Volatile Flavor Components of Corn Tortillas and Related Products

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The volatile components of tortilla type corn products, masa flour, corn tortillas, taco shells, and tortilla chips, were isolated by high-flow dynamic headspace sampling (including closed loop stripping) with Tenax trapping. Separation and identification were carried out by capillary GC–MS. Major components identified in the masa flour include hexanal, pentanol, 4-vinylguaiacol, 2-aminoacetophenone and vanillin. Major components identified in tortillas include 3-hydroxy-2-butanone (acetoin), hexanal, 2-aminoacetophenone, and 4-vinylguaiacol. In addition to the above, major components identified in taco shells and tortilla chips include pyrazine, 2-ethyl-3,6-dimethylpyrazine, 2,4-decadienal, and 2-acetyltetrahydropyridine. Odor threshold studies indicated that compounds with high probabilities of contributing to the aroma of tortillas include 2-aminoacetophenone, β-ionone, 3-methylbutanal, 4-vinylguaiacol, hexanal, and 1-octen-3-ol. Compounds with high probabilities of contributing to taco shell aroma include 2,4-decadienal, 2-aminoacetophenone, 2-acetyl-1-pyrroline, 2-ethyl-3,6-dimethylpyrazine, 2-nonenal, 3-methylbutanal, 2-acetyltetrahydropyridines, and 3-(methylthio)propanal (methional).

Keywords: *Corn tortilla; masa; taco; volatiles; flavor; identification; concentrations; odor threshold*

INTRODUCTION

We recently reported studies of the volatile flavor components of sweet corn (Buttery et al., 1994) and of the importance of 2-aminoacetophenone to the aroma of masa corn flour products (Buttery and Ling, 1994). A recent paper by Karahadian and Johnson (1993) reported similar studies on corn masa dough, flour, and tortillas. They reported GC–MS (+RT) identification of (1) alkylpyrazines with the substituents 2-methyl-, 2,5- and 2,6-dimethyl-, 2-ethyl-, 2-ethyl-5(and 6)-methyl, 2-ethyl-3,6(and 5)-dimethyl-, 2-ethenyl-5-methyl-, 2,3-diethyl-5-methyl-, and 2,6-diethyl-3-methyl-; (2) the lipid oxidation products hexanal, 2-heptanone, octanal, nonanal, 3-octen-2-one, 2-octenal, 1-octen-3-ol, (*E*,*E*)-2,4-heptadienal, decanal, (*E*)-2-nonenal, (*E*,*Z*)- and (*E*,*E*)-2,4-decadienal, and (*E*,*Z*)- and (*E*,*E*)-3,5-octadien-2-one; and (3) others including 3-methylbutanol, 2-(methylimino)-3-butanone, benzaldehyde, β-ionone, 2-acetylpyrroline, and 2-acetylpyridine. They tentatively identified several additional compounds by odor and retention time.

In the present paper we report additional studies that we believe will give a more complete understanding of the aroma and flavor components of these tortilla-related corn products.

EXPERIMENTAL PROCEDURES

Materials. The masa corn flour was Quaker Masa Harina. Fresh corn tortillas, taco shells, and tortilla chips were major brands purchased from local supermarkets. These were stored at refrigerator temperatures (2–4 °C) and used within 1–3 days. Diethyl ether was freshly distilled, stored in the dark, and contained ca. 0.001% Ethyl Corp. antioxidant 330. Sodium chloride and sodium carbonate were heated at 150 °C for 2 h to remove any possible volatiles.

