REVIEWS

Current Knowledge of Soft Cheeses Flavor and Related Compounds

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Cheese aroma is the result of the perception of a large number of molecules belonging to different chemical classes. The volatile compounds involved in the soft cheese flavor have received a great deal of attention. However, there has been less work concerning the volatile compounds in the soft smear-ripened cheeses than in the mold-ripened cheeses. This paper reviews the components that contribute to the characteristic flavor in the soft cheeses such as surface-ripened, Camembert-type, and Blue cheeses. The sensory properties and quantities of the molecules in the different cheeses are discussed.

Keywords: *Cheese flavor; soft cheese; volatile compounds; sensory properties*

INTRODUCTION

Cheese ripening is a complex process involving enzyme-catalyzed reactions which cause flavor and textural changes typical of the different varieties. Enzymatic processes are responsible for the production of a considerable number of compounds which, as a result of their presence, concentration, and proportions, are often characteristic of particular cheese types. It has been shown that only lower molecular weight compounds contribute significantly to the taste of soft or hard cheeses (Kubickova and Grosch, 1998b; Warmke et al., 1996). An important component of the low molecular weight molecules are the volatile compounds.

Most of the studies on the volatile components of soft cheeses have centered on mold-ripened cheeses such as Camembert, Brie, or Blue cheeses. Less work has been devoted to the aroma of surface-ripened cheeses. When ripe, Blue cheese is characterized by a network of blue or green-blue veins within the whole cheese mass, whereas a thin layer of white mold covers the Camembert-type cheese. The presence of mold within the cheese or on the surface gives these cheeses their characteristic appearance, and the high biochemical activities produce particular aroma and taste. Surface-ripened cheeses, also called soft smear cheeses, have yeast and bacterial growth on the surface that contributes to the development of the characteristic cheese flavor.

The purpose of this paper is to review the volatile aroma compositions of these cheeses. We have presented the work on the soft cheeses made with cow milk. Traditional soft cheeses have a marked aroma in which trained panelists can detect different notes. The sensorial properties of the main flavor compounds encountered (odorous notes and perception thresholds) are presented.

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ACID COMPOUNDS

In most soft cheeses, the preliminary studies concentrated on the volatile fatty acids which are the most abundant compounds in the volatile fraction. In fact, lipolysis is particularly important in soft cheeses such as Camembert and blue-veined cheeses where free fatty acids can reach up to 10% of total fatty acids (Kuzdzal-Savoie and Kuzdzal, 1967; Gripon, 1993). Lipolysis is due to lipase activity from the somatic cells and microorganisms (particularly molds) (Molimard and Spinnler, 1996). In blue-veined cheeses, the mold lipases have more contact with the fat because of the presence of mold within the cheese matrix. This explains why the concentration of volatile fatty acids in blue cheese is always higher than in mold surface-ripened cheeses (Table 1).

The whole range of volatile fatty acids (up to 12 carbon atoms) has been detected in most soft cheeses (Table 1). The concentrations of each acid vary in different cheeses, sometimes with great variations even in the same variety of cheese. This discrepancy could originate from the use of different extraction techniques to analyze the volatile cheese compounds. Generally, the amounts of acetic, propionic, 2-methylpropionic, butanoic, 3-methylbutanoic, and 4-methylpentanoic acids are higher in Munster than in other soft cheeses. Nevertheless, according to several authors (Schörmuller and Langner, 1960; Kuzdzal-Savoie and Kuzdzal, 1971; Berdague, 1986), these short-chain acids are the most important quantitatively in Camembert (except 4-methylpentanoic acid). Blue cheeses contain the highest concentrations of C6−C12 even-numbered acids (Table 1). On the other hand, the 4-methyloctanoic and 4-ethyloctanoic acids associated with the typical goat cheese flavor (Ha and Lindsay, 1991a,b; Le Quere et al., 1996, 1998) have not been detected in the soft cheeses made with cow milk.

Although the threshold values for the different fatty

10.1021/jf990414f CCC: $18.00
Published on Web 11/04/1999

Table 1. Flavor Notes, Thresholds,[a−i] and Quantities of Acid Compounds Identified in Soft Cheeses

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
acetic acid	vinegar, pungent	22[a]−7[b]	19	Camembert	13−66/300/++/59−92	12,14/4,17/20/11
		54[a]/100[a]	16/13	Munster	1248−1921	12
		5[b,g]	21	Livarot	267−743	12
		0.145[d]	18	Pont-l'Eveque	165	12
				Brie	75	12
				Vacherin	70	12
				Epoisses	1760	4
				Romadur	1968	17
				Limburger	++	20
				Gorgonzola	0%[e]/0.72%[f]	7
				Blue cheese	13−113/514/826	12/14/2
propionic acid	vinegar, pungent	40.3[a]	1	Camembert	3−137[h]/29/0/13−26	12/17/20/11
				Munster	906−2666[h]	12
				Livarot	392−1364[h]	12
				Pont-l'Eveque	280[h]	12
				Brie	53[h]	12
				Vacherin	110[h]	12
				Epoisses	1490	4
				Romadur	947	17
				Limburger	++/2.7%	20/15
				Blue cheese	33−55[h]	12
2-methylpropionic acid	sweet, applelike, rancid butter	5.3[a]	5	Camembert	3−137[h]/537/NQ	12/17/10
		0.0195[d]	18	Munster	906−2666[h]	12
				Livarot	392−1364[h]	12
				Pont-l'Eveque	280[h]	12
				Brie	53[h]	12
				Vacherin	110[h]	12
				Epoisses	320	4
				Romadur	633	17
				Limburger	1%	15
				Blue cheese	33−55[h]	12
butanoic acid	rancid, cheesy, putrid, sweaty	6.2[a]−0.66[b]	19	Camembert	35−206/264/122−130/tr	12,4,9,22,14/17/11/8,20
		6.8[a]−0.6[b]−25[c]	16	Munster	474−2360	12
		3[b,g]	21	Livarot	293−327	12
		1.1[a]/0.3−0.48[a]	1/3	Pont-l'Eveque	53	12
		0.2[a]−0.0389[d]	18	Brie	105/7−284	12/9,22
				Vacherin	48	12
				Epoisses	2340	4
				Romadur	139	17
				Limburger	+++/19.2%/1457	20/15/22
				Blue cheese	53−610/640/1448	12/14/2,22
2-methylbutanoic acid	fruity, sour, sweaty	1.6−3.2[a]	5	Romadur	163	17
3-methylbutanoic acid	rotten fruit, mild, sweaty	0.07−1[a]	5	Camembert	8−214/100/3.4−4.5	12/4/11
		0.13−0.14[a]	1	Munster	497−1980	12
		0.75[a]−0.002 45[d]	18	Livarot	455−467	12
				Pont-l'Eveque	170	12
				Brie	50	12
				Vacherin	24	12
				Epoisses	430	4
				Romadur	130	17
				Limburger	6.1%	15
				Blue cheese	100−125	12
pentanoic acid	cheesylike, sweaty, rancid, waxy	1.1−6.5[a]/1.4[a]	5/1	Camembert	0/NQ	17,20/10
				Romadur	245	17
				Limburger	+++	20
4-methylpentanoic acid	pungent, cheeselike	0.61[a]	5	Munster	455−797	12
				Livarot	78−278	12
				Pont-l'Eveque	35	12
				Brie	3	12
				Vacherin	4	12
				Epoisses	120	4
				Romadur	464	17
				Blue cheese	0.1	12
hexanoic acid	pungent, blue cheese, sour	15[a]	19	Camembert	23−143/290/5/tr/58.5−70	12/17/9,22/8,20/11
		5.4[a]−2.5[b]−14[c]	16	Munster	63−335	12
		1[a]/3[a]	13/6	Livarot	14−103	12
		9.2[a]/6.7−27.1[a]	1/3	Pont-l'Eveque	30	12
		10[b,g]	21	Brie	35/5−135	12/9,22
		0.0126[d]	18	Vacherin	28	12
				Epoisses	160	4
				Romadur	139	17
				Limburger	tr/9%/688	20/15/22
				Blue cheese	30−215/1135/909/777	12/14/2/22
octanoic acid	goaty, waxy, soapy, musty, rancid, fruity	5.8[a]−350[b]	16	Camembert	144/14/25/tr/62−70	17/9,22/14/8/11
		10[b,g]	21	Brie	17−82	9,22
		3[a]/0.00398[d]	6/18	Limburger	29.3%/24	15/22
		19[a]/2.2−11.3[a]	1/3	Blue cheese	1345/771/546	14/2/22
decanoic acid	rancid, fatty	3.5[a]−200[b]	16	Camembert	313/35/0.6−3.4%/196−219	17/9,22/8/11
		200[b]/5[b,g]	19/21	Brie	35−157	9,22
		10[a]	6	Romadur	705	17
		2.2[a]/1.4−16[a]	1/3	Limburger	26.3%/50	15/22
				Blue cheese	1547/1275	14/22
undecanoic acid	oily, sweet, waxy	0.1[a]	5	Camembert	tr	8
dodecanoic acid	fatty	700[b]	16, 19	Camembert/Brie	200/43/2.1−3.9%/NQ//62−171	17/9,22/8/10//9,22
		50[b,g]	21	Romadur	600	17

