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Volatile compounds of rehydrated French beans, bell peppers and leeks. Part 1. Flavour release in the mouth and in three mouth model systems

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Flavour release from three rehydrated vegetables: French beans, red bell peppers, and leeks, was studied directly in the mouth of 12 assessors (oral vapour) and in three mouth model systems; purge-and-trap, and dynamic headspace with and without mastication. Volatile compounds were analysed by gas chromatography and mass spectrometry, which resulted in 30, 52 and 42 identified compounds in French beans, bell, peppers, and leeks, respectively. Propanal, 2-methylpropanal, 2- and 3-methylbutanal, pentanal, hexanal, 2-pentenal, *trans*-2-hexenal, 2-heptenal, 2-butanone, and 6-methyl-5-hepten-2-one were present in each of them. Flavour release from the three vegetables in model system 'dynamic headspace and mastication' did not differ significantly from release in the mouth. Peak areas of volatiles released in the mouth had larger coefficients of variance than the ones released in the model system. Although assessors released volatile compounds with different efficiencies, they showed a statistically consistent efficiency in flavour release across the vegetables.

INTRODUCTION

Many methods have been developed for analysing the flavour of foods over the last decades. Some methods have been used for quantitative extraction of volatile compounds, e.g. combined steam and organic solvent distillation techniques. Others have tried to link instrumental analysis to sensory properties of foods. Extraction and headspace analysis are the main methods for isolation of volatile compounds in vegetables (Buttery *et al.*, 1969; Wu & Liou, 1986; Fischer & Grosch, 1987; Mtebe & Gordon, 1987; Shinohara *et al.*, 1991).

Foods can be subjected to substantial changes during the eating process which affects the profile of volatile compounds markedly. The breakdown of the food matrix through mastication enhances flavour release (Haring, 1990; Van Ruth *et al.*, 1994) as well as retronasal odour perception (Burdach & Doty, 1987). The generation of volatile compounds, as some plant tissues are disrupted, changes the volatile composition (Fleming *et al.*, 1968; Hatanaka & Harada, 1973; Wu & Liou, 1986; Luning *et al.*, 1994). The physical form of food affects the volatile profile and it changes during consumption, e.g. due to hydration and dilution of (dry) foods by saliva. Saliva components, such as mucin and α-amylase, can influence the flavour release from foods (Van Ruth *et al.*, 1995). These factors may create significant differences between the classical headspace volatile profile and the actual volatile profile in the mouth. The ability to measure this actual profile in the mouth/nose is, therefore, of interest as it relates more directly to the human perception of flavour when food is consumed.

In breath-by-breath analysis the release of volatiles from a food during consumption can be measured near to the nasal space. A membrane separator method using a direct mass spectrometry technique was developed by Soeting and Heidema (1988) for determining flavour profiles in the expired air of volunteers as a function of time. Lee III (1986) developed an instrumental technique using dynamic headspace mass spectrometry to monitor continuously headspace concentrations of a model system. In direct mass spectrometry techniques only one volatile compound can be monitored at a time, although foods are usually more complex. Linforth *et al.* (1994) and Taylor and Linforth (1994), as well as Delahunty *et al.* (1994) reported expired breath sampling techniques using Tenax traps, which were applied to whole foods with lower levels of aromas. A procedure for determining flavour release from chocolate flakes by oral vapour gas chromatography was presented by Roozen and Legger-Huysman (1994).

Previously three mouth model systems were developed to study the effect of different mouth conditions such as volume, temperature, salivation and mastication on flavour release (Van Ruth *et al.*, 1994). The present study deals with flavour released from three rehydrated vegetables; French beans, red bell peppers and leeks in three mouth model systems in comparison with flavour released from them directly in the mouth of 12 assessors.

MATERIALS AND METHODS

Plant material

Three commercially air-dried vegetables; French beans and leeks from the Netherlands, and red bell peppers from Hungary were supplied in pieces (8 × 8 mm) by Top Foods bv (Elburg, The Netherlands). The vegetables were packed in glass jars and stored at 4°C in the absence of light until sampling for 6 weeks max.