Isolation of Volatiles. Some of the earlier isolation work used high-flow dynamic headspace trapping with air or nitrogen as the sweep gas as was described previously (Buttery and Ling, 1994). In more recent work the following "closed loop" method was used. The corn product (25 g) was blended with 150 mL of water containing 54 g of NaCl. For each product, isolation was carried out at three different pH values: (1) at the normal pH of the product, (2) at near neutral, ca. pH 7.4–7.6, by addition of 7.5 g of $NaHCO_3$ to the blending jar, and (3) at slightly basic conditions (pH 9.4–9.8) by the addition of 7.5 g of Na_2CO_3. The blending was carried out for 30 s. The mixture was then placed in a 1-L flask containing a large efficient magnetic stir bar. Fitted to the neck of the flask was a suitable Pyrex glass head which allowed entry of sweep gas onto the surface of the rapidly stirred corn mixture and exit through a large (10 g) Tenax trap. The sweep gas system was based on the principle of "closed-loop stripping" described by Grob and Zurcher (1976). In the present study a Teflon diaphragm pump with Teflon body, fittings, and connecting tubing was used. All inner material surfaces were either Teflon or Pyrex glass. The recirculating sweep gas was purified argon at a flow rate of 6 L/min and was continued for 2 h. The Tenax trap was then removed, and the volatiles were eluted from the trap with freshly distilled diethyl ether (ca. 50 mL). The ether extract was then concentrated to ca. 50 μL using a warm water bath and a micro-Vigreux distillation column.

Capillary GC–MS. The capillary column was 60 m long × 0.25 mm i.d., fused silica, coated with bonded methylsilicone DB-1. The column was held at 30 °C for the first 25 min and then programmed at 4 °C/min to 200 °C and held at this upper temperature for a further 20 min. The injector temperature was 170 °C and was used with a 1/20 split. The column was used in an HP5890 GC instrument directly coupled to an HP5970 quadrupole mass spectrometer. The average (He) carrier gas velocity was 22 cm/s.

Quantitative Analysis. This was carried out by GC in a way similar to that previously described (Buttery et al., 1994) using internal standards and determining recovery factors relative to the internal standards for each compound. For the slightly alkaline (pH 9.4–9.8) conditions, 2-pentanone, 3,5-dimethylpyridine, and quinoline were used as internal standards. For neutral conditions (with $NaHCO_3$, pH 7.4) or slightly acidic conditions (pH 4.5–6.4), the internal standards 2-pentanone, 6-methyl-5-hepten-2-one, and 4-phenyl-2-butanone were used. Recovery factors were determined for each compound relative to the particular internal standards used and the pH conditions.

Authentic Samples. Authentic samples of identified compounds were obtained from commercial sources or synthesized according to established methods [e.g. synthesis of 2-acetyl-1-pyrroline and 2-acetyltetrahydropyridine; cf. Buttery et al. (1994)]. They were purified by preparative GC and their identities verified by spectral (MS and/or IR) methods.

Odor Threshold Determination. This was carried out as previously described (Guadagni and Buttery, 1978) using a panel of 16–24 experienced judges. Sniffing of the GC effluent was also carried out by 1–3 judges. This involved turning off the flame (H_2 off, air on) on the HP5890 GC and sniffing a short (1 cm) Teflon extension tube from the detector.

RESULTS AND DISCUSSION

Isolation Method. The volatiles were isolated from the corn product using high-flow dynamic headspace trapping. Part of the work was carried out using the particular technique we described previously (Buttery and Ling, 1994). An improved technique was developed during the study and was used for the later experiments. This involved using the high-flow dynamic headspace sweeping in a closed-loop stripping arrangement similar to that described by Grob and Zurcher (1976), in which the sweep gas is recirculated by means of a noncontaminating Teflon pump. Using this method any compound that "breaks" through the trap is passed through the system again for further exposure to the Tenax. Recoveries were close to quantitative (70–100%) for most moderate polarity (C_5–C_{15}) compounds but (within the 2-h isolation period) still relatively low for some very water soluble compounds such as 3-hydroxy-2-butanone (11% recovery). The present availability of all-Teflon, inert, noncontaminating, pumps makes the closed loop stripping method much more feasible. Three different pH conditions were used. With the first condition the corn product was mixed with only water and NaCl where the pH varied from 4.5 to 6.4 depending on the corn product. The second pH condition involved adding $NaHCO_3$ to bring the mixture to close to neutral, ca. pH 7.4. The third pH condition used Na_2CO_3 to make the mixture slightly basic at pH 9.4–9.8. The commercial tortillas contained sodium propionate and sorbate added by the manufacturer as preservatives. Isolation at their normal pH (ca. 4.5) showed free propionic and sorbic acids which gave large interfering GC peaks. These were greatly decreased by the use of $NaHCO_3$ or Na_2CO_3. As expected, the bases identified in these products showed better recovery under the mildly alkaline (Na_2CO_3) conditions.