Table 1 (Continued)

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
				Limburger	5%/92	15/22
				Blue cheese	1835	22
tetradecanoic acid	waxy, oily	5000[b]	19	Camembert/Brie	69/8.9−11.6%//138−341	9,22/8//9,22
		10[a]	6	Limburger	602	22
				Blue cheese	4147	22
hexadecanoic acid		10 000[b]	19	Camembert/Brie	270/18−24.3%//410−843	9,22/8//9,22
				Limburger	565	22
				Blue cheese	11416	22
octadecanoic acid		15 000[b]	19	Camembert/Brie	210[i]/5.9−12%//98−197/1314	9,22/8//9/22
		20[a]	6	Limburger	709	22
				Blue cheese	14088	22
oleic acid		8000[b]	19	Camembert/Brie	210[i]/28.4−37.4%//485−894	9/8//9
linoleic acid				Camembert/Brie	210[i]/2.3−7.1%//11−45	9/8//9
linolenic acid				Camembert/Brie	210[i]/1.4−6.9%//10−29	9/8//9

[a−i] The olfactive or taste threshold level is defined as the most dilute concentration of the compound which more than half the judges can correctly identify as being present [a]in water; [b]in oil or butter; [c]in milk; [d]in air; [e]in ripe cheese; [f]in young cheese; [g]taste threshold; [h]propionic + 2-methylpropionic acids; [i]octadecanoic + oleic + linoleic + linolenic acids; % relative percentage in relation to total extracted compounds; +++ abundant compound; ++ medium compound; tr traces; 0 not found; NQ not quantified; (1) Amoore et al., 1968; (2) Anderson and Day, 1966; (3) Baldwin et al., 1973; (4) Berdague, 1986; (5) Brennand et al., 1989; (6) Buttery et al., 1988; (7) Contarini and Toppino, 1995; (8) Hôte-Baudart, 1967; (9) Karahadian et al., 1985b; (10) Kubickova and Grosch, 1997; (11) Kubickova and Grosch, 1998a; (12) Kuzdzal-Savoie and Kuzdzal, 1971; (13) Larsen and Poll, 1990; (14) Oruhanbayala and Andoh, 1994; (15) Parliment et al., 1982; (16) Patton, 1964; (17) Schormüller and Langner, 1960; (18) Shimoda et al., 1996; (19) Siek et al., 1969; (20) Simonart and Mayaudon, 1956; (21) Urbach et al., 1972; (22) Woo et al., 1984.

acids ranged from 0.00245 to 15000 ppm (Table 1), the majority of the short- and moderate-chain fatty acids (between four and 12 carbon atoms) have threshold values <5 ppm. Moreover, each compound has a characteristic odorous note. Therefore they can be involved in cheese aroma or in a rancidity defect when they are present in very large amounts. It is also important to note that the pH of the cheese affects the concentration of volatile fatty acid molecules. Only protonated forms of the fatty acids are odor-active and contribute to the ripened cheese flavor (Brennand et al., 1989). They mainly correspond to the acids dissolved in the fat phase of the cheese (Kubickova and Grosch, 1998b). Among volatile fatty acids, the acetic, butanoic, 3-methylbutanoic, and octanoic acids are the most potent odorants of Camembert cheese (Kubickova and Grosch, 1997, 1998b). The importance of butanoic acid to Camembert flavor has already been indicated by detection of Camembert-like flavor in a cheese base containing a mixture of butanoic acid and different neutral compounds (Moinas et al., 1975). The blue-veined cheeses exhibit a strong goaty, soapy, and rancid flavor all at once, which are supported by high concentrations of C4−C12 even-numbered acids (Rothe et al., 1982, 1994; Woo et al., 1984). On the other hand, the perception thresholds of long-chain fatty acids (>12 carbon atoms) are very high, and they may play only a minor role in cheese flavor even if they are detected in large amounts in some cheeses.

Moreover, we can underline the importance of fatty acids in soft cheeses aroma not only by their aromatic notes but also as precursors of methyl ketones, alcohols, lactones, and esters (Molimard et al., 1997).

The presence of other acids such as benzoic, hydroxybenzoic, phenylacetic, hydroxyphenylacetic, hydroxyphenylpropionic acids, ... has occasionally been reported in the soft cheeses, particularly in Camembert (Adda and Dumont, 1974), in Romadur (Schormüller and Langner, 1960), and in Blue cheeses (Bassett and Harper, 1958), but these compounds have been seldomly quantified and their role in cheese flavor has not yet been shown.

