×	×
1280	1287	3-hydroxybutan-2-one (acetoin) ^e	A, B		×	×
1289	1280	octanal ^d	A, B	×	×	×
1290		1-hydroxypropan-2-one	B		×	×
1310		oct-1-en-3-one	B			×
1323	1323	2,5-dimethylpyrazine	A, B		×	×
1328	1308	2,6-dimethylpyrazine	A, B		×	×
1333	1354	ethylpyrazine	A, B		×	×
1340		6-methylhept-5-en-2-one ^d	B	×	×	×
1346	1308	2,3-dimethylpyrazine	A, B		×	×
1363	1360	hexan-1-ol	A, B	×	×	×
1370	1377	dimethyltrisulfide	A, B		×	
1385		2-ethyl-6-methylpyrazine	B		×	
1390	1388	nonan-2-one	A, B	×	×	
1392	1395	2-ethyl-5-methylpyrazine ^e	A, B		×	
1394	1391	(Z)-hex-3-en-1-ol ^e	A, B			×
1396	1385	nonanal	A, B	×	×	×
1405	1395	2-butoxyethanol ^e	A, B	×	×	×
1406		trimethylpyrazine	B		×	
1427	1408	oct-2-enal (isomer)	A, B	×	×	×
1434		vinylpyrazine	B		×	×
1447	1435	3-ethyl-2,5-dimethylpyrazine	A, B		×	
1451	1458	3-methylthiopropional (methional)	A, B		×	
1452		acetic acid	B	×	×	×
1460		oct-1-en-3-ol	B	×	×	×
1460	1455	furfural	A, B	×	×	×
1464	1449	2-ethyl-3,5-dimethylpyrazine ^e	A, B		×	×
1465	1467	heptan-1-ol ^e	A, B	×	×	×
1479		dipropylene glycol methyl ether ^e	B		×	×
1488		2-methyl-6-vinylpyrazine	B		×	×
1495		2-methyl-5-vinylpyrazine ^d	B		×	×
1495		decan-2-one	B		×	
1497		3,5-diethyl-2-methylpyrazine ^e	B		×	
1499	1487	2-ethylhexan-1-ol ^d	A, B	×	×	×
1500	1484	decanal	A, B	×	×	×
1501	1490	2-acetylfuran ^d	A, B	×	×	×
1520	1495	benzaldehyde	A, B	×	×	
1532		1-(2-methoxypropoxy)-propan-2-ol	B	×	×	×
1534	1510	non-2-enal	A, B	×		×
1538		dimethyl-2-vinylpyrazine (isomer)	B		×	×
1569	1553	octan-1-ol	A, B	×	×	×
1569		octa-3,5-dien-2-one ^e	B	×	×	×
1570	1560	5-methylfurfural ^e	A, B		×	
1598		dimethylcyclohexanol (isomer)	B	×	×	×
1617		dihydro-(3H)-furan-2-one ^d	B	×	×	×
1622	1605	2-acetylpyrazine ^d	A, B		×	×
1628	1610	oct-2-en-1-ol ^e	A, B		×	
1637		butanoic acid ^d	B		×	×
1636	1625	phenylacetaldehyde	A, B		×	×
1640		methylbenzaldehyde (isomer) ^e	B	×	×	×
1644	1624	2-acetylthiazole	A, B		×	×
1645	1645	acetophenone	A, B	×	×	×

by the losses during baking or by interactions with the ingredients (21).

Moreover, the release of the aroma compounds from the

products could be affected by these factors. Although it has been shown that some important odor compounds, such as pyrazines, are quickly lost from bread after baking (22), the

