Aroma Compounds in Sweet Whey Powder

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ABSTRACT

Aroma compounds in sweet whey powder were investigated in this study. Volatiles were isolated by solvent extraction followed by solvent-assisted flavor evaporation. Fractionation was used to separate acidic from nonacidic volatiles. Gas chromatography/mass spectrometry and gas chromatography/olfactometry were used for the identification of aroma compounds. Osme methodology was applied to assess the relative importance of each aroma compound. The most aroma-intense free fatty acids detected were acetic, propanoic, butanoic, hexanoic, heptanoic, octanoic, decanoic, dodecanoic, and 9-decenoic acids. The most aroma-intense nonacidic compounds detected were hexanal, heptanal, nonanal, phenylacetaldehyde, 1-octen-3-one, methional, 2,6-dimethylpyrazine, 2,5-dimethylpyrazine, 2,3-dimethylpyrazine, 2,3,5-trimethylpyrazine, furfuryl alcohol, p-cresol, 2-acetylpyrrole, maltol, furaneol, and several lactones. This study suggested that the aroma of whey powder could comprise compounds originating from milk, compounds generated by the starter culture during cheese making, and compounds formed during the manufacturing process of whey powder.

(Key words: sweet whey powder, aroma, Osme, pyrazine)

Abbreviation key: GCMS = gas chromatography/mass spectrometry, GCO = gas chromatography/olfactometry, RI = retention index.

INTRODUCTION

Sweet whey powder is obtained by drying fluid whey collected from the manufacture of Cheddar, Swiss, Mozzarella, Monterey Jack, and similar cheeses. It typically contains about 70% lactose, 1.5% fat, 12% proteins, 4% moisture, and 8.5% other solids (U.S. Dairy Export Council, 2004). Whey has become an important ingredient in dairy and other food products (Whetstine et al.,

2003) with a total production greater than 1.3 billion pounds in 2003 (USDA, 2004). In spite of its large production, whey is often thought of as having an undesirable flavor that is unpleasant to consumers, which limits its use in bland or delicately flavored foods (Whetstine et al., 2003).

Flavor quality in liquid whey has been evaluated recently. Karagul-Yuceer et al. (2003) identified aroma compounds in liquid Cheddar whey and found that 2,3-butanedione, hexanal, 2-acetyl-1-pyrroline, methional, (E,E)-2,4-nonadienal, (E,E)-2,4-decadienal, and various short-chain volatile acids could be important to the aroma of liquid whey. Whetstine et al. (2003) found that whey made from different types of cheeses has different flavors, and that flavor variability exists within the same cheese type. Tomaino et al. (2004) studied the flavor variability of liquid whey produced from laboratory-scale Cheddar cheese using individual strains of *Lactococcus lactis* spp. *lactis*. They confirmed that there were differences in liquid whey produced in a noncommercial setting from different starter culture strains.

Whey powder is expected to have a different flavor profile than liquid whey because of the further steps involved in its processing such as concentration and spray drying. These additional steps may reduce or generate flavor compounds, thus change the flavor profile of whey powder. Although Ferretti and Flanagan (1971) reported a wide variety of volatiles in whey powder, no direct information was provided about its flavor components. Livney and Bradley (1994) reported saltiness, brothiness, diacetyl, bitterness, and acidity as some of the flavor characteristics in acid whey. They suggested that whey flavor may be due to components traced to the original milk or developed during processing, but they did not identify those aroma compounds. Whitfield (1992) hypothesized that the Maillard reaction and lipid oxidation initiate flavor development in whey products but so far, there is no experimental data to support this hypothesis.

To date, no information is available on the aroma compounds present in sweet whey powder and hence this study is aimed at identification of flavor compounds in this dairy ingredient. In this research, flavor compounds in commercially produced sweet whey powder

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were analyzed using gas chromatography/olfactometry (GCO) and gas chromatography/mass spectrometry (GCMS).

MATERIALS AND METHODS

Sweet Whey Powder

Fresh sweet whey powder samples (Cheddar cheese whey, US extra grade) obtained from the Midwest (sample A) and Pacific Northwest (sample B) were used for analysis. The samples were stored frozen (-37°C) and used within 3 mo.