NEUTRAL COMPOUNDS

Alcohols. Generally the primary alcohols, mostly 3-methylbutanol and 2-phenylethanol, are the dominant alcoholic compounds in the soft smear cheeses (Table 2). However, these compounds are not specific of this type of cheese. 3-Methylbutanol is present at high concentration in Camembert and Blue cheese, and 2-phenylethanol is abundant in Camembert (Table 2). These compounds give an alcoholic and floral note, respectively. 2-Phenylethanol represents one of the major volatile compounds identified in 7 day old Camembert (Dumont et al., 1974c). Its maximal concentration is reached after the first week of ripening and then decreases (Roger et al., 1988). The levels of phenylethanol found in mature cheese are slightly lower but correspond to the most sensitive taster thresholds. This compound may therefore cause the floral flavor that some panel members detected in traditional Camembert cheeses. In contrast, 2-phenylethanol has never been found in blue-veined type cheese.

Except butan-2-ol in Pont-l'Evêque, the secondary alcohols are not found in large amounts in surface-ripened cheeses (Table 2). In mold-ripened cheeses, the principal secondary alcohols are heptan-2-ol and nonan-2-ol (Table 2). These alcohols correspond to the high methyl ketone contents of the same cheeses. Dumont et al. (1974c) isolated pentan-2-ol in ripe Camembert cheeses, whereas, according to Groux and Moinas (1974), this alcohol appeared in significant quantities only in young cheeses.

Octen-3-ol is only found in large amounts in the Camembert and Brie samples (Table 2). Octen-3-ol contributes to their characteristic flavor with its mushroom note and its low perception threshold (Stark and Forss, 1964; Dumont et al., 1974c; Kubickova and Grosch, 1997, 1998a,b). However, the odor intensity of this alcohol might be enhanced by the corresponding ketone octen-3-one (Kubickova and Grosch, 1997). With quantities of 5−10 ppm octen-3-ol added to a neutral cheese base, Moinas et al. (1973) obtained a flavor close to that of ripened Camembert cheese. However, when the level of octen-3-ol is too high, the aroma is faulty (Dumont et al., 1974c).

Ketones. Methyl ketones are by far the most abundant neutral compounds in the volatile fraction of mold-ripened cheeses, particularly Camembert and blue-veined cheeses (Table 3). The latter however, contains a greater quantity of ketones than does Camembert. The carbonyl compounds identified in Camembert and Blue cheeses are numerous and varied, whereas only heptan-

Table 2. Flavor Notes, Thresholds,[a−g] and Quantities of Volatile Alcohols Identified in Soft Cheeses

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
methanol				Pont-l'Eveque	tr	27
				Gorgonzola	0.42[e]%/0.04[f]%	7
ethanol	alcohol, mild			Camembert	+/<1%/tr/0.62	26/36/31/14
				Livarot	++	24
				Pont-l'Eveque	++	24
				Langres	++++	24
				Epoisses	NQ	24
				Vacherin	1−5%/+	31/25
				Trappist	16.3	33
				Gorgonzola	0.49[e]%/0.81[f]%	7
				Blue cheese	14.6	14
propanol	alcohol, sweet			Camembert	tr/0.62	26/14
				Maroilles	tr	24
				Livarot	tr	24
				Pont-l'Eveque	+++	24
				Langres	++++	24
				Epoisses	NQ	24
				Vacherin	1−5%/tr−++	31/25
				Trappist	2.9	33
butanol	sweet, fruity	0.5[a]	6	Camembert	tr−++	26
		3.5[d]	35	Pont-l'Eveque	+	24
				Epoisses	tr	24
				Vacherin	tr−+	25
				Trappist	0.7	33
pentanol		4[a]	6	Pont-l'Eveque	tr	27
				Blue cheese	0.745	30
hexanol		2.5[a]	6	Camembert	tr−+	26
				Livarot	tr	24
				Pont-l'Eveque	tr	24,27
				Vacherin	tr	25
				Blue cheese	0.01	30
heptanol	fragrant, oily, heavy, woody	2.4[a]/20[b]	19	Camembert	5−10%	36
				Vacherin	tr	25
				Blue cheese	0.01	30
octanol	fatty, waxy, citrus	0.11[a]/0.19[a]	6/23	Vacherin	+	25
		0.054[a,g]	23			
propan-2-ol	slightly buttery taste			Pont-l'Eveque	+	24
				Langres	NQ	24
				Vacherin	+	25
butan-2-ol		1.7[d]	18	Livarot	+	24
				Pont-l'Eveque	++++	24
				Langres	+	24
				Maroilles	+	24
				Trappist	0.3	33
				Gorgonzola	0.48[e]%/1.37[f]%	7
				Limburger	+−++	25
pentan-2-ol	mild green, fusel oil			Camembert	tr−++	26
				Brie	0.02−2.92	9
				Maroilles	+	24
				Pont-l'Eveque	+	24
				Vacherin	1−5%/tr−+	31/25
				Gorgonzola	0.55[e]%/0[f]	7
				Blue cheese	3.8/0.29−1.41/0.4	14/30/2
hexan-2-ol				Camembert	+	26
				Vacherin	+	25
heptan-2-ol	earthy, oily, sweetish			Camembert	+−+++/10−20%/1.26/NQ	26/36,31/14/10
				Brie	0.403−5.56	9
				Maroilles	+	24
				Pont-l'Eveque	+	24
				Langres	+	24
				Vacherin	1−5%/+	31/25
				Blue cheese	6.2/0.785−0.83/6.1	14/30/2
nonan-2-ol	fatty, melon, mild green			Camembert	tr−++++/5−10%/1.82	26/36,31/14
				Brie	0.178−8.4	9
				Livarot	tr	24
				Pont-l'Eveque	tr	24
				Langres	tr	24
				Vacherin	tr/+−++	31/25
				Blue cheese	4.8/0.45−0.97/3.5	14/30/2
undecan-2-ol				Camembert	tr−++	26
				Brie	0.004	9
				Pont-l'Eveque	tr	27
				Vacherin	tr−+	25
				Blue cheese	0.05−0.13	30
octen-3-ol	mushroom	0.01[a]/0.001[a]	34.9/6	Camembert	+−+++/5−10%/0.075−0.130	26/36,31/11
		0.048[d]/0.034[b]	32/11	Brie	0.123−0.41	9
				Blue cheese	0.01−0.02	30
octa-1,5-dien-3-ol				Camembert	NQ	10
3-methyl-2-cyclohexenol				Camembert	tr	28
2-methylpropanol	alcohol, penetrating			Camembert	tr−++	26
				Maroilles	+	24
				Livarot	+	24
				Pont-l'Eveque	tr	24
				Langres	+	24
				Epoisses	+++	24

Table 2 (Continued)