Pieces of vegetables (1·2 g) were rehydrated by adding 10 ml distilled water, followed by heating in a waterbath at 100°C for 10 min, and cooling down in a waterbath at 25°C for 4 min.

Isolation of volatile compounds

The rehydrated diced vegetables were transferred into the sample flask (70 ml) of one of the three mouth model systems; purge-and-trap (PT), dynamic headspace (DH), and dynamic headspace and mastication (DHM). Artificial saliva (4 ml) was added (Van Ruth *et al.*, 1994). This saliva consisted of 5·208 g $NaHCO_3$, 1·369 g $K_2HPO_4.3H_20$, 0·877 g NaCl, 0·500 g NaN_3, 0·477 g KCl, 0·441 g $CaCl_2.2H_2O$, 2·160 g mucin, and 200,000 units α-amylase (Merck, Darmstadt, Germany) in 1 litre distilled water (adjusted to pH 7). In the PT model system the vegetable/saliva mixture was purged by purified nitrogen gas (250 ml/min) for 12 min at 37°C, in order to trap the volatile compounds in 0·1 g Tenax TA 35/60 mesh (Alltech Nederland bv, Zwijndrecht, The Netherlands), packed in a glass tube, 3 mm id and 100 mm long. In the DH and DHM model system, the headspace of the mixture was flushed with nitrogen gas at the same rate, for the same time, and at the same temperature as in the PT model system. In DHM the plunger made about four up and down screwing movements/min in order to simulate mastication.

Twelve assessors (aged 20–50) participated in oral vapour analysis. Volatile compounds released from the rehydrated vegetable pieces in oral vapour, were directed from the mouth to a Tenax TA trap by a vaccum pump at 250 ml/min for 12 min as described by Roozen and Legger-Huysman (1994). The assessors were instructed to make four chewing movements at 1 min intervals during mouth sampling.

Analysis of volatile compounds

The volatile compounds were analysed on a Carlo Erba MEGA 5300 gas chromatograph (GC; Interscience bv, Breda, The Netherlands) equipped with a flame ionisation detector (FID) at 275°C. The volatiles were desorbed by a thermal desorption (210°C, 5 min)/cold trap (–120°C/240°C) device (Carlo Erba TDAS 5000, Interscience bv, Breda, The Netherlands) and injected onto a Supelcowax 10 capillary column, 0·25 mm id and 60 m long. Compounds were chromatographed using a linear temperature gradient from 40 to 92°C at 2°C/min after a 4 min delay; followed by a 6°C/min linear gradient to 272°C.

The volatile compounds trapped in Tenax TA were identified by combined gas chromatography/mass spectrometry (GC/MS; Carlo Erba, MEGA 3600, QMD 8000, Interscience bv, Breda, The Netherlands) equipped with a thermal desorption unit (Carlo Erba, Tekmar 5010, Interscience bv, Breda, The Netherlands). Capillary column and oven temperature program were similar to those for GC/FID analyses. Mass spectra were recorded in the electron impact mode at an ionisation voltage of 70 eV.

Statistical analysis

The FID data presented in the tables, represent the mean value of six (mouth model systems) and 12 replicates (oral vapour). FID data were subjected to a Friedman analysis of variance by ranks, followed by sets of sign tests in order to determine significant differences between model systems and oral vapour. The Friedman analysis of variance was used to determine significant differences between assessors as well. A significance level of $P < 0·05$ was used throughout the study.