Volatiles Identified. Table 1 lists compounds identified. Many of the volatiles were common to the four corn products. The taco shells and tortilla chips contained additional compounds resulting from the higher heat conditions of the frying process as well as compounds apparently derived from the frying oils. Table 2 gives some idea of the concentrations found in masa flour, tortillas, and taco shells. The identities of components found in tortilla chips were the same as those found in taco shells, and the concentrations of components were of the same order of magnitude. Although these quantitative data were measured as carefully as possible, they are only meant to give some idea of the order of magnitude of the concentrations. The figures shown are means of analyses of at least three different samples for the pH 7.4 isolations (using $NaHCO_3$), but they were similar to the data obtained at the other pH conditions, although the recovery factors for some compounds were dependent on the pH. For example, the recovery for 2-aminoacetophenone was 33% at pH 7.4 but only 11% at pH 5.0.

Many of the compounds identified in the masa flour and tortillas are similar to those reported previously by Karahadian and Johnson (1993) and also to those identified in popcorn (Schieberle, 1991).

Major components in the masa flour include hexanal, pentanol, 4-vinylguaiacol, 2-aminoacetophenone, vanillin, and benzoic acid. Major components in the tortillas

Table 1. Volatile Compounds Identified (1) in Corn Masa Flour (Masa Harina) and Tortillas and (2) in Taco Shells and Tortilla Chips

compound[a]	major MS ions[b] (one each 14 mass units)	Kovats[c] GLC index (DB-1)
(1) Identified in Masa Flour and Tortillas		
2,3-butandione	43, *86*, 29, 53	558
3-methylbutanal	44, 58, 29, 71, *86*	627
2-methylbutanal	57, 29, 41, *86*, 71	637
1-penten-3-one	55, 29, *84*, 39	660
1-penten-3-ol	57, 29, 41, 67, *86*	665
pentanal	44, 29, 58, 71, *86*	668
3-hydroxy-2-butanone	45, 43, *88*, 73	674
3-methylbutanol	55, 42, 70, 31	714
2-methylbutanol	57, 41, 31, 70	718
(*E*)-2-pentenal	55, 29, 41, *84*, 69	723
pentanol	42, 55, 70, 31	752
hexanal	44, 56, 29, 72, 82	772
hexanol	56, 43, 31, 69, 84	848
2-heptanone	43, 58, 71, *114*, 99	865
heptanal	44, 70, 55, 29, 86	876
2-acetylfuran	95, 39, *110*, 68, 51	876
2,5-dimethylpyrazine	*108*, 42, 81, 52, 66, 93	883
benzaldehyde	77, 105, 51, 39, 63	926
(*E*)-2-heptenal	41, 55, 83, 70, 97, *112*	927
1-octen-3-ol	57, 43, 72, 85, 99, 110	962
2-ethyl-5-methylpyrazine	121, 39, 56, 94, 107, 66	970
2-pentylfuran	81, 53, *138*, 39, 95, 68	977
limonene	68, 93, 39, *136*, 53, 79	1020
acetophenone	105, 77, *120*, 51, 43	1031
(*E*,*Z*)-3,5-octadien-2-one	95, 43, 81, 53, *124*, 109	1040
2-ethyl-3,6-dimethylpyrazine	135, 42, 56, 108, 121, 67	1054
(*E*,*E*)-3,5-octadien-2-one	95, 43, 81, 53, *124*, 109	1063
nonanal	57, 41, 29, 70, 98, 82	1082
(*E*)-2-nonenal	41, 55, 29, 70, 83, 96	1133
methyl salicylate	120, *152*, 92, 39, 65, 53	1166
4-vinylphenol	*120*, 91, 39, 65, 51, 79	1190
2-aminoacetophenone	120, *135*, 92, 65, 39, 52	1261
(*E*,*Z*)-2,4-decadienal	81, 41, 67, 55, 95, *152*	1267
4-vinylguaiacol	*150*, 135, 39, 77, 51, 107	1280
(*E*,*E*)-2,4-decadienal	81, 41, 67, 55, 95, *152*	1287
vanillin (4-hydroxy-3-methoxybenzaldehyde)	151, 81, 109, 53, 123, 39	1349
α-ionone	121, 93, 43, 136, 77, 109	1404
geranylacetone	43, 69, 93, 107, 53, 136	1429
β-ionone	177, 43, 122, 91, 135, 149	1462
(2) Additional Compounds Identified in Taco Shells and Tortilla Chips[d]		
pyrazine	*80*, 53, 26, 38	706
pyrrole	*67*, 39, 52	730
2-methylpyrazine	*94*, 67, 39, 53	796
furfural	39, *96*, 29, 67, 50	800
furfuryl alcohol	*98*, 41, 81, 53, 70, 31	827
3-(methylthio)propanal (methional)	48, 29, *104*, 61, 76, 35	856
ethylpyrazine	107, 80, 53, 39, 66, 93	887
2,3-dimethylpyrazine	67, *108*, 42, 52, 93	890
2-acetyl-1-pyrroline	43, 69, 83, *111*, 55	892
2-vinylpyrazine	*106*, 53, 79, 39	901
2-octanone	43, 58, 71, *128*, 85, 113	967
octanal	43, 57, 84, 29, 69, 100	979
phenylacetaldehyde	91, *120*, 65, 39, 51, 77	1006
2-acetyl-1,4,5,6-tetrahydropyridine	43, 55, 82, *125*, 97, 70	1017
2-acetyl-3,4,5,6-tetrahydropyridine	82, *125*, 54, 43, 110, 68	1110
2-undecanone	58, 43, 71, 85, *170*, 112	1273