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
				Vacherin	+	25
				Blue cheese	0.09−0.28	30
2-methylbutanol		0.115[d]	18	Vacherin	tr−+	25
				Gorgonzola	4.91[e]%/3.15[f]%	7
				Blue cheese	0.9/0.98	14/30
3-methylbutanol	fruity, alcohol	3.2−4.75[a]	34,9,29	Camembert	++−++++	26
		4.75[c]	29	Brie	0.115−0.138	9
		0.3[a]	6	Maroilles	++	24
				Livarot	++++	24
				Pont-l'Eveque	+++	24
				Langres	++++	24
				Epoisses	++++	24
				Vacherin	+−++	25
				Gorgonzola	0.01[e,f]%	7
				Blue cheese	0.11−3.18	30
3-methylpentanol	pungent, wine			Epoisses	NQ	24
phenylmethanol				Maroilles	+	24
2-phenylethanol	rose, floral	7.6[j]/9.1[jg]	37	Camembert	+−+++/1[e]−1.15[f]/0.137	26/37/11
		0.24[a]/0.07[c]	29	Maroilles	++++	24
		1.1[a]/0.211[b]	6	Livarot	++++	24
				Pont-l'Eveque	++++	24
				Langres	++++	24
				Epoisses	++++	24
				Vacherin	+−++	25
				Limburger	tr	15
2-phenyl-ethan-2-ol				Maroilles	+	24
				Livarot	+	24
				Pont-l'Eveque	tr	24
				Langres	+	24
				Vacherin	+	25

[a−g] %, ++, +, tr, 0, NQ, (1)−(22): see Table 1. [j] In a cheese base; ++++ major compound; + minor compound; (23) Ahmed et al., 1978; (24) Dumont et al., 1974a; (25) Dumont et al., 1974b; (26) Dumont et al., 1974c; (27) Dumont et al. 1976a; (28) Dumont et al., 1976b; (29) Dunn and Lindsay, 1985; (30) Gallois and Langlois, 1990; (31) Groux and Moinas, 1974; (32) Hall and Anderson, 1983; (33) Hardi, 1987; (34) Karahadian et al., 1985a; (35) Laing et al., 1978; (36) Moinas et al., 1973; (37) Roger et al., 1988.

2-one and nonan-2-one have been detected in large concentrations in Brie.

The methyl ketones identified in the soft smear cheeses are commonly found in mold-ripened cheeses (Table 3). However, the soft smear cheeses have a lower methyl ketone content. Tuckey et al. (1959) observed that ketones identified in Limburger cheese do not appreciably increase in concentration during ripening. The authors concluded that flavor of surface-ripened cheeses was independent of these compounds, as Groux and Moinas (1974) confirmed in Vacherin cheese. However, among the soft smear cheeses, Vacherin and Maroilles contain the highest concentrations of several carbonyl compounds (Table 3).

French Camembert contains higher level of all ketones than Japanese (Oruhanbayala and Andoh, 1994), Danish, or American Camembert-type cheese (Schwartz and Parks, 1963a). In the surface mold-ripened cheeses, ketones are detected from the first week of ripening (Dolezalek and Brabcova, 1964; Moinas et al., 1973; Dumont et al., 1974c), and according to Dolezalek and Brabcova (1964), they were absent in the very mature cheeses. This observation agrees with the findings of Moinas et al. (1973) where butan-2-one and pentan-2-one were identified only in young Camembert cheese and their concentration decreased to nondetectable levels during ripening. Dumont et al. (1974c) reported that methyl ketones with an even carbon number, except butan-2-one, are never present in large amounts in Camembert, except in very ripe cheeses; conversely nonan-2-one, heptan-2-one, and undecan-2-one quantities steadily increase during ripening of Camembert. Dartey and Kinsella (1971) observed that the concentration of methyl ketones in Blue cheese increases up to day 70 of ripening and then decreases.

Concerning unsaturated ketones, nonen-2-one and undecen-2-one are detected sometimes in significant quantities in very ripe Camembert cheeses (Table 3). Recently, the presence of octen-3-one in Camembert cheese was reported for the first time, and the authors agree that octen-3-one is one of the most potent odorants of white mold cheeses (Kubickova and Grosch, 1997, 1998a,b). They also suggest that butane-2,3-dione causes the buttery note in Camembert-type cheese. Propiophenone, methylfuryl ketone, and acetophenone have been identified in trace amounts in mold-ripened cheese (Table 3). However, propiophenone and methylfuryl ketone do not appear as key compounds in Camembert flavor when added to a neutral cheese base (Moinas et al., 1975). On the other hand, acetophenone has been found in significant quantities in different soft smear cheeses such as Maroilles and Vacherin (Table 3), and this compound may contribute to the floral aroma of these cheese types.

Mushroom, musty, and fruity notes associated with various ketones such as pentan-2-one, heptan-2-one, octan-2-one, nonan-2-one, decan-2-one, octan-3-one, and octen-3-one are characteristic of the mold-ripened cheese (Table 3). Due to their typical odors and their low odor thresholds as well as their concentration in cheese, ketones and methyl ketones have a key role in the flavor of surface-mold ripened (Schwartz and Parks, 1963a; Dumont et al., 1974c; Groux and Moinas, 1974; Karahadian et al., 1985a,b; Oruhanbayala and Andoh, 1994) and blue-veined cheeses (Patton, 1950; Day and Anderson, 1965; Dartey and Kinsella, 1971; Rothe et al., 1982, 1986, 1994; Gallois and Langlois, 1990; Lubbers et al., 1997). The two major methyl ketones, heptan-2-one and nonan-2-one, are thought to be the most representative neutral compounds in determining the flavor of mold-ripened cheese. The synthesis of methyl ketones in cheese is associated with enzymatic activity of molds (Molimard and Spinnler, 1996).

Esters. Various esters have been detected in every soft cheese studied (Table 4). For example, 57 esters have been identified by Gallois and Langlois (1990) in

Table 3. Flavor Notes, Thresholds,[a−f] and Quantities of Volatile Ketones Identified in Soft Cheeses