Table 2. Continued

RI-exp ^a	RI-ref ^b	compounds	identification ^c	dough-e	SC-e	SC-p
1669		furfuryl alcohol	B		×	×
1673		nonan-1-ol ^d	B	×	×	×
1678		1-methyl-2-pyrrolidone ^d	B	×	×	×
1679		2-acetyl-5-methylpyrazine ^e	B		×	×
1688		2-acetyl-6-methylpyrazine	B		×	×
1694		γ-hexalactone	B	×	×	×
1699		verbenone ^e	B	×	×	×
1704		α-terpineol	B	×	×	×
1706	1677	borneol ^e	A, B	×	×	×
1729		(5-methylfurfur-2-yl)-methanol ^d	B		×	×
1744	1090	pentanoic acid ^e	A, B	×	×	×
1745		5H-furan-2-one ^e	B		×	×
1752	1767	2-acetylthiazoline ^e	A, B		×	×
1753	1753	(E,Z)-deca-2,4-dienal (isomer) ^e	A, B	×	×	×
1805	1805	(E,E)-deca-2,4-dienal ^e	A, B	×	×	×
1800		1-(2-butoxyethoxy)ethanol ^d	B		×	×
1851	1826	hexanoic acid	A, B	×	×	×
1860	1859	2-methoxyphenol (guaiacol)	A, B		×	×
1871		hexyl butanoate ^d	B		×	×
1879	1865	benzyl alcohol	A, B	×	×	×
1895		dimethylsulfone	B	×	×	×
1905		benzopyrazine ^d	B		×	×
1914	1925	2-phenylethanol ^e	A, B	×	×	×
1910	1881	γ-octalactone ^e	A, B	×	×	×
1948		benzothiazole ^e	B	×	×	×
		2-ethylhexanoic acid	B	×	×	×
1960		heptanoic acid	B	×	×	×
1971		2-acetylpyrrole ^e	B		×	×
2008		phenol ^e	B	×	×	×
2023	2042	γ-nonalactone	A, B	×	×	×
2041		isopropyl tetradecanoate ^e	B	×	×	×
2067	2083	octanoic acid ^e	A, B	×	×	×
2136	2103	γ-decalactone ^e	A, B	×	×	×
2174	2202	nonanoic acid	A, B	×	×	×
2180		hexadecan-1-ol ^d	B		×	×
2190	2216	δ-decalactone ^e	A, B	×	×	×
2197		2-methoxy-4-vinylphenol ^e	B		×	×
2281	2361	decanoic acid	A, B	×	×	×
2322		propane-1,2,3-triol	B		×	×
2433		benzoic acid	B	×	×	×
2523		dodecanoic acid ^d	B		×	×

^a Retention index obtained experimentally using a DB-Wax stationary phase with a series of alkanes between C₈ and C₃₀. ^b Retention index from literature using a C20M stationary phase (Flavornet data base, T. Acree, 2004). ^c The identification proposal is indicated as follows: A, compounds identified by MS and GC (retention index) as compared with standards injected in the same conditions or with those published in the literature; B, tentative identification by MS. ^d Compounds detected only in the SAFE extracts. ^e Compounds detected only through purge and trap in Tenax.

release of aroma compounds deliberately added to aromatize a dough has not been widely studied in the products after baking in spite that could be especially important to explain the modification in the aroma of flavored baked goods during the storage.

Among existing methods to follow aroma release from solid or semisolid food products, the use of cumulative headspace analysis is possible and favors the extraction of the volatile compounds that are carried by a gas flow. This technique enables the detection by gas chromatography (GC) of aroma compounds at small concentrations in the gas phase. The use of increasing purging times could simulate the release expected during storage and provide data comparable to an accelerated aging of the product. Recently, Juteau et al. (23) have showed the feasibility of this method for determining the ratio of aroma release from flavored food matrices and Cayot et al. (24) have successfully used it to study the rate of release of isoamyl acetate from starch pastes.

The aim of the present investigation was (i) to determine the volatile compounds that can contribute to the aroma of a sponge cake and to identify the key aroma compounds by GC-olfactometry (O) and (ii) to study the effect of the substitution

of eggs by baking powder on the aroma composition and release after baking in model studies with flavored sponge cakes. Both added and generated aroma compounds are taken into account in this study.

MATERIALS AND METHODS

Materials. Dough Formulation. Ingredients listed in Table 1 were purchased at a local market and were used to make the sponge cake dough.

Dough Flavoring. The dough was flavored with a blend of 19 aroma compounds considered responsible for a viennoiserie aromatic note (propylene glycol solvent). The aroma compounds are listed hereafter with their CAS numbers and concentrations in the flavor mixture: ethyl acetate (141-78-6) (5 mg/L), 1,2-benzodihydropyrene (dihydrocoumarin) (119-84-6) (5 mg/L), 5-(2-hydroxyethyl)-4-methylthiazole (sulfuro) (137-00-8) (3 mg/L), 3-methoxy-4-hydroxybenzaldehyde (vanillin) (121-33-5) (200 mg/L), ethyl butanoate (105-54-4) (3 mg/L), ethyl hexanoate (123-66-0) (2 mg/L), butanoic acid (107-92-6) (5 mg/L), decanoic acid (334-48-5) (3 mg/L), hexanoic acid (142-62-1) (1 mg/L), methyl cinnamate (103-26-4) (2 mg/L), γ-decalactone (706-14-9) (8 mg/L), δ-decalactone (705-82-2) (10 mg/L), 3-hydroxybutan-2-one (acetoin) (513-86-0) (6 mg/L), 4-hydroxy-2,5-dimethyl-(2H)-furan-2-one (furanol) (3658-77-3) (10 mg/L), 2-methyl-3-hydroxy-pyran-4-one

(maltol) (118-71-8) (15 mg/L), benzaldehyde (100-52-7) (2 mg/L), citral (5392-40-5) (5 mg/L), and butane-2,3-dione (diacetyl) (431-03-8) (3 mg/L). Sigma Aldrich (L'Ile d'Abeau, France) supplied all of the aroma compounds and the solvent for this mixture.