[a] Mass spectrum and GC Kovats retention index found are consistent with that of an authentic sample. [b] One major ion each 14 mass units with most intense ions first. Molecular ion if present is italicized. [c] Kovats GC retention index found on DB-1 capillary. [d] Tortilla and masa flour components not detected in taco shells and tortilla chips are indicated by a dash in the concentration column in Table 2.

Table 2. Concentrations of Volatiles Found in the Different Forms of Masa Corn Product in Milligrams of Compound per Kilogram of Product (ppm)

compound	concn[a] (mg/kg of product) (ppm) tortilla flour	corn tortilla	taco shell
aliphatic alcohols			
1-penten-3-ol	0.01	–	0.05
3-hydroxy-2-butanone[b]	0.04	0.31	0.08
3-methylbutanol	–	–	0.02
2-methylbutanol	–	–	0.01
pentanol	0.84	0.04	0.34
hexanol	0.12	0.004	0.04
1-octen-3-ol	0.07	0.01	0.02
aliphatic aldehydes and ketones			
2,3-butanedione	0.06	0.006	–
3-methylbutanal	0.007	0.02	0.14
2-methylbutanal	0.005	0.01	0.10
2,3-pentadione	–	–	0.21
pentanal	0.08	0.04	–
hexanal	0.99	0.17	1.8
2-heptanone	0.02	0.003	0.06
heptanal	–	–	0.11
(*E*)-2-heptenal	0.02	0.08	0.09
(*E,Z*)-3,5-octadien-2-one	0.01	0.001	0.05
(*E,E*)-3,5-octadien-2-one	0.02	0.004	0.05
nonanal	0.02	0.01	0.14
(*E*)-2-nonenal	–	0.01	0.05
(*E,Z*)-2,4-decadienal	–	–	0.09
2-undecanone	–	–	0.02
(*E,E*)-2,4-decadienal	–	0.01	0.26
nitrogen compounds			
pyrazine[b]	–	–	0.7
pyrrole[b]	–	–	0.03
2-methylpyrazine	–	0.04	0.18
2,5-dimethylpyrazine	0.01	0.009	0.14
ethylpyrazine	–	–	0.09
2,3-dimethylpyrazine	–	–	0.06
2-acetyl-1-pyrroline	–	–	0.08
2-vinylpyrazine	–	–	0.04
2-ethyl-5-methylpyrazine	0.005	–	0.05
2-acetyl-1,4,5,6-tetrahydropyridine	–	–	0.13
2-ethyl-3,6-dimethylpyrazine	–	0.004	0.30
2-acetyl-3,4,5,6-tetrahydropyridine	–	–	0.10
2-aminoacetophenone	0.25	0.22	0.39
furans and aromatic compounds			
furfural	–	0.09	0.01
furfuryl alcohol	0.003	0.01	0.08
2-acetylfuran	0.02	0.003	–
benzaldehyde	0.05	0.01	0.05
2-pentylfuran	0.07	–	0.05
phenylacetaldehyde	–	–	0.04
acetophenone	0.04	0.002	–
methyl salicylate	0.05	0.008	–
benzoic acid[b]	0.18	0.1	–
4-vinylphenol	0.02	0.06	0.14
4-vinylguaiacol	1.1	0.18	0.43
vanillin	0.23	0.05	0.09
isoprenoid compounds			
limonene	0.06	0.03	0.10
α-ionone	0.005	0.002	–
β-ionone	–	0.002	–
geranylacetone	0.005	0.009	–
others			
3-(methylthio)propanal[b] (methional)	–	–	0.04