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
acetone	ethereal, powerful, fruity	125[b]	19	Camembert	20−40[f]%/tr[e]/6.95	36/31,36,39/14
				Vacherin	1−5%	31
				Trappist	1,6	33
				Gorgonzola	0.1[f]%−3.85[e]%	7
				Blue cheese	3.99/++++/3.1	14/39/2
propan-2-one	acetone			Blue cheese	1.7−3.9/0[f]−2.95[e] μmol/10 g DC	41/40
					0−5.1 μmol/10 g FM	44, 45
butan-2-one	acetone, etheral	30[b]	19	Camembert	tr/1−5[f]%	26/36
		61[d]	32	Maroilles	+	24
				Livarot	tr	24
				Pont-l'Eveque	+	24
				Vacherin	1−5%/tr−++	31/25
				Trappist	0.3	33
				Gorgonzola	0.03[f]%−0[e]	7
pentan-2-one	fruity, acetone, sweet, etheral	22[d]/1.5[d]	32/18	Camembert	tr/1−5[f]%/21,05/0−3 μg/g FM	26/36/14/43
		61[b]	19	Maroilles	+	24
		0.5[c]	31	Pont-l'Eveque	tr	27
				Vacherin	20−40%/+	31/25
				Limburger	0.7%	15
				Trappist	0.98	33
				Gorgonzola	0.12[f]%−8.35[e]%	7
				Blue cheese	23.11/6.5−20.9/+/0.34−3.44	14/41/39/30
					15.2/0.25[f]−6.6[e] μmol/10 g DC	2/40
					0−20 μmol/10 g FM	44, 45
hexan-2-one	floral, fruity	4.7[d]	32	Camembert	tr/6,37	26/14
				Vacherin	tr	25
				Limburger	0.4%	15
				Pont-l'Eveque	tr	27
				Blue cheese	6.23/0.01−0.06	14/30
heptan-2-one	Blue cheese, spicy, Roquefort cheese, musty	1.3[d]	32	Camembert	+−+++/1−5%/5.58	26/36,31/14
		15[b]	19		7−17.4 μg/g FM	43
		0.7[c]	31	Brie	2.51−15	9
		3[a]/0.14[a]	9/6	Maroilles	++	24
				Livarot	+	24
				Pont-l'Eveque	+	24
				Langres	tr	24
				Vacherin	20−40%/tr−++	31/25
				Limburger	3.8%	15
				Trappist	0.45	33
				Gorgonzola	0.06[f]%−4.21[e]%	7
				Blue cheese	40.8/17.9−71.8/1.81−2.90	14/41/30
					34.8/0.6[f]−52.5[e] μmol/10 g DC	2/40
					4.2−30.2 μmol/10 g FM	44, 45
octan-2-one	fruity, musty, floral, green, herbaceous	0.23[d]	32	Camembert	tr−++	26
		0.15−1[a]	19/9	Brie	0.095−0.325	9
		2.5−3.4[b]	19	Pont-l'Eveque	tr	27
		0.05[a]	6	Limburger	0.1%	15
				Blue cheese	0.04−0.06	30
nonan-2-one	fruity, musty, floral	1.7[d]	32	Camembert	++−++++/15.09/20−48 μg/g FM	26/14/43
		7.7[b]	19		1−5[f]%/20−40[e]%/NQ	36/36, 31/10
		7.7[a]/0.2[a]	9/6	Brie	3.14−8.4	9
				Maroilles	+++	24
				Livarot	+	24
				Pont-l'Eveque	+	24
				Langres	tr	24
				Epoisses	tr	24
				Vacherin	1−5%/+−++++	31/25
				Limburger	1.4%	15
				Blue cheese	28.8/19.8−88.3/1.6−4.57	14/41/30
					33.1/0.4[f]−40.9[e] μmol/10 g DC	2/40
					2.6−12.9 μmol/10 g FM	44, 45
decan-2-one	fruity, musty	0.11[d]	32	Camembert	tr−+++	26
		0.19[a]	19	Pont-l'Eveque	tr	27
		9.3−11[b]	19	Blue cheese	0,06	30
undecan-2-one	floral, rose, iris, herbaceous	5.4[a]/0.007[a]	9/6	Camembert	+−++++/1−5%/0.18−0.7	26/36, 31/11
		100[b]/3.4[b]	11		8−11.6 μg/g FM	43
				Brie	0.395−0.883	9
				Maroilles	++	24
				Pont-l'Eveque	tr	27
				Epoisses	+	24
				Vacherin	1−5%/+−+++	31/25
				Limburger	0.9%	15
				Blue cheese	4.9−29.9/0.455−1.49/8.5	41/30/2
					0.4[f]−10.4[e] μmol/10 g DC	40
					0.3−1.7 μmol/10 g FM	44, 45
dodecan-2-one				Camembert	+−++	26
				Pont-l'Eveque	tr	27
tridecan-2-one	fruity, green, slightly spicy	182[b]	19	Camembert	+−+++	26
				Brie	0.026	9
				Maroilles	+++	24
				Pont-l'Eveque	tr	27
				Vacherin	+	25
				Limburger	0.2%	15
				Blue cheese	0.23−0.41	30
					0.12[f]−4.6[e] μmol/10 g DC	40

Table 3 (Continued)

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
pentadeca-2-one				Limburger	0.1%	15
				Blue cheese	0.25[f]−2.6[e] μmol/10 g DC	40
pentan-3-one				Vacherin	tr	25
octan-3-one	mushroom fruity, spicy	0.05[a]	34.9	Camembert	tr−+/NQ	26/10
		0.028[a]	6	Brie	0.034	9
				Vacherin	tr	25
				Blue cheese	0.01	30
3-methylpentan-2-one				Camembert	tr−+	26
4-methylpentan-2-one	fruity, ethereal			Camembert	tr	26
methylhexan-2-one				Camembert	tr	26
hydroxypropan-2-one				Pont-l'Eveque	tr	27
hept-5-en-2-one				Blue cheese	0.005−0.010	30
4-methylpent-3-en-2-one	pungent, vegetable mushroom			Pont-l'Eveque	tr	27
octen-3-one	Geranium leaf, soil	0.01[b]	11	Camembert	0.0022	11
octa-1,5-dien-3-one		0.001 ppb[a]	34, 9	Camembert	tr	9
				Brie	tr	9
nonen-2-one[k]				Camembert	tr−+++/5%	26/42
				Vacherin	+++	25
undecen-2-one[k]				Camembert	+−+++	26
acetoin	buttery	1[a]	13	Camembert	+	26
				Vacherin	tr−+++	25
diacetyl =	buttery	0.014[c]/0.0054[a]	19/19	Camembert	1−5[f]%/tr/0.074−0.11	36/39/11
butane-2,3-dione		0.032−0.055[b]	19	Limburger	0.9%	15
		0.2/0.01[c]	38	Trappist	0.8	33
		0.01[b]	11	Blue cheese	tr	39
acetophenone	orange blossom, floral, sweet	0.065[a]	6	Camembert	tr	26
				Maroilles	++++	24
				Livarot	++	24
				Pont-l'Eveque	++	24
				Langres	++	24
				Limburger	0.7%	15
				Vacherin	++−+++	25
				Blue cheese	0.015	30
methylfuryl ketone				Camembert	0.3%	42
phenylpropan-2-one				Pont-l'Eveque	tr	27
propiophenone				Camembert	0.2%	42

[a−f] %, ++++ to +, tr, 0, NQ, (1)−(37): see Tables 1 and 2. [k] The position of the double bond is unspecified by the authors; DC dry cheese; FM fatty mater; (38) Antinone et al., 1994; (39) Bassett and Harper, 1958; (40) Dartey and Kinsella, 1971; (41) Gripon, 1993; (42) Moinas et al., 1975; (43) Schwartz and Parks, 1963a; (44) Schwartz and Parks, 1963b; (45) Schwartz et al., 1963.

Blue cheeses where they constitute 6−15% of the aroma compounds.

Most esters have floral and fruity notes and may contribute to the aroma by minimizing the sharpness and bitterness imparted by fatty acids and amines, respectively (Anderson and Day, 1966; Gallois and Langlois, 1990). Several authors suggest particularly that 2-phenylethyl acetate caused the floral odor note of Camembert (Dumont et al., 1974c; Roger et al., 1988; Kubickova and Grosch, 1997). After only 7 days ripening, 2-phenylethyl acetate was the principal compound in Camembert followed by 2-phenylethyl alcohol (Dumont et al., 1974c; Roger et al., 1988). The amounts of this ester (4.6 ppm) exceeded those of methyl ketones and their corresponding secondary alcohols. After 30 days ripening, phenylethyl alcohol was still present in rather large amounts (about 1 ppm) although it was no longer the dominant volatile compound in the cheese. The 2-phenylethyl acetate/nonan-2-one ratio decreased as the cheeses ripened (Dumont et al., 1974c; Moinas et al., 1975). Moinas et al. (1975) identified methyl cinnamate in trace amounts in the Camembert extracts and attached a key aroma role to this compound when mixed with heptan-2-one, heptan-2-ol, nonen-2-one, octen-3-ol, nonan-2-ol, phenol, and butanoic acid. Dumont et al. (1976b) doubted the authenticity of these results. To date, methyl cinnamate has never again been found in Camembert cheese.