Sponge Cake Preparation. Dough Preparation. To obtain the SC-e dough, eggs, sucrose, and salt were mixed together with a household electric mixer in a water bath at 50 °C for 5 min. The mixture was removed from the water bath and, after 1 min of rest, was mixed again for 2 min. Flour was then added little by little and gently incorporated into the foam with a wooden spoon. The aroma mixture was added to the melted palm oil and then immediately added to the dough. Two hundred ten grams of this dough was used to prepare each sponge cake. Fresh dough was prepared for each sponge cake. For preparing dough SC-b, the ingredients were mixed without the water bath for the same time as was used for the SC-e dough. In the two types of dough, the aroma mixture was added to the dough at 0.1% (w/w).

Baking Conditions. Dough (210 g) was placed in a Teflon-coated aluminum mold (25 cm × 10 cm). Baking was done in a household convection electric oven (Rowenta 28L-1500W) for 25 min at 170 °C. Five dough batches were baked one at a time and always in the same position in the oven. Halfway through cooking (12.5 min), the position of the baking pans was rotated by 180°.

Storage and Sampling. After cooking, the cakes were immediately removed from the molds and then left to cool for 15 min at ambient temperature. Five cakes of the same formulation were mixed together, sampled, and stored at -20 °C until analysis. For the crust and crumb extractions, the crust was carefully separated from the crumb with a kitchen knife. Both crust and crumb were cut and separately ground in a mill under cryogenic conditions with liquid nitrogen and stored at -20 °C until analysis.

Water Content Determination. The water content was determined by placing a known amount of the sample (dough or sponge cake) in an oven at 105 °C until constant weight was achieved. The water contents of the three matrices are shown in **Table 1**. The measurements were carried out in triplicate.

Solvent-Assisted Flavor Evaporation Extraction (SAFE Extraction). Seventy grams of sample (sponge cake, crust, or crumb) was mixed with 150 mL of Milli-Q water and homogenized with an Ultraturax for 30 s. The mix was introduced into the SAFE apparatus (25), and vacuum distillation (10⁻² Pa) was performed for 2 h at 30 °C. The water phase containing the volatile compounds was stirred twice with 10 mL of distilled dichloromethane. After liquid-liquid separation, the organic phase was collected and filtered through glass wool, dried over anhydrous sodium sulfate into a graduated flask, and made up to 25 mL using dichloromethane. The extract was concentrated to 1 mL using a Kuderna-Danish apparatus in a 70 °C water bath and then to a final volume of 400 µL under a nitrogen steam. The extractions were performed in duplicate.

Cumulative Dynamic Headspace Analysis. Twenty grams of ground cake was placed in a 500 mL glass vessel inside a water bath at 25 °C. The headspace was purged with a constant flow of N₂ (25 mL/min) for a given duration (5, 15, 30, and 60 min). The aroma compounds entrained in the gas phase were trapped in a capillary glass tube (3 mm internal diameter) containing 100 mg of Tenax adsorbent. The analyses were carried out in triplicate, and a new sample was used for each purge step. Experiments using 14 h of purge time were carried out trying to recover all volatiles from the cakes and facilitate the identification of volatile compounds. In these experiments, two Tenax traps were connected in series to determine if breakthrough of compounds occurred. The two traps were desorbed independently.

The desorption and the analysis of the aroma compounds trapped on the Tenax adsorbent were performed on a Hewlett-Packard (Palo Alto, CA) 5890 series II gas chromatograph, equipped with a Chrompack TCT/PTI 400 injector. The injection parameters were the following: precool of glass trap—130 °C, 4 min; desorption, 10 min at 250 °C with a helium flow of 20 mL/min; finally flash injection at 250 °C. The gas chromatograph was equipped with a flame ionization detector operated at 250 °C. A deactivated fused-silica precolumn (30 cm × 0.32 mm i.d., Supelco, Bellefonte, PA) and a fused-silica capillary column (30 m × 0.25 mm i.d., 0.5 µm film thickness) coated with a stationary phase DB-Wax (J & W Scientific) were used. Helium was

used as carrier gas, and after 5 min, the oven temperature was programmed from 40 to 250 °C at a rate of 4 °C/min, with a final isotherm of 15 min. After each analysis, the Tenax tube was reconditioned during 2 h in an oven (280 °C) with a nitrogen flow (80 mL/min).

MS Detection. The identification of the volatile compounds was carried out in a GC-MS (model 5973 Agilent Co., Palo Alto, CA) with the same column and chromatographic conditions previously described. MS was taken at 70 eV and a scan range between 29 and 350 amu. Compounds were identified by comparison with standard mass spectra (when available) and using the mass spectra libraries (Willey, NIST, and INRA database) and by the calculation and comparison of the GC retention index of a series of alkanes (C₈ to C₃₀) with the retention index from published data calculated under the same conditions. The quantitative data were obtained by electronic integration of the TIC peak areas.