[a] Values can only be considered accurate to the correct order of magnitude. [b] These compounds have very low recovery factors, and the values can only be considered approximate.

include acetoin, hexanal, 2-aminoacetophenone, and 4-vinylguaiacol. The taco shells and tortilla chips contained larger concentrations of volatiles. The major ones include hexanal, 4-vinylguaiacol, pyrazine, 2-aminoacetophenone, 2,4-decadienal, 2-ethyl-3,6-dimethylpyrazine, and 2-acetyl-tetrahydropyridine (1,4,5,6- and 3,4,5,6- isomeric forms).

No noticeable differences were found between the volatiles of white corn and yellow corn products.

2-Acetyl Nitrogen Heterocyclic Compounds. We found good evidence for the presence of relatively significant concentrations of the important popcorn (or cracker)-like aroma compounds 2-acetyltetrahydropyridine (two isomeric forms) and 2-acetyl-1-pyrroline in taco shells and tortilla chips. Tentative evidence (from detection of its odor at its retention time in the GC effluent) was also found for traces of 2-propionyl-1-pyrroline in these fried products. These compounds had been previously found in popcorn by Schieberle (1991). We were unable to detect any of these 2-acetyl- or 2-propionyl nitrogen heterocyclic compounds in tortilla flour or tortillas, however, by mass spectrometry or GC effluent sniffing.

2-(Methylimino)-3-butanone. Karahadian and Johnson (1993) had reported finding tentative evidence for the presence of 2-(methylimino)-3-butanone in masa dough and tortillas. However, the mass spectrum they reported is not consistent with that reported by Parliment (1989) or with a spectrum obtained by us (consistent with Parliment's) on a sample that we synthesized following the procedure of Parliment (1989). We found no evidence for the presence of this compound in any of these masa corn products. We confirmed Parliment's finding that this compound has a strong cereal-like odor in its pure state. On dissolving in dilute solution in water, however, it hydrolyzed in seconds back to methylamine and biacetyl, its synthetic starting materials. A similar slower breakdown (in minutes) occurred in solutions in paraffin oil, possibly from some traces of moisture. It seems unlikely that it could survive in the moist tortilla.

2-Aminoacetophenone. We had reported previously (Buttery and Ling, 1994) the identification of 2-aminoacetophenone in corn masa flour, tortillas, and taco shells. It had been found by us also in tortilla chips, which are produced from tortillas (cut into segments) by essentially the same cooking process (frying in oil) as taco shells. We had found 2-aminoacetophenone to have the highest concentration/threshold ratio of the components identified in masa flour and tortillas and among the highest in taco shells and tortilla chips. Its tortilla character was very evident on GC effluent sniffing and was the main description used by panels for dilute water solutions of it. As mentioned previously (Buttery and Ling, 1994), 2-aminoacetophenone probably results from breakdown of tryptophan occurring during the normal lime treatment of corn during the preparation of masa dough. In the absence of air, tryptophan is stable to alkali, but under certain conditions tryptophan can be oxidized to an intermediate compound (kynurenine), which is converted to 2-aminoacetophenone under alkaline conditions (Spacek, 1954).