Sulfur Compounds. Coryneform bacteria, especially *Brevibacterium linens*, are considered to be the key producers of sulfur compounds in cheeses (Hemme et al., 1982; Jollivet et al., 1992). This explains the formation of significant concentrations of sulfur compounds in white mold cheese and soft smear cheese where the coyneform bacteria grow abundantly on the surface (Table 5).

Methanethiol appeared to be one of the characteristic flavor compounds in soft white mold cheeses (Tsugo and Matsuoka, 1962). In Camembert, the production of hydrogen sulfide and dimethyl disulfide is very low, but that of methanethiol reaches 0.542 ppm after 3 weeks' ripening. These sulfur compounds cause the garlic note that is clearly detectable in ripe traditional Camembert. In later studies concerning mold-ripened cheeses, sulfur compounds were only detected in trace amounts (Table 5). This is thought to be due to their high volatility (Moinas et al., 1973). During their work on the identification of the minor components of Camembert aroma, Dumont et al. (1976b) detected several sulfur compounds in a garlic note fraction. They identified 2,4-dithiapentane, 2,4,5-trithiahexane, and 3-methylthio-2,4-dithiapentane which could originate from methanethiol. Recently, methional, dimethyl sulfide, and methanethiol were detected in significant quantities in Camembert cheese (Kubickova and Grosch, 1998a). In Brie, dimethyl disulfide and dimethyl trisulfide have been detected in mature cheeses only when the coryneform bacteria grew significantly on cheese surface (Karahadian et al., 1985b). Sulfur compounds have not been often reported in the studies of Blue cheese aroma. However, Gallois and Langlois (1990) detected sulfur compounds in relatively large amounts in "Bleu des Causses" and "Bleu d'Auvergne", especially dimethyl sulfide and dimethyl disulfide.

Volatile sulfur compounds also play an important part in the flavor of surface-ripened cheeses. Their contribu-

Table 4. Flavor Notes, Thresholds,[a−j] and Quantities of Volatile Esters Identified in Soft Cheeses

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
methyl butanoate		0.043[a]/0.059[a,g]	23	Gorgonzola	0.7[e]−0.06[f]%	7
		4.68[d] ppb	18	Trappist	0.42	33
				Blue cheese	0.02−0.025	30
methyl hexanoate	pineapple, etheral			Trappist	1.5	33
				Blue cheese	0.07	30
methyl octanoate	green, fruity			Pont-l'Eveque	tr	27
				Blue cheese	0.06−0.07	30
methyl decanoate	oily, winelike, fruity			Camembert	+	26
				Pont-l'Eveque	tr	27
				Blue cheese	0.25−0.29	30
methyl tetradecanoate	fatty			Vacherin	++	25
				Blue cheese	0.11−0.13	30
methyl hexadecanoate		>2[a]	6	Vacherin	+	25
				Blue cheese	0.015	30
methyl cinnamate	fruity			Camembert	5%	42
ethyl formate	ethereal pungent			Limburger	0.5%	15
ethyl acetate	solvent, pineapple, fruity	6.6[a]/22[b]	19	Camembert	++−++++	26
		4.7[c]	19	Maroilles	+++	24
		5[a]/0.263[d]	18	Livarot	+++	24
				Pont-l'Eveque	++	24
				Langres	+	24
				Epoisses	+++	24
				Vacherin	++	25
				Gorgonzola	0[f]−0.16[f]%	7
ethyl propanoate	pineapple, sweet, solvent	0.0099[a]	23	Camembert	tr	26
		0.0049[a,g]	23	Pont-l'Eveque	+	24
				Langres	+	24
				Epoisses	NQ	24
ethyl butanoate	pineapple, sweet, banana, fragrant	0.00013[a]	23	Camembert	tr−+	26
		0.45[a]	9	Brie	0.012	9
		0.015[a]/0.6[b]	19	Langres	+	24
		0.016[c]	19	Epoisses	++	24
				Vacherin	tr	25
				Trappist	0.6	33
				Pont-l'Eveque	tr	27
				Blue cheese	0.03−0.055	30
ethyl hexanoate	pineapple, banana, apple, powerful	0.85[b]	19	Camembert	tr−++/NQ	26/10
				Brie	0.021−3.44	9
				Livarot	+	24
				Pont-l'Eveque	tr	24,27
				Langres	++	24
				Epoisses	+	24
				Vacherin	tr−++	25
				Blue cheese	0.06−0.07	30
ethyl octanoate	apricot, wine, floral			Camembert	+−+++	26
				Brie	0.011	9
				Livarot	+	24
				Pont-l'Eveque	tr	24,27
				Langres	+	24
				Epoisses	++	24
				Vacherin	++	25
				Limburger	tr	15
				Blue cheese	0.05−0.08	30
ethyl decanoate	fruity, grape			Camembert	+−++	26
				Brie	0.348	9
				Livarot	tr	24
				Langres	tr	24
				Epoisses	+++	24
				Vacherin	+−++	25
				Pont-l'Eveque	tr	27
				Blue cheese	0.02−0.27	30
ethyl dodecanoate	fruity, floral			Camembert	tr−+	26
				Epoisses	+++	24
				Vacherin	+−++	25
				Blue cheese	0.255	30
ethyl tetradecanoate	mild waxy, soapy			Vacherin	tr−++	25
				Blue cheese	0.15	30
ethyl-3-methyl butanoate				Epoisses	+	24
				Blue cheese	0.005	30
propyl acetate	powerful, celery pineapple, banana, sweaty			Pont-l'Eveque	tr	27
propyl butanoate				Camembert	tr	26
				Pont-l'Eveque	tr	27
butyl formate	plum			Pont-l'Eveque	tr	27
butyl acetate	pineapple	0.066[a]/0.195[d]	18	Camembert	tr	26
				Vacherin	tr	25
				Pont-l'Eveque	tr	27
amyl acetate	ethereal, fruity			Pont-l'Eveque	tr	24
isoamyl formate	plum			Pont-l'Eveque	tr	27
isoamyl acetate	pear, banana, apple, solvent			Camembert	tr−++	26
				Vacherin	tr−+	25
				Pont-l'Eveque	tr	25
isoamyl propanoate	apricot, pineapple			Camembert	+	26
isoamyl butanoate	apricot, pineapple			Camembert	tr	26
				Pont-l'Eveque	tr	27
diethyl phthalate				Livarot	++++	24

Table 4 (Continued)