Aroma Extraction

One kilogram of sweet whey powder was mixed with 500 mL of 2:1 freshly distilled pentane (Mallinckrodt Baker, Phillipsburg, NJ) and diethyl ether (Honeywell International, Muskegon, MI) for 4 hr during each extraction, in a tightly capped Erlenmeyer flask with intermittent shaking every 15 min. Extractions were repeated 3 times. All extracts were combined and concentrated to 500 mL under the hood. The extracts were distilled at 50°C by solvent-assisted flavor evaporation under vacuum (28 inch Hg) to separate volatiles from nonvolatiles. Liquid nitrogen was used for condensation of volatiles. The distillate was further concentrated to 50 mL by letting it evaporate in a fume hood, and was then subjected to fractionation.

Fractionation

The aroma concentrate was separated into acidic and nonacidic (neutral, basic) fractions. The concentrate (50 mL) was washed twice with 3 mL of 1 M sodium bicarbonate solution containing sodium chloride (Sigma Chemical Co., St. Louis, MO). The upper (ether) phase, containing the nonacidic volatiles, was dried over anhydrous sodium sulfate (EMP Chemicals, Gibbstown, NJ) and concentrated to 500 μL for sample A and to 50 μL for sample B under a stream of nitrogen. The pooled aqueous phase (bottom layer) was acidified to pH 2.5 with HCl (Reagent grade, USP, Integra Chemical Company, Renton, WA). The acidic volatiles were further extracted (3 $\times$) with 0.5 mL of freshly distilled diethyl ether. The diethyl ether extract was then dried over anhydrous sodium sulfate and was concentrated to 500 μL for sample A and to 50 μL for sample B with a stream of nitrogen.

Gas Chromatography

A Hewlett Packard 5890 gas chromatograph equipped with a flame ionization detector and an olfac-

tometer was used. Samples were analyzed on a DB-Wax column (30 m $\times$ 0.25 mm i.d. coated with crosslinked polyethylene glycol 20M, film thickness, 0.5 μm ; J&W Scientific, Folsom, CA) and a DB-5 column (30 m $\times$ 0.32 mm i.d. coated with crosslinked 5% phenyl-methyl polysiloxane, film thickness, 1 μm ; J&W Scientific). The column effluent was split 1:1 (by volume) into the flame ionization detector and a heated sniffing port with a splitter (Alltech Associates, Inc., Deerfield, IL). Gas chromatography operating parameters were: injection port temperature = 250°C , detector temperature = 250°C , oven temperature from 40 to 230°C at the rate of $5^{\circ}\text{C}/\text{min}$ with initial and final hold times of 2 and 10 min for DB-Wax, and 4 and 10 min for DB-5 columns, respectively. The helium column flow rate was 2.0 mL/min measured at 25°C . A sample (2 μL) of acidic fraction was injected onto the DB-Wax column and 2 μL of nonacidic fraction was injected onto both columns at a split ratio of 1:1.

GCO

Seven volunteers from Oregon State University performed GCO analysis on the whey samples. Panelists participated in 4 trial runs of each acidic and nonacidic fraction of the 2 samples to identify product attributes, clarify reference terminology, and verify or establish references for flavor and intensity values (Da Silva et al., 1994). Each fraction was used at the same concentration as required for analysis. At the end of 4 sessions, 4 subjects were chosen based upon their ability to consistently perceive and describe odors as the aroma compounds eluted from the sniff port. During actual analysis, sniffing was performed twice on each fraction by each panelist using the Osme technique (McDaniel et al., 1990) with minor modification. A 16-point intensity scale, with 0 = none, and 15 = extreme, was used to assign intensity to aromas detected (Miranda-Lopez et al., 1992; Roberts et al., 2003).

GCMS

Gas chromatography/mass spectrometry analysis was performed using an Agilent 6890 gas chromatograph equipped with a 5973 mass selective detector. System software control and data analysis were performed using enhanced ChemStation Software, G1707CA v. C.00.01.08 (Agilent Technologies, Inc., Wilmington, DE). Volatile separation was achieved with 2 fused silica capillary columns: DB-Wax (30 m $\times$ 0.25 mm i.d. coated with crosslinked polyethylene glycol 20M, film thickness, 0.5 μm , J&W Scientific) and DB-5 (30 m $\times$ 0.32 mm i.d. coated with crosslinked 5% phenyl-methyl polysiloxane, film thickness, 1 μm , J&

W Scientific). The oven temperature was programmed as for the GCO analysis. Injector, detector transfer line, and ion source temperatures were 250, 280, and 230°C respectively. Helium was used as carrier gas with constant flow of 2 mL/min. A splitter was used at the end of the column as described by Qian and Reineccius (2002). One milliliter of the flow was directed to mass spectrometry and the remainder was directed to an olfactometer. Standard electron impact mass spectroscopy was used, and the ionization voltage was set at 70 eV. An m/z range of 35 to 300 was collected at 5.27 scans/s. A sample (2 μ L) of each fraction was injected in the splitless mode.