RESULTS AND DISCUSSION

Volatile compounds of rehydrated French beans, red bell peppers and leeks were isolated in three mouth model systems and in the oral vapour of 12 assessors. Figure 1 represents the FID chromatogram of volatile compounds of French beans isolated in the three mouth model systems DH, DHM, PT, and in oral vapour. FID chromatograms of leeks and bell peppers showed similar differences in patterns between isolation procedures as the French beans. The model system chromatograms of the bell peppers were similar to chromatograms presented previously (Van Ruth *et al.*, 1994). The volatile compounds of rehydrated beans, bell peppers, and leeks identified by GC/MS are presented in Tables 1, 2 and 3, respectively. The compounds were further characterized by their retention times and their peak areas. The numbers above the peaks in Fig. 1 refer to the compounds listed in Table 1. In French beans, bell peppers and leeks, respectively, 15 out of 30, 20 out of 42, and 37 out of 52 compounds have not been identified previously in the vegetables concerned (Maarse *et al.*, 1989).

The volatile compounds identified in French beans

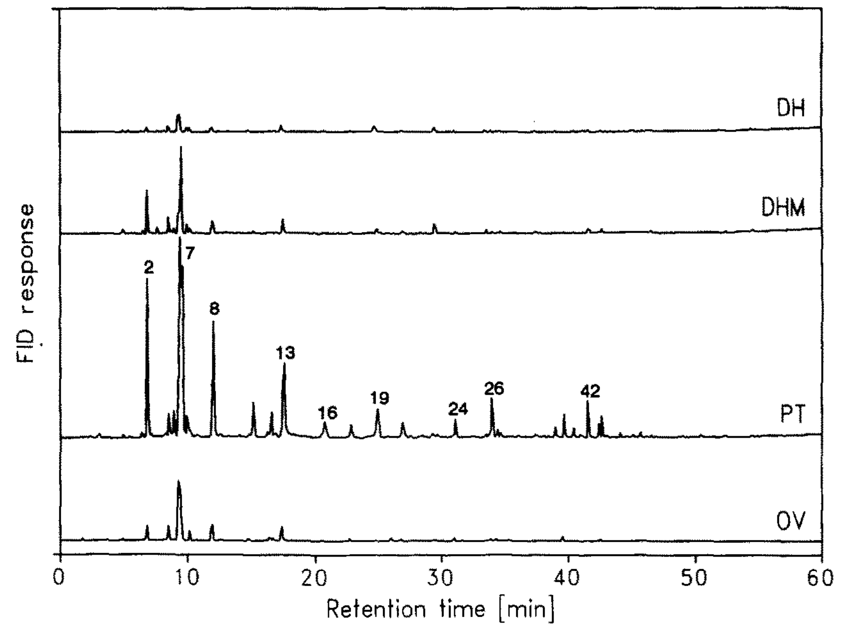

Fig. 1. Chromatograms of volatile compounds of French beans isolated in three mouth model systems (DH/DHM/PT) and in oral vapour (OV). Explanation of codes in Table 1, numbers in the PT chromatogram refer to compounds in Table 1.

Table 1. Volatile compounds of rehydrated French beans isolated in three mouth model systems (DH/DHM/PT) and in oral vapour (OV), their retention times, average peak areas, and coefficients of variance (DH/DHM/PT: *n* = 6; OV: *n* = 12)