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
				Pont-l'Eveque	+++	24
				Langres	+	24
dimethyl phthalate				Livarot	+++	24
				Pont-l'Eveque	+++	24
2-phenylethyl acetate	floral, rose	19.8[j]/18.5[j,g]	37	Camembert	1[e]−4.6[f]/0.25−0.32	37/11
		0.137[b]	11		+−++++/0.4%	26/42
				Maroilles	+	24
				Livarot	++	24
				Pont-l'Eveque	tr	24
				Langres	+++	24
				Epoisses	++++	24
				Vacherin	tr−+++	25
				Blue cheese	0.025	30
2-phenylethyl propanoate	floral, fruity	18[j]/16.8[j,g]	37	Camembert	tr[e]−0.15[f]/+−++	37/26
				Livarot	tr	24
				Langres	+	24
				Epoisses	++	24
				Vacherin	++	25
				Pont-l'Eveque	tr	27
2-phenylethyl butanoate	floral, rose, honey			Camembert	0.1%/+	42/26
				Pont-l'Eveque	tr	27
				Blue cheese	0.11	30

[a−j]%, ++++ to +, tr, 0, NQ, (1)−(42): see Tables 1−3.

tion to Limburger and Trappist aroma has been recognized for some time (Grill et al., 1966a,b). The authors reported the identification of methanethiol and hydrogen sulfide in these cheeses and presented evidence showing methanethiol as the primary compound contributing to the strong, putrid aroma normally associated with the cheese. Dimethyl disulfide has been found in significant quantities in Limburger, Maroilles, Livarot, Pont-l'Eveque, Langres, Epoisses, and Vacherin. The high vacuum distillation technique used by Dumont

Table 5. Flavor Notes, Thresholds,[a−c] and Quantities of Volatile Sulfur Compounds Identified in Soft Cheeses[d]

compound	flavor note	odor threshold (ppb)	refs	cheese	quantity in cheese (ppm)	refs
3-methylthiopropanol				Camembert	tr	28
methanethiol	cooked cabbage	2[a]/0.06[b]	49/11	Camembert	0.542/0.26−0.275	49/11
(methyl mercaptan)				Trappist	2.3	48
				Blue cheese	NQ	30
hydrogen sulfide				Camembert	0.031	49
				Trappist	1.9	48
dimethyl disulfide	cauliflower, garlic, very ripe cheese	120[a]	9	Camembert	0.011/+−++++/NQ	49/26/10
(methyl disulfide)		12	47	Brie	0.034	9
				Maroilles	++	24
				Livarot	+++	24
				Pont-l'Eveque	++	24
				Langres	+++	24
				Epoisses	NQ	24
				Vacherin	+−+++	25
				Limburger	13.2%	15
				Trappist	0.11	33
				Blue cheese	0.024−0.090	30
dimethyl sulfide	boiled cabbage, sulfurous	9−170[b]	19	Camembert	0.25−0.41	11
(methyl sulfide)		19[c]/1.2[b]	19/11	Blue cheese	0.008−0.070	30
dimethyl trisulfide	alliaceous, meaty, penetrating, over ripened cheese	2.5[b]/0.1[c]	11/46	Camembert	0.01/tr−+	11/26
(2,3,4-trithiapentane)				Brie	NQ	9
				Limburger	0.8%	15
				Pont-l'Eveque	tr	24,27
				Maroilles	tr	24
				Livarot	+	24
				Langres	tr	24
				Vacherin	tr−++	25
dimethyl tetrasulfide				Limburger	tr	15
methylethyl disulfide				Camembert	tr−++++	26
				Vacherin	+	25
diethyl disulfide				Camembert	tr	28
2,4-dithiapentane	garlic	60[c]	46	Camembert	tr	28
methional	boiled potato	0.2[b]	11	Camembert	0.027−0.125	11
				Limburger	0.1%	15
3-methylthio −2,4-dithiapentane				Camembert	tr	28
2,4,5-trithiahexane				Camembert	tr	28
1,1-bis-methylmercaptodisulfide				Camembert	+	26
methanethiol acetate	cooked cauliflower	5[c]	46	Pont-l'Eveque	tr	24
(methyl thioacetate)				Langres	++	24
				Epoisses	NQ	24
				Vacherin	tr	25
				Limburger	0.5%	15
methyl thiopropanoate	cheesy	100[c]	46	Vacherin	tr−+	25
methyl thiobenzoate				Maroilles	tr	24
benzothiazole	quinoline, rubbery	0.08[a]	6	Camembert	tr−+	26
				Pont-l'Eveque	tr	27
methylthiobenzothiazole				Pont-l'Eveque	tr	27
methylethyl sulfonate				Pont-l'Eveque	tr	27
methylmethane thiosulfonate				Pont-l'Eveque	tr	27
thiophen-2-aldehyde				Camembert	0.4%	42

[a−c] %, ++++ to +, tr, 0, NQ, (1)−(42): see Tables 1−3. [d] (46) Cuer et al., 1979; (47) Grill et al., 1966a; (48) Grill et al., 1966b; (49) Tsugo and Matsuoka, 1962.

Table 6. Flavor Notes, Thresholds,[a−g] and Quantities of Miscellaneous Compounds Identified in Soft Cheeses