GC-O. The odor active compounds of the crust and crumb of the sponge cake SAFE extracts were determined by high-resolution GC-O on a Hewlett-Packard (HP) 6890 gas chromatograph equipped with a split-splitless injector, a flame ionization detector (FID), and a sniffing port, using the same column and chromatographic conditions described earlier. A panel of eight trained judges (same panel for all the samples) evaluated the effluents enriched with purified, humidified air (100 mL/min). For each odor stimulus, panelists recorded the detection time and odor description. GC-O frequency analysis was performed following the methodology described by Charles (26). Linear retention indices (RI) of the compounds were calculated using a series of *n*-alkanes (C₈ to C₃₀) injected under the same chromatographic conditions.

Statistical Analysis. Statgraphics v. 3.0 was used to calculate the regression models of the time-dependent aroma release curves and the confidence intervals for the slopes.

RESULTS AND DISCUSSION

Volatile Compounds Identified in the Dough and Corresponding Sponge Cakes. The use of both the SAFE and the P&T (purge and trap in Tenax) allowed the identification of more than 100 volatile compounds in the dough and corresponding sponge cake (**Table 2**). Although most of them were identified in the extracts obtained with both preparative techniques, the P&T technique yielded a greater number of compounds. As foreseen, the longer purge time used (up to 14 h) resulted in a very intense exhaustion of volatile compounds from the samples. Some volatile compounds such as diacetyl, acetoin, and 2-ethyl-5-methyl-pyrazine, among others, were only identified in the extracts from P&T, while other volatile compounds (for example, limonene) were only detected in the SAFE extracts. Therefore, the techniques were complementary and collectively provided a good representation of the volatile composition of the dough and sponge cakes.

As expected, the number of volatile compounds detected in the dough, which directly came from the ingredients, was lower than the number of volatile compounds detected in the sponge cakes. Alcohols, acids, aldehydes, and ketones formed mainly the aroma composition of the dough (**Table 2**). Also, some lactones and terpenes, such as γ -hexalactone, verbenone, and α -terpineol, that have been identified in wheat flour (27, 28) were found.

The majority of volatile compounds in the sponge cakes was produced during baking as a result of thermally induced reactions. In the sponge cakes, the most abundant chemical groups were alcohols (22.9%), pyrazines (19.7%) aldehydes (16.6%), and ketones (10.4%). Other important groups were acids (8.3%), furans (5.2%), and sulfides (3.1%). Other types of compounds, such as lactones, terpenes, thiazoles, etc., made up the remaining 13.5% of the total volatiles identified.

When the eggs in the traditional sponge cakes (SC-e) were substituted by baking powder as the leavening agent (SC-b),

Table 3. Odor Active Compounds Identified in Crust and Crumb SAFE Extracts by GC-O (Eight Panellists)^a

odor RI ^b	descriptors (intensity)	frequency of detection		difference in frequency of detection (crust–crumb)	tentative identification	% peak areas ^c	
		crust	crumb			crust	crumb
978	butter, fruity, caramel-like	9	6	3	butane-2,3-dione (diacetyl)	NQ	NQ
1089	floral, fruity, herbal	11	9	2	hexanal	3.68	2.29
1240	vegetal, floral, fruity	15	11	3	ethyl hexanoate (IS)	7.56	8.11
1260	foot, cauliflower, pungent	0	6	–6	pentan-1-ol	1.44	1.84
1292	floral, citrus fruit	6	7	–1	octanal	0.65	0.39
1298	mushroom	15	6	9	oct-1-en-3-one	NQ	NQ
1325	solvent, hospital	3	5	2	2,5-dimethylpyrazine	14.56	17.47
1331	cake, roasted, bread crust, rice	16	14	2	2,6-dimethylpyrazine	1.28	0.94
1363	cardboard, solvent, potatoes	7	0	7	hexan-1-ol	0.73	0.86
1377	solvent, gas, wastewater, pungent	10	6	4	dimethyltrisulfide	0.12	0.04
1408	herbal, earthy, potatoes	8	10	–2	trimethylpyrazine	3.71	3.89
1438	biscuit, cooked rice, roasted	12	7	5	vinylpyrazine	0.21	0.07
1450	floral, earthy, potatoes	4	5	–1	3-ethyl-2,5-dimethylpyrazine	1.12	0.72
1454	potatoes	11	14	–3	3-methylthiopropional (methional)	0.96	0.24
1459	mushroom	6	6	0	oct-1-en-3-ol	3.17	3.23
1464	earthy, potatoes, green pea	5	0	5	furfural and/or 2-ethyl-3,5-dimethylpyrazine	2.15	2.25
1491	vegetables, potatoes	8	12	–4	6-methyl-2-vinylpyrazine	0.72	0.36
1536	vegetal, solvent	6	5	1	non-2-enal	0.16	NQ
1541	pungent, herbal, potatoes	3	4	–1	dimethyl-2-vinylpyrazine (isomer)	1.14	0.58
1567	biscuit, chocolate, roasted, cake	5	2	3	octa-3,5-dien-2-one and/or 5-methylfurfural	0.47	0.57
1602	roasted, biscuit, hazelnut	0	6	–6	dihydro-(3H)-furan-2-one	0.70	1.33
1640	rose, honey, floral	10	2	8	phenylacetaldehyde	4.18	0.53
1800	rice, cooked, baked	0	6	–6	(<i>E,E</i>)-deca-2,4-dienal	0.45	0.13
1866	sweat, fish, unpleasant	8	0	8	hexanoic acid	2.36	5.61

