CHEMISTRY AND FLAVOUR*

I Molecular Structure and Organoleptic Quality

By H. Boelens, L. M. van der Linde, D. de Rijke, P. J. de Valois, J. M. van Dort, and H. J. Takken
RESEARCH DEPARTMENT, NAARDEN INTERNATIONAL, P.O. BOX 2, NAARDEN-BUSSUM, THE NETHERLANDS

1 Introduction

Flavour is one of the main elements which distinguishes between food and nutrition; however, the total flavour complex usually represents less than 0.1 % by weight of any food. Existing flavourings can be prepared from the following raw materials:[1] (*a*), natural flavourings; (*b*), nature-identical substances; (*c*), artificial flavourings.

The approximate numbers of flavouring raw materials mentioned in the literature are shown in Table 1.

Table 1 *Flavouring raw materials*

	Number	*Ref.*
Natural	600	2
Nature-identical	4200	3
Artificial	250—350	4, 5

The estimated number of nature-identical substances in use (see Table 2) is still increasing, whereas the number of artificial substances is decreasing.

The organoleptic quality of flavouring components of a particular fruit or foodstuff can be divided into: (*a*) more or less characteristic; (*b*) not characteristic, but still essential; (*c*) neither characteristic, nor essential.

This article is concerned with some substances whose organoleptic quality is more or less characteristic of a special kind of fruit or foodstuff; the scope and limitations of structure–activity relationships in flavour chemistry are discussed briefly and some physico-chemical parameters of flavouring substances which may govern the human organoleptic response are also mentioned.

*These papers were originally presented at a 'Chemistry and Flavour' symposium, organised by the Chemical Society Food Chemistry Group, and held at the Scientific Societies Lecture Theatre, Savile Row, London W1, on 19th October 1977.

[1] J. P. Ostendorf, 'Flavours', Food Chemistry Group, London, 1976.
[2] Food Additives and Contaminants Committee, Report on the Review 'Flavourings in Food', 1976.
[3] F. Rijkens and H. Boelens, Proc. Int. Symp. Aroma Research, Zeist, 1975.
[4] FEMA-GRAS lists no. 3—10, *Food Techn.*, 1965, **253**, 151.
[5] F. Grundschober, 'Flavours', Food Chemistry Group, London, July—August, 1975.

Table 2 *Volatile nature-identical and artificial flavouring substances* (June 1977)

Chemical group	*Nature-identical*	*Artificial (FEMA–GRAS lists)*[4]
Hydrocarbons	300	1
Alcohols and Phenols	300	11
Ethers	100	7
Acetals	110	14
Carbonyls (functionalized)	460	43
Carboxylic acids	370	4
Esters	600	151
Lactones	140	5
Furans and Pyrans	160	23
Functionalized isoprenoids	650	34
Sulphur compounds	350	44
Aliphatic N-compounds	220	12
Pyrazines and Imidazoles	200	2
Pyridines and Pyrrols	150	2
Oxazoles and Thiazoles	90	4
Total	4200	357

2 Structures with Fruity Flavour

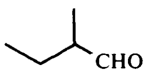
Hundreds of compounds have been isolated from fruits and subsequently identified. The number of publications, the number of identified compounds, and three examples are given in Table 3.

Table 3

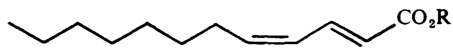
Fruit	*Publ.*	*Substances*	*Examples*	*Ref.*
Apple	83	340	2-Methyl butanal (1)	6
Pear	33	155	Ethyl dodecadienoate (2)	7
Raspberry	30	150	*p*-Hydroxybenzylacetone (3)	8

It is difficult to believe that there exists a relationship between the structures of a wide variety of fruit qualities. Study of the organoleptic quality of apples in more detail shows that there are at least three different types of apples,[6,9] with regard to flavour quality, *viz.* alcohol, aldehyde, and ester type. In Table 4 a substance characteristic of the main flavour types of apples is shown. The structural aspects of substances with the different apple qualities are not very alike.