Peak No.	Retention time (min)	Compound	Peak area (V.s.)			
			DH[a]	DHM	PT	OV
1	6·53	Propanal	0·04	0·31	0·61	0·18
2	6·92	2-Methylpropanal	0·62	3·49	12·62	5·79
3	8·23	Butanal	0·07	0·24	1·33	0·14
4	8·69	2-Methyl-2-propenal	0·07	0·39	0·14	0·13
5	8·94	2-Butanone	0·09	0·39	2·44	0·70
6	9·31	2-Methylbutanal	1·38	5·85	22·13	6·15
7	9·47	3-Methylbutanal	1·83	7·16	31·96	8·22
8	11·96	Pentanal	0·70	1·98	14·97	2·98
9	13·82	1-Penten-3-one	tr[b]	tr	0·22	0·08
10	16·23	2,3-Pentadione	tr	0·17	1·06	0·16
11	16·49	2-Methyl-1-penten-3-one	0·11	0·32	3·83	0·70
12	16·72	Butyl acetate	0·03	0·22	0·55	0·36
13	17·38	Hexanal	0·84	1·93	16·76	2·36
14	18·19	2-Methyl-2-butenal	tr	0·10	0·27	0·19
15	19·97	Ethylbenzene	tr	0·03	0·18	0·14
16	20·97	2-Pentenal	0·03	0·10	1·54	0·15
17	22·74	1-Penten-3-ol	0·02	0·21	2·11	0·47
18	24·05	2-Heptanone	tr	0·03	0·18	0·04
19	24·18	Heptanal	0·02	0·03	0·34	0·01
20	25·61	Limonene	tr	tr	0·18	1·13
21	26·94	*trans*-2-Hexenal	0·15	0·21	2·73	0·56
22	28·32	6-Methyl-2-heptanone	tr	tr	0·40	0·15
23	31·80	2-Octanone	tr	tr	0·49	0·06
24	32·41	Octanal	tr	0·04	0·19	0·02
25	33·93	2-Heptenal	0·21	0·29	0·42	0·49
26	34·62	6-Methyl-5-hepten-2-one	0·09	0·13	0·87	0·35
27	35·92	Dimethyl trisulfide	tr	0·04	0·18	0·09
28	37·30	Nonanal	0·02	0·37	0·62	0·21
29	39·05	1-Octen-3-ol	tr	0·07	1·21	0·19
30	41·54	Decanal	0·27	0·69	0·24	0·34
		CV[c] [%]	64	27	22	67

[a] DH = dynamic headspace, DHM = dynamic headspace and mastication, PT = purge-and-trap.
[b] tr = peak area < 0·01 V.s.
[c] CV = average coefficient of variance of individual compounds.

Table 2. Volatile compounds of rehydrated red bell peppers isolated in three mouth model systems (DH/DHM/PT) and in oral vapour (OV), their retention times, average peak areas, and coefficients of variance (DH/DHM/PT: *n* = 6; OV: *n* = 12)