^a The data correspond to all of the experiments performed in duplicate; IS, internal standard; NQ, not quantified. ^b Retention index calculated in a DB-Wax stationary phase with a series of alkanes between C₈ and C₃₀. ^c Only the % of peak area of the compounds associated with a characteristic odor is shown. The calculation was done by automatic integration of the peak area of the compound/Σpeak areas of all compounds identified in the chromatograms.

some important changes in volatile composition were observed. Some alcohols, such as hexan-1-ol and oct-2-en-1-ol, were identified only in the SC-e. The contribution of egg lipids to the pool of unsaturated fatty acids, mainly oleic and linoleic acids (29), could be responsible for the major carbonyl compounds generated on heating the SC-e [e.g., heptanoic acid, aldehydes such as 3-methylbutanal, or ketones such as decan-2-one and nonan-2-one (Table 2) (30)]. The eggs also provided a higher level of amino acids, which would readily react with sugars during baking and could be responsible for the 5-methylfurfural and methional detected only in SC-e. These compounds could be produced by the Strecker degradation of lysine and methionine, respectively (31). Also, the higher amounts of amino acids provided by eggs could explain a wide number of alkylpyrazines (2-ethyl-6-methylpyrazine, 2-ethyl-5-methylpyrazine, 3-ethyl-2,5-dimethylpyrazine, and 3,5-diethyl-2-methylpyrazine) that were detected only in the SC-e (32). Some sulfur compounds such as dimethyltrisulfide and dimethylsulfone were only detected in the SC-e. The first compound has been identified in heated whole eggs (33–35) while the second has been reported as one of the major odorants in bovine, caprine, and ovine milk (36).

Determination of Odor Active Compounds in the Sponge Cake with Eggs. In order to identify the odor active compounds that potentially contribute the most to the aroma of the traditional sponge cakes (SC-e), GC-O analyses of the crust and crumb extracts were carried out by a panel of eight trained judges. Table 3 shows these results. Some aldehydes, e.g., hexanal and octanal, were likely responsible for the floral and fruity notes, while alcohols such as pentan-1-ol and hexan-1-ol were associated with unpleasant descriptors (although they may or may

not be significant at the levels present in the cakes). Butane-2,3-dione was associated with an intense “butter” aromatic note, and it was previously reported as an odorant of middle importance in rye bread crust and crumb (8). The aromatic descriptor “mushroom” appeared in the SAFE extracts and is systematically linked in the literature with the compound oct-1-en-3-one (37). As it was shown in Table 2, although oct-1-en-3-one was not identified in the SAFE extracts, it was identified in the extracts obtained by P&T, which confirmed this assignment.

Methional is widely reported to contribute a dusty, potato-like odor, being a compound with a very low detection threshold and, thus, highly perceptible in small concentrations (8, 38). 3-Methylthiopropional (methional) and 2,6-dimethylpyrazine were among the compounds with the highest frequency of detection both in crust and in crumb extracts. This is in agreement with the results obtained by Rychlik and Grosch (1) and Zehentbauer and Grosch (10) who found methional as a key odorant contributing a roasty-smelling compound in bread.

Pyrazines have been shown to strongly influence the aroma of some bakery products such as bread (2, 38). The most potent pyrazines in the sponge cakes were 2,6-dimethylpyrazine, trimethylpyrazine, vinylpyrazine, 3-ethyl-2,5-dimethylpyrazine, 6-methyl-2-vinylpyrazine, and dimethyl-2-vinylpyrazine (isomer). Although all can be responsible for the characteristic roasted aroma of the sponge cakes, some of them such as 2,6-dimethylpyrazine, trimethylpyrazine, vinylpyrazine, and 6-methyl-2-vinylpyrazine, with a frequency of citation above 8, are likely the most important contributors. Other potent aroma compounds in the sponge cakes were phenylacetaldehyde,

Table 4. Volatile Compounds Due to Exogenous Flavoring in the Flavored Sponge Cakes Formulated with Eggs (SC-e) or with Baking Powder (SC-b)