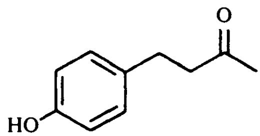
[6] S. Oishi, Kaseigaku Zasshi, 1976, **27**, no. 8, 566.
[7] W. G. Jennings and R. Tressl, *Chem. Mikrobiol. Techn. Lebensm.*, 1974, **3**, 52.
[8] M. Winter, *Helv. Chim. Acta*, 1961, **44**, 2110.
[9] F. Drawert, *Phytochemistry*, 1968, **7**, 881.



(1)



Dodeca-*cis*-4, *trans*-2-dienoates
(2)

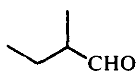


(3)

Table 4

Alcohol type	*Aldehyde type*	*Ester type*
Hex-*cis*-3-enol (4)	2-Methyl butanal (5)	Ethyl non-*cis*-3-enoate[10] (6)

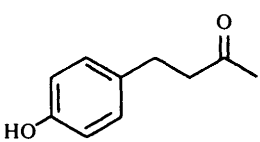
(4)



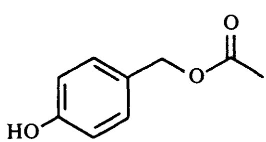
(5)

(6)

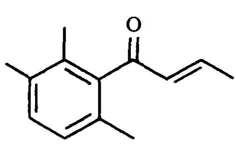
The following structures have a raspberry flavour: *p*-OH-benzylacetone, (7); *p*-OH-benzylacetate, (8); *ar*-damascone, (9); *β*-damascone, (10). With some imagination one can recognize a resemblance in these structures; however, there



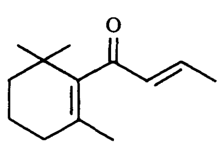
(7)



(8)



(9)



(10)

[10] R. Tressl, Dissertation, Techn. Hochschule Karlsruhe, 1967.

are other different structures giving rise to the perception of similar organoleptic quality.

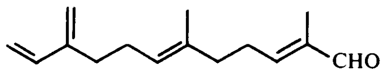
3 Structures with Citrus-like Flavours

Many aliphatic and isoprenoid substances have been isolated from the most common citrus fruits[11]. Up until now 108 publications have appeared in which 450 substances have been described. A few structures with more or less characteristic qualities are shown in Table 5.

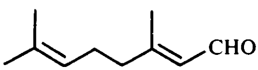
Table 5

Orange	*Lemon*	*Grapefruit*
n-Decanal (11)	Citral (13)	(+) Nootkatone (15)
β-Sinensal[12] (12)	3-Methyl oct-2-enal (14)	

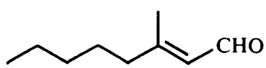
(11)



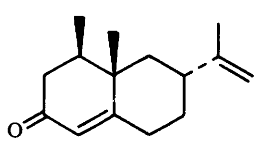
(12)



(13)



(14)



(15)

The substances with an orange quality have quite different structures. 3-Methyl oct-2-enal has been identified in lemon oil and has a typical lemon odour.[13] Its structure shows some resemblance to that of the more generally known citral. (+)-Nootkatone has a fresh, green, sour, fruity character, strongly resembling that of grapefruit, with a threshold value of 0.8 p.p.m.[14] However its optical

[11] E. Kovats, Swiss P., 15 667/1967.
[12] K. L. Stevens, *J. Org. Chem.*, 1965, **30**, 1690.
[13] H. Boelens, in 'Proceedings of the International Symposium Food Science and Technology' Madrid, 1974, vol. 1, p. 79.
[14] H. G. Haring, *J. Agric. Food Chem.*, 1972, **20**, no. 5, 1018.

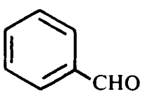
antipode, (–)-nootkatone, has no fruity character at all and its threshold value is about 600 p.p.m. These types of stereo-isomers have the same molecular volume, and differ only in optical activity, *i.e.* chirality. One must conclude from this that there exist almost identical structures (optical antipodes) with completely different organoleptic quality.

4 Structures with Spicy–Aromatic Flavours

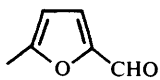
The structures of substances with bitter almond flavour have been studied in detail.[15] Less is known about the structural aspects of compounds with cumin characteristics. Some structural examples of both classes are depicted in Table 6.