Retention Index

A sample containing series of hydrocarbons (C_5 to C_{25}) was injected on the DB-Wax and DB-5 columns using the same conditions mentioned as above for the 2 samples. Retention indices (RI) for the aroma compounds were calculated using the modified Kovats method (Van Den Dool and Kratz, 1963).

Identification of Odorants

Positive identifications were made by comparing calculated RI with standards, panelist's aroma description, and individual mass spectra (Wiley 275.L mass spectral database; Agilent Technologies, Inc.). Tentative identifications were based on retention indices and odor descriptors.

RESULTS AND DISCUSSION

Many acids were identified on the DB-Wax column in sweet whey powder samples from the Midwest (sample A) and Pacific Northwest (sample B). The most important acids found in sample A were acetic, butanoic, 3-methylbutanoic, hexanoic, and octanoic acids based on their high Osme value (Osme value >8) (Table 1). Acetic acid, with its sharp vinegar-like odor, could be one of the most prominent among the identified acids. It showed a high Osme value indicating its important role in imparting the unique aroma to sweet whey powder. Butanoic, hexanoic, and octanoic acids contributed to the cheesy and rancid odors. Of these, butanoic acid showed high aroma intensity. 3-Methylbutanoic acid gave a sweaty odor with a relatively high Osme value. Pentanoic and dodecanoic acids gave pungent odors, and octanoic acid gave an animal-like odor. Formic acid with its pungent odor showed a weak intensity in both samples. Propanoic, 2-methylpropanoic, decanoic, and dodecanoic acids showed relatively low Osme values in the 2 samples. 9-Decenoic acid gave a fatty aroma with

weak Osme values in both samples. Among the 12 acids identified in the acidic fraction, all were present in sample A, whereas 2-methylpropanoic and dodecanoic acids were absent in sample B. Short-chain FFA have been identified in many foods including cheese (Aston and Dulley, 1982; Qian and Reineccius, 2002; Qian et al., 2002) and liquid whey (Karagul-Yuceer et al., 2003; Whetstine et al., 2003; Tomaino et al., 2004). Free fatty acids can be formed through the action of milk or bacterial lipases on triglycerides and phospholipids (Ferretti and Flanagan, 1971; Badings, 1991; Kim et al., 2003). Because the FFA were isolated by their chemical properties, and well separated and identified on the DB-Wax column, analysis was not necessary on an additional column.

The nonacidic fraction was analyzed on DB-Wax (Table 2) and DB-5 (Table 3) columns. The chemical classes of compounds identified on the 2 columns consisted of aldehydes, ketones, lactones, sulfur-containing compounds, and many others.

Many aldehydes were identified in sample A to have very intense aroma on DB-Wax column (Table 2). Saturated aldehydes identified were hexanal, heptanal, and nonanal, and they had characteristic grassy, green, floral aromas. Most of the unsaturated aldehydes were tentatively identified by their RI and descriptive odor properties. The most prominent of these were (E)-2-octenal, (Z)-2-nonenal, (E,Z)-2,6-nonadienal, (E,E)-2,4-nonadienal, (E,E)-2,4-octadienal, (E,Z)-2,4-decadienal and (E,E)-2,4-decadienal. These aldehydes are formed from the autooxidation of unsaturated fatty acids (Wadodkar et al., 2002). Phenylacetaldehyde, an aroma compound with a floral note, was detected only in sample A. This compound is believed to have derived from Strecker degradation of phenylalanine (Counet et al., 2002).

Two straight chain ketones were identified in the whey powder. Diacetyl was identified with its characteristic buttery note. It is a product of citrate metabolism, involving *Lactococcus lactis* ssp. *lactis* biovar *diacetylactis* during cheese making (Kaneko et al., 1987; Bendall, 2001; Kieronczyk et al., 2003). It is believed that diacetyl undergoes reduction to form acetoin, an aromatic hydroxy ketone (Hugenholtz et al., 2000), which was also detected with its typical butter-like aroma in both samples. 1-octen-3-one was detected with a typical mushroom-like odor. Although the intensity for this compound was from moderate to small on DB-Wax (Table 2) and moderate on DB-5 (Table 3), it showed unique earthy aroma characteristics to the odor profile of whey powder.