Peak No.	Retention time (min)	Compound	Peak area (V.s.)			
			DH[a]	DHM	PT	OV
1	6·07	Propanol	0·10	1·46	2·68	0·21
2	6·43	2-Methylpropanal	0·10	4·78	16·24	9·25
3	6·71	Methyl acetate	tr[a]	0·06	0·13	tr
4	7·73	Ethyl acetate	0·01	0·45	2·32	0·22
5	7·85	2-Methyl-2-propenal	tr	0·24	0·40	0·02
6	8·17	Diethoxyethane	tr	0·30	0·64	0·21
7	8·41	2-Butanone	0·05	0·28	1·87	0·45
8	8·83	2-Methylbutanal	0·22	2·57	14·18	2·63
9	9·06	3-Methylbutanal	0·45	7·46	39·26	7·03
10	9·40	Benzene	0·52	3·81	2·93	3·43
11	9·60	3-Buten-2-one	tr	0·15	2·18	0·35
12	10·13	2-Pentanone	tr	0·01	1·21	0·01
13	11·28	Pentanal	0·14	1·49	10·17	1·90
14	11·38	2,3-Butadione	0·13	1·52	10·49	1·75
15	13·28	1-Penten-3-one	tr	0·40	2·31	0·46
16	14·39	Toluene	tr	0·64	1·60	0·86
17	15·48	2,3-Pentadione	tr	tr	0·29	tr
18	16·08	Butyl acetate	tr	0·14	0·37	0·15
19	17·23	Hexanal	1·69	23·31	171·67	26·86
20	19·82	2-Pentenal	0·47	1·04	6·55	0·79
21	19·98	m-Xylene	tr	0·49	4·29	0·28
22	20·32	Pentyloxirane	tr	0·14	3·11	0·94
23	21·96	1-Penten-3-ol	0·22	1·26	8·68	2·44
24	23·37	2-Heptanone	tr	0·13	3·38	0·40
25	23·54	Heptanal	tr	0·45	2·89	0·47
26	24·01	Limonene	0·12	1·21	13·45	12·49
27	25·94	*trans*-2-Hexenal	tr	0·67	5·93	0·62
28	26·54	1-Methoxy-3-methylene-2-pentanone	tr	tr	1·47	0·28
29	27·25	6-Methyl-2-heptanone	tr	0·03	0·72	0·16
30	27·88	4-Heptenal	tr	0·01	0·18	tr
31	28·30	1-Pentanol	0·26	1·10	4·86	1·23
32	29·20	Methylisopropylbenzene	tr	tr	0·18	0·14
33	30·65	2-Octanone	tr	tr	0·40	0·12
34	30·89	Octanal	0·02	0·50	1·08	0·52
35	31·57	*trans*-3-Hepten-2-one	tr	0·17	1·37	0·18
36	32·48	2,2,6-Trimethylcyclohexanone	0·11	0·28	1·52	0·30
37	33·17	2-Heptenal	tr	0·59	5·36	0·69
38	33·90	6-Methyl-5-hepten-2-one	0·16	0·64	5·81	1·12
39	34·69	1-Hexanol	0·20	tr	4·01	1·91
40	36·71	Nonanal	0·21	2·04	1·71	0·30
41	37·03	3,5,5-Trimethyl-2-cyclohexen-1-one	tr	0·14	1·96	0·40
42	37·34	3-Octen-2-one	tr	0·09	1·21	0·16
43	37·68	5-Ethyl-1-cyclopentene-carbaldehyde	tr	0·17	1·88	0·15
44	38·34	2-Octenal	tr	0·35	7·66	0·75
45	39·01	1-Octen-3-ol	tr	0·25	3·47	0·60
46	39·78	2,4-Heptadienal isomer	0·14	0·85	7·17	0·62
47	40·88	2,4-Heptadienal isomer	0·56	3·17	11·95	0·97
48	41·42	3-Nonen-2-one	tr	0·12	0·22	0·06
49	41·89	Benzaldehyde	tr	1·94	4·23	0·80
50	41·95	2-Isobutyl-3-methoxypyrazine	tr	tr	tr	tr
51	42·40	Linalool	0·13	0·21	4·45	0·82
52	44·94	β-Cyclocitral	tr	0·40	5·19	0·87
		CV[a] [%]	64	28	21	82

[a] Explanation of codes in Table 1.

consisted of 16 aldehydes, 8 ketones, and 2 alcohols. Self *et al.* (1963) and Kermasha *et al.* (1988) reported both the low-boiling volatiles propanal and methylpropanal in cooked French beans. Propanal, butanal, and 2-pentenal were identified in cooked and rehydrated runner beans (MacLeod & Macleod, 1970), while Lovegren *et al.* (1979) identified methylpropanal, 2-butanone, methylbutanal, and hexanal in dried beans. Toya *et al.* (1974) and Stevens *et al.* (1967) concluded that 1-octen-3-ol was among the volatile compounds of primary importance in the flavour of canned snap beans. In winged beans, the less volatile

Table 3. Volatile compounds of rehydrated leeks isolated in three mouth model systems (DH/DHM/PT) and in oral vapour (OV), their retention times, average peak areas, and coefficients of variance (DH/DHM/PT: *n* = 6; OV: (*n* = 12)