compound	flavor note	odor threshold (ppm)	refs	cheese	quantity in cheese (ppm)	refs
indole	unpleasant, putrid, fecal, cadaverous, musty	0.14[a]/0.02[b]	6/21	Camembert	tr−+++	26
				Livarot	++++	24
				Pont-l'Eveque	++++	24
				Langres	+	24
				Epoisses	NQ	24
				Maroilles	++++	24
				Vacherin	++++	25
				Limburger	7.3%	15
methylindole				Camembert	tr	26
				Maroilles	+	24
				Vacherin	tr	25
				Pont-l'Eveque	tr	27
phenol	medicinal	10[a]/0.25[a,g]	9/51	Camembert	tr−+++/tr	26/36
		0.15[b]	29	Brie	0.019	9
		0.047[d]	51	Maroilles	++++	24
		0.01[f,g]	21	Livarot	+	24
				Pont-l'Eveque	++++	24
				Vacherin	+−++++	25
				Limburger	54.3%	15
p-ethylphenol	phenolic, pungent			Camembert	tr−+/tr	26/36
p-cresol	medicinal, heavy	0.002[a]/0.055[a]	51/6	Camembert	tr−+/tr/NQ	26/36/10
		0.3[b]	29	Livarot	tr	24
		0.001[d]	51	Pont-l'Eveque	tr	24,27
		0.002[f,g]	21	Limburger	0.7%	15
		Lactones				
γ -nonalactone	coconut, almond, anise, liquorice	0.065[a]/2.4[b]	50/19	Camembert	tr	36
γ -decalactone	fruity, peach	1[b]/0.011−0.09[a]	19/50	Blue cheese	0.02−0.04	30
γ -dodecalactone	fatty, peach, butter, musky	0.007[a]/1[b]	50/21	Limburger	tr	15
				Blue cheese	0.37−1.03	30
6-dodecen-γ-lactone	green, fruity coconut			Camembert	NQ	10
δ-octalactone				Camembert	NQ	10
δ-decalactone	creamy, coconut, peach, milk	0.14[a]/1.4[b]	19	Camembert	tr/+−++/0.91−1.08	36/26/11
		0.1−0.16[a]	50	Limburger	tr	15
		1[b]/0.4[b]	21/11	Vacherin	+−+++	25
δ-dodecalactone	fruity, coconut peach, pear, buttery	0.1−9.8[a]	50	Camembert	tr	36
		95[b]/10[b]	19/21	Vacherin	+++	25
				Blue cheese	0.7	30
δ -tetradecalactone		500[b]/50[b]	19/21	Blue cheese	0.31	30
		Aldehydes				
acetaldehyde	ethereal, pungent, green	1.3[a]/0.11[b]	19	Camembert	2.06/++/0.015−0.025	14/39/11
		0.22 ppb[b]	11	Trappist	1.10	33
				Gorgonzola	0.5[e]−0.14[f]%	7
				Pont-l'Eveque	tr	27
				Blue cheese	+	39
butanal		0.0159[a]/0.2[d]	23/32	Gorgonzola	0[e]−0.34[f]%	7
		0.00526[ag]	23			
2-methylbutanal				Camembert	tr	26
3-methylbutanal	green, malty	0.013[b]	11	Camembert	+−++/0.094−0.142	26/11
				Gorgonzola	5.12[e]−0.42[f]%	7
				Blue cheese	0.16	30
2-methylpropanal	green, malty			Gorgonzola	0.47[e]−0[f]%	7
				Camembert	NQ	10
hexanal	green, grassy, penetrating, powerful	0.0045−0.016[a]	19,23,18	Camembert	tr−+/0.124−0.144	26/11
		0.00366[a,g]	23	Blue cheese	0.01	30
		0.19−0.8[b]/0.12[b]	19/11			
		0.0138[d]/0.043[d]	18/32			
heptanal	oily, heavy, woody, sweet penetrating	0.002[a]/0.031[a]	18/19	Camembert	tr	26
		0.75−0.9[b]	19			
		0.00479[d]/0.26[d]	18/32			
nonanal	floral, citrus, orange, rose, fatty, waxy	0.001[a]/0.0025[a]	18/23	Camembert	tr	26
		0.00425[a,g]/1[b]	23/19			
		0.0022−0.0045[d]	18			
2-methylbuten-2-al	green fruit			Vacherin	tr−+	25
benzaldehyde	bitter almond, aromatic, sweet	0.35[a]/0.003[a]	6/18	Camembert	tr	26
		0.0417[d]	18	Vacherin	tr	25
				Pont-l'Eveque	tr	27
phenylacetaldehyde		0.004[a]	6	Camembert	NQ	10
				Limburger	tr	15
				Blue cheese	0.06	30

[a−g] %, ++++ to +, tr, 0, NQ, (1)−(39): see Tables 1−3. [h] (50) Dufossé et al., 1994; (51) Ha and Lindsay, 1991b.

et al. (1974a) to extract these cheeses' aroma did not allow the detection of very volatile methanethiol, but they detected methanethiol acetate in Pont-l'Eveque, Langres, and Epoisses.

The sulfur compounds found in cheese are described as having a strong garlic and very ripe cheese odor (Table 5). Moreover their perception thresholds are very low so they are probably involved in the final aroma of mold-surface ripened and soft smear cheeses.

Miscellaneous Compounds. Other volatile compounds have been detected in soft cheeses (Table 6). Indole, phenol, and their derivated compounds, 2-acetylpyrroline, hydrocarbons such as heptane, nonane, decane, cyclohexane, and benzenic, and chloride compounds such as toluene, benzene, naphthalene, dichlorobenzene, and chloroform, are often detected in trace amounts in Camembert-type cheese (Dumont et al., 1974c; Moinas et al., 1973, 1975; Kubickova and Grosch, 1998a). So far these molecules have been seldomly identified in Blue cheese (Gallois and Langlois, 1990), and their importance in the mold-ripened cheese flavor has not yet been elucidated. Concerning the surface-

ripened cheese, phenol and indole are included in the principal detected compounds (Dumont et al., 1974a,b; Parliment et al., 1982). The mixture of phenol and indole has pungent-sweet floral aroma in dilution (Parliment et al., 1982).

The presence of different γ- and δ-lactones in the soft cheeses (Table 6), in particular δ-decalactone in Camembert cheese (Kubickova and Grosh, 1997), might be important in the final flavor because of their strong fruity note and low perception threshold. The lactone content could be related to the use of pasteurized milk since the Blue cheeses made with heated milk have been shown to increase their lactone level (Gallois and Langlois, 1990). The soft cheeses also contain various aldehydes (Table 6). Among these compounds, 3-methylbutanal, which the concentration in Camembert and Blue cheeses exceeds the threshold value, would belong to the most potent odorants in cheese (Kubickova and Grosch, 1997, 1998b). 3-Methylbutanal is described as having a green and malty odor. The most striking feature of Vacherin is the high concentration of several terpene compounds (limonene, myrcene, β-pinene, linalool, isoborneol, ...) that is observed in the rind (Dumont et al., 1974b).

CONCLUSION

Detailed analysis of soft cheeses aroma components allowed for identification of several compounds. To determine the most potent odorants, the modern literature offers specialized sensory techniques such as the sensory sniffing technique in combination with the gas chromatographic separation of aroma compounds and a dilution regime or the similar concept called Charm Analysis (Acree et al., 1984; Kubickova and Grosch, 1997, 1998a) and the sensory tasting technique where selected single components are added to a neutral-tasting cheese base (Rothe et al., 1994; Kubickova and Grosch, 1998b). Thus the authors agree with the most important volatile compounds which are partially responsible for the characteristic flavor of soft ripened cheeses.

Heptan-2-one and nonan-2-one in combination with corresponding secondary alcohols are found to be the dominant compounds of blue-veined cheese flavor. Short- and moderate-chain fatty acids are the second important compounds in these cheeses. The homologous series of odd-chain methyl ketones, from C3 to C15, are some of the most important compounds in the aroma of white mold-ripened cheese. Octen-3-ol, 2-phenylethanol, and 2-phenylethyl acetate are also quantitatively important in Camembert-type cheese. These molecules together with sulfur compounds, octen-3-one, and probably lactones such as δ-decalactone are reported as the key aroma substances of Camembert cheese. The most potent odorants of soft smear-ripened cheeses are not as well characterized. Nevertheless, the sulfur compounds, especially methanethiol, hydrogen sulfide, and dimethyl disulfide, are responsible for the strong garlic and putrid aroma of this type of cheese. The short-chain fatty acids, phenol, and indole may also be important in the flavor although it has never been clearly shown.

In conclusion, the flavor of the soft cheeses is the result of a complex mixture of many sapid compounds. The understanding and control of cheese flavor is still difficult with the differences in the efficacy of sensory compounds depending upon their relative distributions between fat−protein and aqueous phases in foods (Adda and Richard, 1991).

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Received for review April 28, 1999. Revised manuscript received August 31, 1999. Accepted September 9, 1999.

JF990414F