Several sulfur-containing compounds were identified on the DB-Wax column (Table 2). Both dimethyl disulfide and dimethyl trisulfide have an onion, cabbage

Table 1. Aroma compounds in the acidic fraction of sweet whey powder analyzed on DB-Wax column.

Compound	RI ¹	Aroma	Osme value		Identification ²
			A	B	
Acetic acid	1460	Vinegar-like	11	9	1,2,3
Formic acid	1510	Pungent	5	6	1,2,3
Propanoic acid	1550	Rancid	5	2	1,2,3
2-Methylpropanoic acid	1580	Buttery	6	0	1,2,3
Butanoic acid	1645	Cheesy	12	10	1,2,3
3-Methylbutanoic acid	1682	Sweaty	9	8	1,2,3
Pentanoic acid	1755	Pungent	6	4	1,2,3
Hexanoic acid	1858	Rancid	11	6	1,2,3
Heptanoic acid	1971	Cheesy	6	7	1,2,3
Octanoic acid	2072	Animal-like	9	6	1,2,3
Decanoic acid	2294	Soapy	6	4	1,2,3
9-Decenoic acid	2348	Fatty	4	2	1,2,3
Dodecanoic acid	2505	Soapy	5	0	1,2,3

¹RI = Retention index.²Identification: 1 = aroma descriptor; 2 = retention index (RI); 3 = mass spectroscopy.

note, while methional has a cooked potato aroma. Methional could be a very important flavor compound because of its high Osme value in sample A. It was detected very close to the elution of 2,6-dimethylpyrazine, but was differentiated by the panelists with a cooked potato note for methional and a cooked meaty note for 2,6-dimethylpyrazine. Dimethyl sulfide, dimethyl trisulfide, and methional have been identified in cheese (Aston and Dulle, 1982; Qian et al., 2002; Boscaini et al., 2003; Qian and Reineccius, 2003) and liquid whey (Karagul-Yuceer et al., 2003; Whetstone et al., 2003; Tomaino et al., 2004). Degradation of methionine can form dimethyl sulfide and methanethiol; and methanethiol can be further oxidized to form dimethyl disulfide and dimethyl trisulfide (Bendall, 2001). Dimethyl sulfide can be oxidized to dimethyl sulfone (Livney and Bradley, 1994). Although a peak was detected for dimethyl sulfone by mass spectroscopy, no aroma was sensed. Methional is thought to be generated from Strecker degradation of methionine (Aston and Dulle, 1982; Da Silva et al., 1993; Fu et al., 2002; Boscaini et al., 2003).

Pyrazines are nitrogen-containing heterocyclic compounds which are recognized for their characteristic baked and roasted potato, nut, and meat-like aromas. The most intense of these were 2,6-dimethylpyrazine, 2,5-dimethylpyrazine, 2,3-dimethylpyrazine, 2,3,5-trimethylpyrazine for sample A (Table 2). Most of these pyrazines had moderate Osme values in sample B except 2,5-dimethylpyrazine (Osme value of 10). 2,6-Dimethylpyrazine was only identified in sample A, whereas 2-ethylpyrazine was only identified in sample B. Most of these pyrazines have been identified in Parmesan cheese as compounds responsible for the nutty aroma (Qian and Reineccius, 2002). 2-Methoxy-3-isopropylpyrazine and 2-isobutyl-3-methoxypyrazine have

been identified in liquid whey (Karagul-Yuceer et al., 2003), but were not identified in this study. Pyrazines are the products of Maillard reaction (Friedman, 1996; Alasalvar et al., 2003), possibly formed during concentration, spray drying, or other processes involved in the manufacturing of whey powder.

2-Acetylpyrrole with its characteristic medicinal odor was seen only in sample A (Table 2). 2-Acetylthiazole, 2-acetyl-1-pyrroline, and 2-propionyl-1-pyrroline were tentatively identified to have roasted nuts and fried kind of aromas. 2-Acetyl-1-pyrroline is believed to be formed by the interaction of pyruvaldehyde with 1-pyrroline, which is formed from proline (Bendall, 2001; Karagul-Yuceer et al., 2001). 2-Acetyl-1-pyrroline and 2-propionyl-1-pyrroline possess very low odor thresholds and are frequently cited as compounds that directly contribute to roasted or smoky flavors (Da Silva et al., 1993; Karagul-Yuceer et al., 2003).