Phenolic Compounds. 4-Vinylguaiacol and vanillin had been identified in popcorn by Schieberle (1991). We had also found these and the related 4-vinylphenol in sweet corn products (Buttery et al., 1994). The quantitative data in Table 2 show that they are also major components of tortilla flour, tortillas, and taco shells. It has been well established that these types of compounds are formed by decarboxylation of ferulic and related acids occurring during heating (Fiddler et al., 1967).

Alkylpyrazines. Relatively high concentrations of alkylpyrazines were found in the corn taco shells and

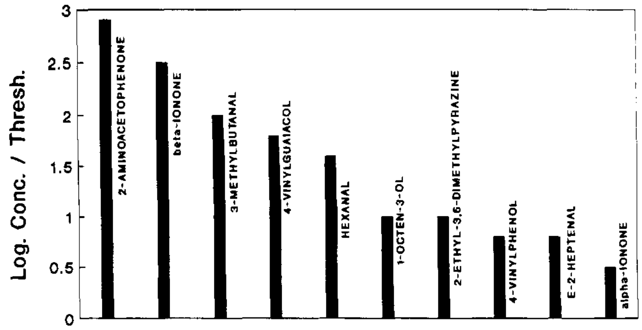

Figure 1. Components with highest concentration/threshold ratios in corn tortillas.

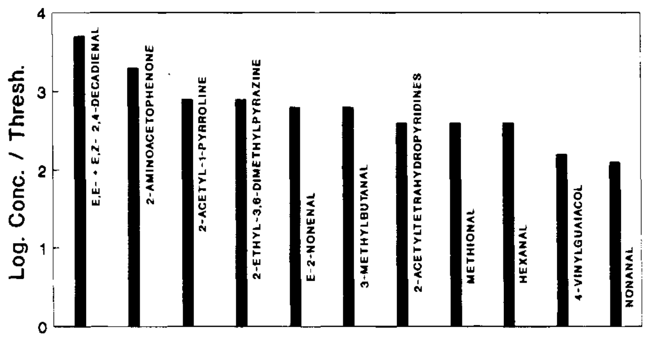

Figure 2. Components with the highest concentration/threshold ratios in taco shells.

tortilla chips; however, only low concentrations were found in the masa flour and tortillas. Karahadian and Johnson (1993) had found higher concentrations in the tortilla samples that they had used. This may reflect a variation that occurs in different methods of preparations of these masa corn products and the degree of cooking. We found no evidence for the presence of 2-methoxy-3-isopropylpyrazine in the commercial samples of tortillas by GC–MS or GC effluent sniffing. The above authors had reported tentative evidence for the presence of this compound in their samples.

Terpenoids. Karahadian and Johnson (1993) had reported identification of α- and β-ionone in masa dough and tortillas. We also identified α-ionone in the masa flour and both α- and β-ionones in the tortillas at trace levels. In addition, we identified the related norisoprenoid geranylacetone in both masa flour and tortillas. None of these were found in taco shells or tortilla chips, however. Possibly they are lost in the frying process.

Limonene was identified in all of the products. It is common at low levels in many foods.

β-Ionone is a potent odorant and even at these trace levels could contribute to the aroma and flavor.

Probable Contribution to Aroma. The second column in Table 3 lists the odor thresholds for most of the compounds identified, measured in water solution. These data are from studies carried out, in the author's laboratory, over a number of years [cf. Buttery et al. (1994)]. Also listed in the third and fourth columns in Table 3 are concentration/threshold ratios (in the $\log_{10}$ form) for most compounds identified. For a largely aqueous food this ratio would correspond closely to the number of threshold concentrations of that compound present. For such foods this ratio would thus indicate which compounds are present well above their threshold (log concentration/threshold > 0) and are capable of contributing to the odor and those which are well below their threshold (log concentration/threshold < 0) and not capable of contributing to the odor. This ratio could be considered a measure of the probability that a compound contributes to the odor (aroma) of the food.