Table 6

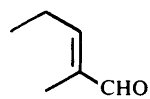
Bitter almond	*Cumin*
Benzaldehyde (16)	*p*-Isopropyl benzaldehyde (19)
5-Methyl furfural (17)	Perilla aldehyde (20)
2-Methyl pent-2-enal (18)	2, 4-Dimethyl hepta-2, 4-dienal (21)



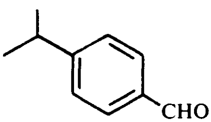
(16)



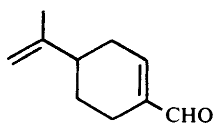
(17)



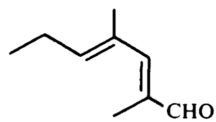
(18)



(19)



(20)



(21)

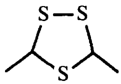
In these cases one may conclude that even rather different compounds can have some structural features in common, which define the bitter almond or cumin quality. These features are: an aldehyde function; at least one conjugated double bond; an aromatic nucleus or isosteric group; bulky *p*-group in cumin.

5 Structures with Meat-like Flavour

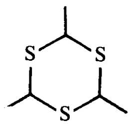
In about 160 publications, 550 compounds have been described which have been isolated from different kinds of meat. When eating one can easily distinguish between beef, mutton and pork; however, it is quite difficult to recognize this specific difference in the organoleptic quality of one single compound. It may be that 4-methyl octanoic acid, which should represent the typical flavour of mutton, is one exception.[16]

[15] H. Boelens and J. Heydel, *Chem.-Ztg.*, 1973, **97**, 1.
[16] E. Wong, *New Zealand J. Agric. Res.*, 1975, **18**, 261.

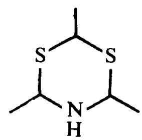
Many substances, especially sulphur compounds, play an important role in the overall flavour of prepared meat. Sulphur compounds are formed in meat, during preparation, by: (*a*), degredation of cysteine[17] [*e.g.* 3,5-dimethyl-1,2,4-trithiolane (22), 2,4,6-trimethyl-1,3,5-trithiane (23), 2,4,6-trimethyl-5,6-dihydro-1,3,5-dithiazine (24) (thialdine)]; (*b*), degredation of vitamin B_1[18] (*e.g*



(22)

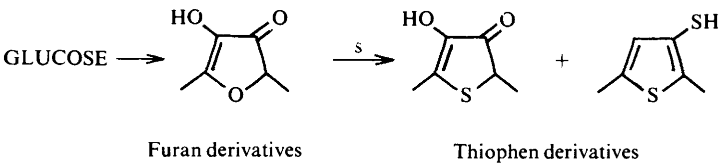


(23)



(24)

thiazole derivatives, thiophen derivatives, furan derivatives); (*c*), reactions of carbohydrates with S-precursors[19] [*e.g.* hydroxyketofuran derivatives, hydroxy-ketothiophen derivatives Scheme (1)]. The compounds derived from cysteine

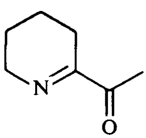


Scheme

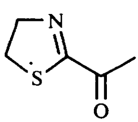
and vitamin B_1 may be essential for the overall meat flavour, however they are not characteristic for a meaty aroma. The substances derived from carbohydrates and sulphur are, rather, characteristic for a meat-like organoleptic quality.

6 Structures with Fried Flavour

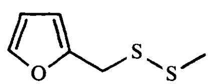
Three structures[20,21,22] [2-acetyl tetrahydropyridine (25), 2-acetyl thiazolidine (26), furfuryl methyldisulphide (27)] are shown which have a typically fried bread (crust) flavour. The first two show some structural resemblance but the



(25)



(26)



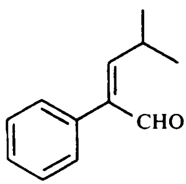
(27)

[17] H. Boelens, *J. Agric. Food Chem.*, 1974, **22**, no. 6, 1071.
[18] B. K. Dwivedi, *Diss. Abs.* (*B*), 1974, **33**, no. 10, 4851.
[19] E. H. M. Gruell, *Chem. Weekblad*, 1974, 17.
[20] I. R. Hunter, *Cerial Science*, 1966, **11**, 493.
[21] C. H. T. Tonsbeek, *J. Agric. Food Chem.*, 1971, **19**, 1014.
[22] E. J. Mulders, *Z. Lebensm.-Untersuch.*, 1973, **151**, 310.