Maltol and furaneol were identified in the whey powder that gave moderate to large intensity in both samples with a burnt sugar-like aroma for maltol and a sweet aroma for furaneol (Table 2). Maltol and furaneol are believed to be products of sugar degradation (Da Silva et al., 1993; Wadodkar et al., 2002). Sotolon gave a spicy note, with high intensity on both samples on DB-Wax column (Table 2). This compound is thought to be formed from α -ketobutyric acid and acetaldehyde (Takahashi et al., 1976). Maltol and sotolon have been identified in liquid whey (Karagul-Yuceer et al., 2003), and furaneol was found in stored nonfat dry milk (Karagul-Yuceer et al., 2001).

Most of the lactones were detected only by the DB-Wax column (Table 2). Only a few compounds such as delta-decalactone and gamma-hexalactone were detected by both columns. Fruity, nutty, and dairy aromas were associated with lactones in both samples, and

Table 2. Aroma compounds in nonacidic fraction of sweet whey powder analyzed on DB-Wax column.

Compound ¹	RI ²	Aroma	Osme value		Identification ³
			A	B	
Diacetyl	1005	Buttery	7	9	1,2
Dimethyl disulfide*	1095	Cooked vegetable	4	6	1,2
Hexanal	1097	Grassy	5	4	1,2,3
Heptanal	1199	Grassy	12	10	1,2,3
(Z)-4-Heptenal*	1231	Sweet	8	8	1,2
1-Octen-3-one	1307	Mushroom	6	3	1,2,3
Unknown*	1323	Buttery	5	8	1
2-Acetyl-1-pyrroline*	1331	Roasted nuts	7	0	1,2
2,6-Dimethylpyrazine	1347	Cooked meat	15	0	1,2,3
2,5-Dimethylpyrazine	1348	Cooked potato	12	10	1,2,3
2-Ethylpyrazine*	1357	Roasted nuts	0	6	1,2
Dimethyl trisulfide*	1367	Sulfury, cabbage	8	7	1,2
2,3-Dimethylpyrazine	1375	Nutty	10	7	1,2,3
2-Acetylthiazole*	1397	Roasted nuts	9	10	1,2
Nonanal	1406	Floral	10	7	1,2,3
(E)-2-Octenal*	1416	Roasted peanuts	10	4	1,2
2-Propionyl-1-pyrroline*	1434	Fried	12	13	1,2
Methional	1464	Cooked potato	13	8	1,2,3
(Z)-2-Nonenal*	1493	Fatty	10	0	1,2
2,3,5-Trimethylpyrazine	1517	Roasted	9	5	1,2,3
Unknown	1522	Pungent	6	10	1
Unknown	1545	Sour	7	12	1
(E)-2-Nonenal*	1558	Pungent	8	13	1,2
(E,Z)-2,6-Nonadienal*	1604	Cucumber	8	13	1,2
Furfuryl alcohol	1613	Burnt rubber	7	5	1,2,3
(E,E)-2,4-Octadienal*	1615	Cucumber	15	10	1,2
Unknown	1619	Rancid	7	0	1
Phenylacetaldehyde	1632	Floral	8	0	1,2,3
(E,Z)-2,4-Nonadienal*	1646	Green	7	7	1,2
(E,E)-2,4-Nonadienal*	1681	Rancid	13	7	1,2
Gamma hexalactone	1736	Coconut	10	9	1,2,3
(E,Z)-2,4-Decadienal*	1752	Green	13	13	1,2
(E,E)-2,4-Decadienal*	1795	Baked	7	10	1,2
Delta-octalactone	1988	Baked	5	5	1,2,3
2-Acetylpyrrole	2002	Herbal medicine	12	0	1,2,3
Maltol	2012	Caramel	8	12	1,2,3
Furaneol	2033	Sweet	8	8	1,2,3
Unknown	2056	Caramel	13	0	1
p-Cresol	2103	Cattle	11	6	1,2,3
Gamma-decalactone	2143	Milk powder	9	10	1,2,3
Sotolon*	2186	Spicy	10	15	1,2
Delta-decalactone	2220	Fruity	10	9	1,2,3
Delta-undecalactone*	2345	Fruity	4	14	1,3
Gamma-dodecalactone	2384	Cheesy	8	5	1,2,3
Delta-dodecalactone	2466	Buttery	3	4	1,2,3
Skatole*	2486	Animal-like	6	8	1,2