RI-exp ^a	RI-ref ^b	compounds	identification ^c	flavored sponge cakes		
				SC-e	SC-b	origin ^d
970	962	butane-2,3-dione (diacetyl)*	A, B	×	×	A, N
1028	1035	ethyl butanoate*	A, B	×	×	A, N
	1192	1-methyl-4-(1-methylethenyl)cyclohexene	B	×	×	O
1220	1240	ethyl hexanoate*	A, B	×	×	A, N
	1247	unknown (43/72/114)	B	×	×	O
	1216	1-ethyl-3-methyl benzene	B	×	×	O
1287	1280	3-hydroxybutan-2-one (acetoin)*	A, B	×	×	A, N
	1320	unknown (43/72/114)	B	×	×	O
1377	1371	(<i>E</i>)-3-hexen-1-ol	A, B	×	×	O
1394	1394	(<i>Z</i>)-3-hexen-1-ol*	A, B	×	×	A
1495	1520	benzaldehyde*	A, B	×	×	A, N
	1600	1,2-propanediol (propylene glycol)*	A, B	×	×	A
	1637	butanoic acid*	A, B	×	×	A, N
1602	1681	(<i>Z</i>)-citral*	A, B	×	×	O
	1733	(<i>E</i>)-citral	B	×	×	A
	1836	neral propylene glycol acetal (isomer)	B	×	×	O
	1840	benzaldehyde propylene glycol acetal	B	×	×	O
	1847	neral propylene glycol acetal (isomer)	B	×	×	O
1826	1851	hexanoic acid*	B	×	×	A, N
	1884	geranial propylene glycol acetal (isomer)	B	×	×	O
	1897	geranial propylene glycol acetal (isomer)	B	×	×	O
	1953	methyl cinnamate (isomer)*	B	×	×	A
1955	1965	2-methyl-3-hydroxy-4-pyranone (maltol)*	A, B	×	×	A
	2039	2,5-dimethyl-4-hydroxy-2,3-dihydrofuran-3-one (furanol)*	B	×	×	A
2056	2070	methyl cinnamate (isomer)	A, B	×	×	A
2103	2136	γ -decalactone*	A, B	×	×	A, N
2202	2174	nonanoic acid*	A, B	×	×	A, N
2216	2190	δ -decalactone*	A, B	×	×	A, N
	2269	1,2-benzodihydropyryone (dihydrocoumarin)*	B	×	×	A
2361	2281	decanoic acid*	A, B	×	×	A, N
	2311	5-(2-hydroxyethyl)-4-methylthiazole (sulfuroil)*	B	×	×	A
2586	2560	3-methoxy-4-hydroxybenzaldehyde (vanillin)*	A, B	×	×	A, N

^a Retention index published from a C20M stationary phase (Flavornet data base, T. Acree, 2004). ^b Retention index calculated in a DB-Wax stationary phase with a series of alkanes between C₈ and C₃₀. ^c The identification proposal is indicated as follows: A, compounds identified by MS and GC (retention index) as compared with standards injected in the same conditions (referred with an asterisk) or with those published in the literature; B, tentative identification by MS. ^d A, aroma compounds deliberately added via flavoring; O, aroma compounds originated from added compounds; and N, aroma compounds also detected in nonflavored sponge cakes.

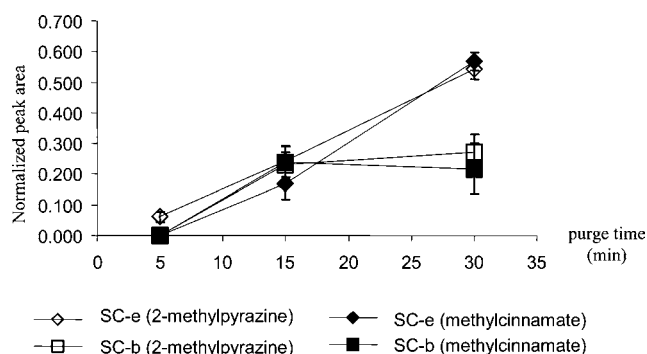


Figure 1. Aroma release curves for two aroma compounds, methyl cinnamate (added to aromatize the sponge cakes) and 2-methylpyrazine (generated during baking), in the flavored sponge cakes made with eggs (SC-e) and with baking powder (SC-b).

associated with floral notes, and dimethyltrisulphide, more related with unpleasant aroma descriptors.

It is important to notice that some compounds that showed important odorant impact for the sponge cake with eggs—such as 3-methylthiopropional and some pyrazines—were not detected in the sponge cake made with baking powder.

Model Studies on Sponge Cakes with Added Flavorings. In order to determine the effect of the dough composition (with eggs or with baking powder) on the stability of added flavorings during processing and on their release after baking, both dough

formulations were flavored as described in the Materials and Methods. After baking, ethyl acetate was the only added volatile that was not detected in any of the flavored sponge cakes. This compound could be lost during flavoring of the dough or during baking because of its high vapor pressure (39). The rest of the compounds added to the dough were detected in the sponge cake with eggs (Table 4). Nevertheless, some compounds such as ethyl butanoate, dihydrocoumarin, and sulfuroil were not detected in the sponge cake with baking powder because of their higher loss and lower retention during baking (19).