Peak No.	Retention time (min)	Compound	Peak area (V.s.)			
			DH[a]	DHM	PT	OV
1	4·92	Hexane	0·09	0·49	1·39	1·00
2	6·10	Propanol	6·70	30·07	105·15	12·30
3	6·49	2-Methylpropanal	0·36	1·47	13·45	8·45
4	6·76	Propanethiol	0·32	0·80	10·56	6·10
5	7·71	Butanal	0·03	0·20	3·92	0·16
6	8·38	2-Butanone	0·04	0·24	2·82	0·48
7	8·75	2-Methylbutanal	0·08	0·63	7·89	0·77
8	8·95	3-Methylbutanal	0·38	2·47	33·34	4·46
9	9·37	Ethanol	1·03	0·74	19·19	0·57
10	9·57	Benzene	0·97	0·73	10·57	3·11
11	10·09	3-Buten-2-one	0·03	0·10	2·76	0·80
12	10·65	2,4-Dimethylfuran	0·02	0·05	1·95	0·04
13	11·45	Pentenal	0·89	3·36	73·04	6·05
14	14·36	2-Butenal	0·16	0·56	11·14	2·92
15	15·86	Dimethyl disulphide	0·10	0·28	3·02	0·98
16	17·31	Hexanal	1·83	9·03	190·94	21·04
17	19·76	2-Methylthiophene	0·25	0·21	4·99	0·20
18	19·94	2-Pentenal	0·22	0·26	4·76	0·21
19	21·43	2,5-Dimethylthiophene	0·19	0·24	4·45	1·36
20	21·89	2-Methyl-2-pentenal	0·51	1·86	38·98	4·88
21	23·69	2,4-Dimethylthiophene	0·40	0·57	20·16	4·86
22	25·95	*trans*-2-Hexenal	0·09	0·37	7·30	0·81
23	28·09	Dimethylthiophene	1·98	3·07	76·80	16·29
24	29·15	Methyl-1-propenyl disulphide isomer	0·46	0·91	27·30	4·49
25	31·01	Methyl-1-propenyl disulphide isomer	0·78	1·76	55·21	9·83
26	32·52	2,2,6-Trimethylcyclohexanone	0·16	0·12	0·94	0·10
27	33·27	2-Heptenal	0·20	0·38	22·67	1·91
28	33·90	2-Methyl-3-octanone	0·01	0·04	1·08	0·02
29	34·68	6-Methyl-5-hepten-2-one	0·05	0·03	1·85	1·59
30	35·76	Dipropyl sulphide	0·11	0·18	4·39	1·07
31	35·83	Dimethyltrisulphide	0·22	0·36	7·04	1·91
32	37·34	3-Octen-2-one	0·35	0·42	12·13	3·91
33	37·69	Propenylpropyl disulphide isomer	tr[a]	0·08	2·28	0·07
34	38·40	2-Octenal	0·54	0·69	22·21	5·51
35	39·04	Propenylpropyl disulphide isomer	tr	0·14	6·47	1·42
36	39·56	2-Ethylthiacyclohexane	0·06	0·06	2·93	0·70
37	40·34	Diallyl disulphide	0·11	0·13	4·60	1·11
38	40·89	Decanal	0·20	1·12	2·95	0·67
39	42·19	Benzaldehyde	0·37	0·49	5·21	0·14
40	42·37	2-Nonenal	tr	0·05	1·20	0·11
41	44·39	β-Cyclocitral	0·07	0·29	0·68	0·20
42	49·02	1-Propenylpropyl trisulphide	0·01	0·03	2·41	0·86
		CV[a] [%]	53	30	22	66

[a] Explanation of codes in Table 1.

compounds such as hexanal, heptanal, octanal, and nonanal were reported beside the low-boiling aldehydes (Mtebe & Gordon, 1987).

Decomposition of hydroperoxides, produced by lipoxygenase-catalysed oxidation of unsaturated fatty acids, is known to be a major pathway contributing to the flavour of various legumes. Hexanal and 2-heptanone are produced in these reactions in winged beans (Christopher & Axelrod, 1971). Hexanol, hexanal, and 1-octen-3-ol have been reported as principal volatile compounds from linoleic acid in green beans, and *trans*-2-hexenal and 1-penten-3-ol can be derived from linolenic acid (De Lumen *et al.*, 1978).