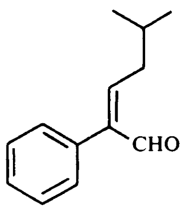
last one has a different structure. It is not understood why such different structures have similar organoleptic qualities.

7 Structures with Cocoa Flavour

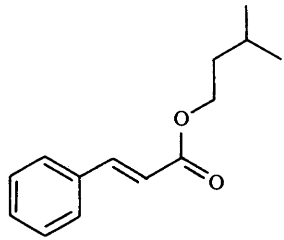
The flavour complexes of roasted foodstuffs like peanut (23 publications, 340 compounds), coffee (55 publications, 650 compounds), and cocoa (27 publications, 380 compounds), have been studied extensively.[23] The structural aspects of compounds with a cocoa quality have been published.[15] A few structures [(28)—(30)] with a cocoa flavour have been selected.[24]



(28)



(29)



(30)

These structures: 2-phenyl-4-methyl-pent-2-enal (28), 2-phenyl-5-methyl hex-2-enal (29), 3-methyl butyl cinnamate (30), are quite similar. One recognizes (Figure 1): an aromatic nucleus (substituted)—feature A, a branched aliphatic chain (C_4—C_6)—feature B, a functional group (—OH, —O—, —C=O, C=C—C=O, —COO—, —N=C)—feature C.

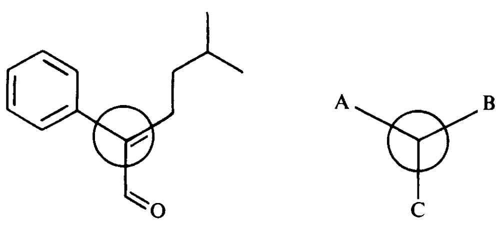


Figure 1 *General structure for cocoa quality. A = aromatic nucleus, B = branched aliphatic chain, C = functional group.*

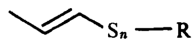
The authors studied 75 compounds with a more or less cocoa flavour and found the following structural features: A, B, and C present, 65%; A and B present, 80%; A or B present, 90%; C present, 90%.

[23] E. Landschreiber and W. Mohr, in '1st International Congress on Cocoa and Chocolate Research', 1974, p. 124.
[24] M. van Praag, *J. Agric. Food Chem.*, 1968, **16**, no. 6, 1005.

8 Structures with Alliceous Flavour

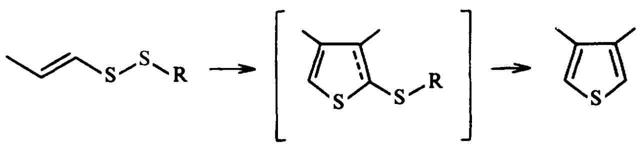
For the organoleptic quality of the allium species, such as onion,[25] garlic, and leek,[26] aliphatic di- and tri-sulphides are very important. About 100 publications concerning this flavour-type have appeared, describing the isolation and identification of 280 compounds.

Characteristics for the flavour complexes of onion and leek are propenyl alkyl di- and tri-sulphides (31), while for the quality of garlic the allyl derivatives play an important role.



(31)

The authors studied the possible formation of sulphur compounds in fresh, boiled, and fried onion.[25] The most characteristic compound for the fresh onion flavour was found to be propylpropane thiosulphonate, and for boiled onion propylpropenyl di- and tri-sulphides. When 3,4-dimethyl thiophen was prepared by heating dipropenyl disulphide (Scheme 2) the endproduct had a distinct flavour of fried onion, probably due to minor impurities.



Scheme 2

The flavour character of dimethyl thiophens has been described by the authors as fried onion-like; however, this has proved to be incorrect.[27] Possibly formed as intermediates, 3,4-dimethyl thiophenyl alk(en)yl (di)sulphides[28] may be responsible for the fried onion character.