¹Compounds with * are tentatively identified.²RI = Retention index.³Identification: 1 = aroma descriptor; 2 = retention index (RI); 3 = mass spectroscopy.

aroma intensities varied from very low to very high. Parlimnet et al. (1966) concluded that the precursors for lactones were triglycerides containing a hydroxyl acid moiety.

p-Cresol, a phenolic compound with a typical cattle-like odor contributed a high Osme value for sample A and a weak Osme value for sample B on the DB-Wax column (Table 2). It has long been known as the factor responsible for the smell of cow urine. It imparts a barn/medicine-like flavor to milk upon liberation from conjugated precursors (Bendall, 2001; Kim et al., 2003).

Skatole was also identified in this study on both columns (Tables 2 and 3). It strongly associated with an unpleasant smell of cow feces. It is produced from the amino acid L-tryptophan in the cow's rumen from the diet. Skatole has been found in liquid whey and in non-fat dry milk (Bendall, 2001; Karagul-Yuceer et al., 2001).

Similar compounds were identified in samples A and B. Sample A showed 45 aroma compounds on DB-Wax and 21 on DB-5. In addition, sample A showed 5 unknowns on DB-Wax and 1 on DB-5. Sample B showed

Table 3. Aroma compounds in nonacidic fraction of sweet whey powder analyzed on DB-5 column.

Compound ¹	RI ²	Aroma	Osme value		Identification ³
			A	B	
Diacetyl*	606	Buttery	5	8	1,2
Hexanal	789	Grassy	5	5	1,2,3
Heptanal	899	Grassy	9	0	1,2,3
Methional	902	Cooked potato	9	3	1,2,3
2,6-Dimethylpyrazine	906	Cooked meat	11	0	1,2,3
2-Acetyl-1-pyrroline*	916	Roasted nuts	11	3	1,2
1-Octen-3-one	974	Mushroom	6	8	1,2,3
Gamma-hexalactone	1047	Coconut	10	8	1,2,3
2-Acetylpyrrole	1072	Herbal medicine	8	0	1,2,3
p-Cresol	1074	Cattle	11	3	1,2,3
Maltol	1088	Burnt sugar	10	12	1,2,3
Nonanal	1101	Floral	6	0	1,2,3
Sotolon*	1108	Spicy	11	0	1,2
(Z)-2-Nonenal*	1147	Fatty	8	6	1,2
(E,Z)-2,6-Nonadienal*	1153	Cucumber	8	12	1,2
(E)-2-Nonenal*	1155	Pungent	9	11	1,2
(E,E)-2,4-Nonadienal*	1211	Rancid	8	6	1,2
(E,E)-2,4-Decadienal*	1313	Baked	9	6	1,2
Skatole*	1391	Animal-like	7	11	1,2
Unknown	1482	Floral	10	11	1
Delta-decalactone	1491	Fruity	12	0	1,2,3

¹Compounds with * are tentatively identified.

²RI = Retention index.

³Identification: 1 = aroma descriptor; 2 = retention index (RI); 3 = mass spectroscopy.

39 aroma compounds on DB-wax and 15 on DB-5. Most of these compounds were identified in both samples. Some compounds, however, were only identified in one sample. For example, ethylpyrazine was identified on DB-Wax column in sample B but was absent in sample A, whereas 2-acetyl-1-pyrroline, 2,6-dimethylpyrazine, (Z)-2-nonenal, phenylacetaldehyde, and 2-acetyl pyrrole were identified in sample A, but were absent in sample B. The Osme values also varied substantially. To perceive the aroma, sample B was evaluated at a concentration 10 times higher than sample A. The fewer aroma compounds identified in sample B and low aroma intensity suggested a bland, clean whey powder.

CONCLUSION

Important aroma volatiles analyzed in sweet whey powder were the short-chain fatty acids, aldehydes and ketones, lactones, sulfur compounds, phenols, indoles, pyrazines, furans, and pyrroles. Some of them are derived from milk or formed during cheese making, whereas others are formed during whey powder processing. Autooxidation of lipids, caramelization of sugar, and Maillard browning can explain the generation of many aroma compounds. Although more sensory work is needed to validate the results, it is likely that the identified compounds are responsible for the characteristic aroma of sweet whey powder.

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