Wu *et al.* (1986) reported several of the 52 volatile compounds identified in the rehydrated diced bell peppers, e.g. ethyl acetate, hexanal, 2-heptanone, heptanal, *trans*-2-hexenal, *trans*-3-hepten-2-one, hexanol, 2-octenal, 1-octen-3-ol, 2,4-heptadienal, and 2-isobutyl-3-methoxypyrazine. The latter compound possesses a distinct bell pepper aroma (Buttery *et al.*, 1969; Luning *et al.*, 1994; Van Ruth & Roozen, 1994). In general more small, low-boiling compounds were identified in the present study, in comparison with other studies (Keller *et al.*, 1981; Chitwood *et al.*, 1983; Wu *et al.*, 1986). This is probably due to the dynamic headspace technique performed here instead of extraction procedures at elevated temperatures used in the other studies.

Many saturated and unsaturated aldehydes and di- and trisulphides were present among the compounds identified in rehydrated leeks. 1-Propanethiol, 2-methyl-

2-pentenal, *trans*-2-hexenal, dimethylthiophene, methylpropenyl disulphide, dimethyl trisulphide, and propenyl propyldisulphide have been reported as odour active compounds of leeks (Schreyen *et al.*, 1976*a*). Several of the aldehydes and di- and trisulphides have been identified in leek (Schreyen *et al.*, 1976*b*) as well as in onion (Boelens *et al.*, 1971). Propanal and dimethylthiophenes are the major volatiles of rehydrated leeks besides lipid oxidation products such as hexanal and pentanal. Schreyen *et al.* (1976*b*) noted propanal and 2-methyl-2-pentenal as the breakdown products of a lachrymatory factor in leeks. Dimethylthiophene isomers can be formed by heating alkenyl disulphides with a loss of hydrogen sulphide.

Comparison of the volatile compounds reveals 11 compounds which are present in each of the three vegetables: propanal; 2-methylpropanal; 2-butanone; 2- and 3-methylbutanal; pentanal; hexanal; 2-pentenal; *trans*-2-hexenal; 2-heptenal; and 6-methyl-5-hepten-2-one. This is in agreement with studies of Self *et al.* (1963), which showed similar patterns of low-boiling volatiles in cooked French beans and leeks, these volatiles varied in relative quantities only. 2-Methylpropanal, 2- and 3-methylbutanal can be formed in Strecker degradation reactions during the drying and cooking process, while most of the other volatiles can be derived from lipid oxidation reactions (Tressl *et al.*, 1981; Frankel, 1991; Whitfield, 1992).

In order to compare the isolation procedures, means of peak areas of volatile compounds released from the French beans, bell peppers, and leeks in the three mouth model systems and oral vapour were subjected to a Friedman two-way analysis of variance. Sets of sign tests were carried out to determine the significance of individual differences (Table 4). DHM and OV did not show significant differences in flavour release, although all other isolation procedures differed significantly, for the three vegetables studied. The flavour profile in the mouth is directly related to the human perception of a food. Headspace sampling techniques (without mastication) are often performed for determining volatile profiles of foods. However, significant differences in release between DH and OV, as well as between PT and OV indicate that these techniques are less suitable for simulation of flavour release in the mouth. Similarly, differences in volatile composition of headspace samples and expired breath for strong mints were reported by Linforth and Taylor (1993), for Cheddar cheese by Delahunty *et al.* (1994), for chocolate flakes by Legger and Roozen (1994), and for tomatoes by Linforth *et al.* (1994). Coefficients of variance (Tables 1, 2 and 3) were larger for the assessors than for the model systems. Similar coefficients of variance for assessors were determined by Roozen and Legger-Huysman (1994) in oral vapour gas chromatography of chocolate flakes. Comparison of flavour release of assessors by a Friedman two-way analysis of variance showed significant differences among them for each of the vegetables (Table 5), which is in agreement with studies of Linforth *et al.* (1994). They reported large differences between assessors in quantities of volatile compounds in expired breath during consumption of tomatoes. The FID peak areas of hexanal released from the three vegetables in the oral vapour of the individual assessors were subjected to a Friedman two-way analysis of variance (Table 6). Assessors released hexanal with statistically consistent efficiencies across the vegetables. Similar results were obtained for other mutual major volatile compounds, e.g. 2-methylpropanal, 2- and 3-methylbutanal. In addition Table 7 presents the average ranks of assessors for FID peak areas of the individual volatile compounds released from each of