Different acetals produced by the reaction between the citral and the solvent (propylene glycol) were identified in the flavored cakes and were not present in the nonflavored cakes (Table 4). Two compounds that seemed to correspond with two isomers of the same compound since they had different retention properties but similar mass spectra (significant mass m/z at 43, 72, and 114) were detected only in the flavored cakes.

Release of Aroma Compounds from the Sponge Cakes with Added Flavorings. The aroma release curves for 14 aroma compounds (added to the dough or produced during baking) in the sponge cakes with eggs and with baking powder were obtained by cumulative headspace analysis (24) applying different purge times of 5, 15, 30, and 60 min. To permit comparison of the release of compounds in the two types of sponge cakes by compensating for differences in aroma losses produced during baking, the peak areas of each compound at

Table 5. Slopes and Confidence Intervals at 95% for Some Added and Generated Aroma Compounds in the Flavored Sponge Cake with Eggs (SC-e) and in the Flavored Sponge Cake Made with Baking Powder (SC-b)

compounds	SC-e			SC-p		significant differences ^d
	log P ^a	initial slope ^b	CI (95%) ^c	initial slope ^b	CI (95%) ^c	
ethyl hexanoate	2.83	0.030	0.021–0.039	0.025	0.021–0.029	no
γ -decalactone	2.57	0.040 ^e	0.006–0.073	ND		yes
methyl cinnamate	2.36	0.013	0.010–0.015	0.017	0.014–0.02	yes
6-methylhept-5-en-2-one	2.06	0.017	0.015–0.019	0.023	0.020–0.027	yes
ethyl butanoate	1.85	0.017	0.016–0.019	0.038	0.029–0.047	yes
hexanal	1.8	0.015	0.013–0.017	0.021	0.016–0.027	yes
benzaldehyde	1.71	0.025	0.021–0.029	0.035	0.023–0.047	no
(Z)-hex-3-en-1-ol	1.61	0.014	0.012–0.016	0.021	0.016–0.026	yes
trimethylpyrazine	1.58	0.013 ^e	0.005–0.021	0.022	0.021–0.022	yes
2,5-dimethylpyrazine	1.03	0.014	0.011–0.016	0.021	0.020–0.021	yes
2-methylpyrazine	0.49	0.017	0.015–0.019	0.016	0.013–0.020	no
maltol	−0.19	0.045	0.031–0.059	0.016	0.013–0.019	yes
acetoin	−0.36	0.016	0.013–0.019	0.013	0.007–0.019	no
1-hydroxypropan-2-one	−0.78	0.012	0.010–0.015	0.013	0.011–0.016	no

^a Expressed by the estimated logarithm of the *n*-octanol/water partition coefficient (from KOWIN v. 1.67). ^b Estimated in triplicate with the linear range of the lines (with the values of 0, 5, and 15 min of purge time). ^c A 95% confidence interval for the slope of the first-order model. ^d Significant differences between the slopes for a given compound in SC-e and SC-p. ^e Although the slopes values are reported in the table, there was no statistically significant relationship between the variables (normalized peak area vs purge time) at the 95% confidence level for a first-order model.