9 Structure–Activity Relationships

The search for correlations between structures and organoleptic properties of flavour compounds is rather complicated. The aforementioned examples show that one has to allow for: the existence of quite different structures with the same characteristics; the occurrence of structurally almost identical compounds with quite different qualities; the existence of groups of rather similar structures with the same organoleptic quality.

It should be noted that the determination of the organoleptic qualities of

[25] H. Boelens, *J. Agric. Food Chem.*, 1971, **19**, no. 5, 984.
[26] L. Schreyen, *J. Agric. Food Chem.*, 1976, **24**, no. 2, 336.
[27] W. G. Galetto and P. G. Hoffman, *J. Agric. Food Chem.*, 1976, **24**, no. 4, 852.
[28] H. Boelens and L. Brandsma, *Rec. Trav. chim.*, 1972, **91**, 141.

compounds is a more or less subjective matter. Several groups[29,30] have tried to 'objectify' their results, which makes their findings more reliable.

10 Some Aspects of Chemoreception

Chemoreception covers the area of the effects of stimulation of the senses of smell and of taste by chemical substances. A chemical substance (stimulus) may interact with a biological system (receptor), which can result in a response. The way interactions occur, or the mechanism of perception, is still unknown. One can study the physico-chemical parameters of the stimulus and the resulting verbal response of human beings.

The authors divide the parameters into: concentration (volatility, partition coefficients); electronicity (polarity, dipole moments); stereocity (molecular size, shape, and chirality); flexibility (rotation and vibration).

The verbal response has as its main aspects: detection (yes/no); intensity (weak/strong); recognition (quality); preference (like/dislike).

11 Calculation of Bitter Almond Quality

The authors made an attempt to objectify the relationship between physico-chemical parameters of a molecule and its organoleptic quality by using the following formula:[31]

$$\text{Odour quality (one facet)} = f(\log P) + f(E) + f(S) + \mathrm{C}$$

$$\log P = \log (C_{\text{octan-1-ol}}/C_{\text{water}}) \text{ (partition coefficient)}$$

$$E = \Delta \mathrm{I}/1000 \quad (\mathrm{I} = \text{Kovats index})$$

$$S = \text{mol volume}/100 + \text{width/height}$$

A total of 16 compounds were studied, with benzaldehyde as reference material, and by using multiple regression analysis a correlation coefficient of 0.95 and a standard deviation of 0.65 (on a scale of 1—9) were determined.

Because these physico-chemical parameters are to a certain extent interrelated and, moreover, other parameters may have their influence it cannot be expected that the given formula gives a complete and absolutely correct description of the correlation between structure and odour quality.

Perhaps a quantum mechanical description of the molecule can lead to a more refined relation with odour quality. The first attempts in this direction have been published recently.[32,33]

12 Experimental Assessments

Finally some qualitative statements which seem to be evident for odoriferous

[29] D. G. Land, in 'Proceedings of International Symposium Aroma Research', ed. H. Maarse and P. F. Groenen, Zeist, 1975, p. 131.
[30] E. von Sydow, *Inst. Food Sci. Technol. Proc.*, 1974, **7**, 190.
[31] H. Boelens, in 'Proceedings ECRO Symposium', ed. G. Benz, Wädenswil, 1975, Information Retrieval Ltd, London, 1976, p. 197.
[32] A. Eriksson, P. Lindner, and O. Märtensson, private ed. 1977, Department Organic Chemistry, Box 531, Uppsala, Sweden.
[33] J. R. McGill and B. R. Kowalski, *Analyt. Chem.*, 1977, **49**, no. 4, 596.

substances are listed: the compound must be *volatile*; the product must have a certain *hydrophilicity* and *lipophilicity*; the organoleptic quality can change by variation of the *concentration*; one chemical compound has several different odour qualities; the number of characteristics increase by increasing the *flexibility* of the compound; the type, number, and place of the *functional group(s)* influences the organoleptic quality; the *size and shape* (*chirality*) of the compound do influence the organoleptic quality; the physico-chemical parameters of a compound, which govern the organoleptic response, are *interrelated.*