Table 4. Differences in peak areas of volatile compounds released from rehydrated French beans, bell peppers, and leeks in three mouth model systems (DH/DHM/PT) and in oral vapour (OV) examined by Friedman two-way analysis of variance by ranks and sign tests

Vegetable	Friedman test χ^2[a]	Sign test			
		DH[b]	DHM	PT	OV
French bean	70	A[c]	B	C	B
Bell pepper	126	A	B	C	B
Leek	80	A	B	C	B

[a] $\chi^2 > 7\cdot8$ indicates a significant difference in flavour release between sampling procedures (Friedman test, $P < 0\cdot05$).
[b] Explanation of codes in Table 1.
[c] Different letters within a row indicate significant differences (Sign test, $P < 0\cdot05$).

Table 5. Differences between assessors in flavour release from French beans, bell peppers, and leeks in oral vapour examined by the Friedman two-way analysis of variance by ranks

Vegetable	χ^2[a]
French bean	93
Bell pepper	227
Leek	219

[a] $\chi^2 > 19\cdot7$ indicates a significant difference in flavour release between assessors (Friedman test, $P < 0\cdot05$).

Table 6. FID peak areas (V.s.) of hexanal released from three vegetables in oral vapour of 12 assessors, ranks in parentheses

Assessor	French bean	Bell pepper	Leek
A	1·0 (1)	7·8 (1)	4·1 (2·5)
B	2·3 (6)	11·7 (2)	0·6 (1)
C	2·5 (7)	14·5 (3)	4·1 (2·5)
D	1·6 (3·5)	16·1 (4)	25·4 (7)
E	1·2 (2)	35·6 (10)	22·7 (4)
F	2·0 (5)	28·0 (6)	24·9 (6)
G	1·6 (3·5)	19·5 (5)	27·9 (9)
H	3·1 (10)	32·2 (8)	25·6 (8)
I	3·0 (9)	30·3 (7)	30·7 (10)
J	2·8 (8)	34·0 (9)	31·6 (11)
K	3·2 (11)	56·4 (12)	22·9 (5)
L	4·0 (12)	36·2 (11)	32·0 (12)
χ^2[a]		321	

[a] $\chi^2 > 19\cdot7$ indicates a significant consistent efficiency in flavour release of assessors across the vegetables (Friedman test, $P < 0\cdot05$).

Table 7. Average ranks of assessors for FID peak areas of volatile compounds released from three vegetables in oral vapour of 12 assessors as presented in Tables 1, 2 and 3

Assessor	French bean	Bell pepper	Leek
A	5·8	3·8	3·5
B	6·4	3·2	2·6
C	5·8	5·2	2·9
D	4·5	3·5	7·1
E	3·2	5·6	6·2
F	6·3	6·9	5·5
G	6·3	6·0	8·0
H	7·7	8·4	8·0
I	8·2	8·1	7·8
J	7·7	8·6	8·6
K	7·7	9·2	8·7
L	8·4	9·4	9·0

the three vegetables, indicating an overall consistency in efficiency of flavour release across the three vegetables. Although assessors were instructed to make four chewing movements/min, differences in flavour release could be due to different efficiency of mastication between people (Pierson & LeMagnen, 1970), as well as to differences in the rate of breathing (Overbosch *et al.*, 1991), the release rate of saliva (Christensen, 1986), and the saliva composition (Shannon *et al.*, 1974).

CONCLUSIONS

Flavour release from rehydrated French beans, bell peppers, and leeks in mouth model system DHM, simulated flavour release in oral vapour quite well; no significant difference was determined between the two methods. Although assessors released volatiles with different efficiencies, a consistent efficiency in release rate of assessors was observed across the vegetables.

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