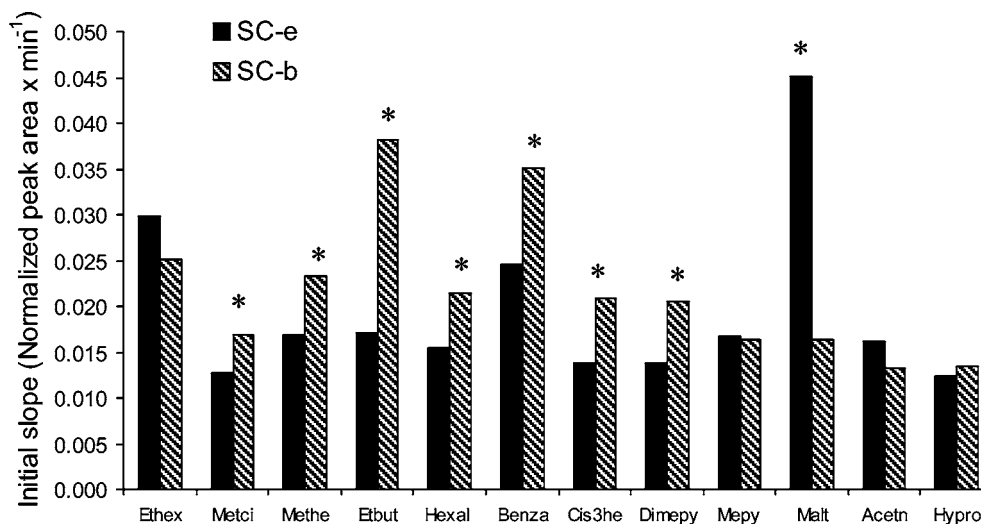


Figure 2. Comparison of the initial slopes of some added and generated aroma compounds in the flavored sponge cakes made with eggs (SC-e) and with baking powder (SC-b). The asterisk shows when the differences were significant at 95%. Ethex, ethyl hexanoate; Metci, methyl cinnamate; Methe, 6-methylhept-5-en-2-one; Etbut, ethyl butanoate; Hexal, hexanal; Benza, benzaldehyde; Cis3he, (Z)-hex-3-en-1-ol; Dimepy, 2,5-dimethylpyrazine; Mepy, 2-methylpyrazine; Malt, maltol; Acetn, acetoin; and Hypro, 1-hydroxypropan-2-one.

different purge times were normalized based on the peak area values corresponding with 60 min of purging.

Figure 1 shows an example of the aroma release curves for two different compounds. Methyl cinnamate was added to the dough before baking, and 2-methylpyrazine was produced during baking. In general, there was an increase in the recovery of aroma compounds from the sponge cakes with an increase in the purge time. There were no noticeable differences in release depending on the origin of the compound (added to the dough or produced during baking). Nevertheless, there were differences in release depending on the cake composition. In the sponge cakes produced with baking powder (SC-b), the cumulative quantities of aroma compounds trapped in the Tenax tube reached a plateau after 15 min of purging. This plateau was not observed for the aroma compounds released from the sponge cake with eggs (SC-e), in which the release increased proportionally with the purge time. Pozo-Bayón et al. (19) used a standard addition procedure to estimate the amount of the added flavorings remaining in the cakes after baking. They reported

higher amounts of added aroma compounds remaining in the sponge cake with eggs. The important release observed for SC-e could also be explained by the higher amount of some compounds produced during the thermal reactions during baking in the sponge cake with eggs as compared with the cake formulated with baking powder. Another explanation could be the different rate of release of the aroma compounds depending on the sponge cake composition.

To determine the differences in the rate of release of the aroma compounds in both sponge cakes, the slopes from the linear regressions of the purge time (using the linear range of the curve) and the normalized peak areas were calculated (**Table 5**). This parameter has been shown to be a measure of the rate of release (24, 40). The confidence intervals for the slopes at 95% were also calculated to determine if the differences were significant. Except ethyl hexanoate, benzaldehyde, 2-methylpyrazine, acetoin, and 1-hydroxypropan-2-one, the rest of the aroma compounds showed significant differences in the slopes (**Table 5**), meaning that the rate of release of these compounds

was influenced by the sponge cake composition. The slopes for all of the aroma compounds in the two sponge cakes (except γ -decalactone and trimethyl pyrazine that did not fit into a first-order model at 95% of significance) are shown in **Figure 2**. Herein, the compounds are ordered in the graph from right to left in increasing order of log *P* value. It is interesting to notice that compounds that did not show a significant influence in their release as a function of cake composition had in general the lowest log *P* values (2-methylpyrazine, acetoin, and 1-hydroxypropan-2-one). Because of the relatively lower hydrophobicity of these compounds, they could be less affected by changes in the lipid composition of the cakes (41, 42). Thus, the substitution of eggs by baking powder in the sponge cake formulation could have a minor effect on their rate of release. Nevertheless, maltol did not follow this tendency, and in spite of its low log *P* value, its release was significantly influenced by the sponge cake composition. Moreover, it is the only compound that showed a higher rate of release from the sponge cake made with eggs. Surprisingly, the rate of release of ethyl hexanoate, the most hydrophobic compound (**Table 5**), did not show an influence of the sponge cake composition. Nevertheless, the rate of release of this compound from the cakes could be strongly influenced by its interaction with the wheat flour starch, since it has been shown that this compound is able to form complexes with amylose (43). The release of benzaldehyde did not seem to be significantly influenced by the composition of the cake, although the wide confidence intervals calculated for the slopes in the SC-b cakes could be the explanation. The rest of the compounds showed higher rates of release, or lower retention, in the SC-b cakes. These compounds would be more easily lost from the cake facilitating their exhaustion when purge time was increased. The slow rate of release of the aroma compounds in the SC-e together with the higher amounts of compounds that remained after baking could be responsible for there still remaining enough aroma compounds to be released in this sponge cake at 30 min of purging.

The change in the traditional recipe of the sponge cake dough in which eggs were substituted by baking powder as a leavening agent produced important changes in their volatile composition and in important odor impact compounds related with some of the most enjoyable aromatic notes in cakes. In flavored sponge cakes, this change in the formulation produced a decrease in the retention of the aroma compounds during and after baking, increasing the rate of release that could increase the aroma losses during the storage reducing the sensorial quality of the flavored sponge cakes.

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