Tortillas are ca. 50% water, and the volatility behavior is likely to be similar to that for water. Taco shells, however, have a low water content and a relatively high oil content. Chewing these foods in the mouth and the accompanying saliva would increase the water content. In a similar study (at our laboratory) of fried potato chips, which also show a high percentage of oil, thresholds were determined in both oil and water [cf. Guadagni et al. (1972)] and comparisons made between both systems. The highly oil soluble aliphatic aldehydes such as 2,4-decadienal and 2-nonenal were relatively less

Table 3. Odor Thresholds in Water Solution and $\log_{10}$ Concentration/Threshold Ratios in Tortillas and Taco Shells

compound	odor threshold[a] (pp 10^9)	$\log_{10}$ concn/threshold: corn tortilla	taco shell
aliphatic alcohols			
1-penten-3-ol	400		−0.9
3-hydroxy-2-butanone	8000	−1.4	−2.0
3-methylbutanol	300		−1.2
2-methylbutanol	300		−1.5
pentanol	4000	−2.1	−1.0
hexanol	2500	−2.8	−1.9
1-octen-3-ol	1	1.0	1.3
aliphatic aldehydes and ketones			
2,3-butanedione	3	0.3	
3-methylbutanal	0.2	2.0	2.8
2-methylbutanal	3	0.5	1.5
2,3-pentadione	20		1.0
pentanal	12	0.5	
hexanal	4.5	1.6	2.6
2-heptanone	140	−1.7	−0.4
heptanal	3		1.6
(*E*)-2-heptenal	13	0.8	0.8
(*E*,*E*)- + (*E*,*Z*)-3,5-octadien-2-one	150	−1.5	−0.2
nonanal	1	1	2.1
(*E*)-2-nonenal	0.08	2.1	2.8
2-undecanone	7		0.5
(*E*,*Z*)- + (*E*,*E*)-2,4-decadienal	0.07		3.6
nitrogen compounds			
pyrazine	180000		−2.4
pyrrole	20000		−2.8
2-methylpyrazine	60000	−3.2	−2.5
2,5-dimethylpyrazine	1700	−2.3	−1.1
ethylpyrazine	6000		−1.8
2,3-dimethylpyrazine	2500		−1.6
2-acetyl-1-pyrroline	0.1		2.9
2-ethyl-5-methylpyrazine	100		−0.3
2-acetyl-tetrahydropyridine 1,4,5,6- and 3,4,5,6	1		2.4
2-ethyl-3,6-dimethylpyrazine	0.4	1.0	2.9
2-aminoacetophenone	0.2	2.9	3.3
furans and aromatic compounds			
furfural	3000	−1.5	−2.5
furfuryl alcohol	2000	−2.3	−1.4
2-acetylfuran	10000	−3.5	
benzaldehyde	350	−1.5	−0.8
2-pentylfuran	6		0.9
phenylacetaldehyde	4		1.0
acetophenone	65	−1.5	
methyl salicylate	40	−0.7	
4-vinylphenol	10	0.8	1.1
4-vinylguaiacol	3	1.8	2.2
vanillin	58	0	0.2
isoprenoid compounds			
limonene	200	−0.8	−0.3
α-ionone	0.6	0.5	
β-ionone	0.007	2.5	
geranylacetone	60	−0.8	
others			
3-(methylthio)propanal	0.2		2.6

[a] Parts of compound in 10^9 parts of water (volume/volume).

important in the oil systems than they were in water, whereas the opposite applied to the more water soluble nitrogen heterocyclic compounds.

Figure 1 compares the log concentration/threshold ratios in bar graph form for the 10 components with the highest of these ratios in tortillas. Figure 2 shows a similar comparison for taco shells (tortilla chips would be expected to be similar).

For tortillas (Figure 1) it can be seen that 2-aminoacetophenone, β-ionone, 3-methylbutanal, 4-vinylguaiacol, and 1-octen-3-ol are prominent. For taco shells (Figure 2) many compounds are in the same general range but 2,4-decadienal, 2-aminoacetophenone, 2-acetyl-1-pyrroline, 2-ethyl-3,6-dimethylpyrazine, 2-nonenal, 3-methylbutanal, 2-acetyltetrahydropyridines, and methional are prominent.

For preliminary qualitative studies a water solution was made up containing the synthetic compounds 2-aminoacetophenone (0.2 μL/L), nonanal (0.1 μL/L), 2-acetyltetrahydropyridine (0.1 μL/L), 2,4-decadienal (0.02 μL/L), and 3-(methylthio)propanal (0.02 μL/L). This synthetic solution was judged by the sensory panel to have an aroma very similar to that of tortilla chips.

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