In our study of this assay system with a crude abdomen homogenate or microsomes, the concentration of BSA needed to obtain a beneficial effect is minimal, 1 mg/sample. In practice, the enzyme assay without BSA would be better than the assay with BSA at greater than 1 mg/sample.

The ratio of parathion activation to degradation appears to differ between insects and mammals. In our work with the housefly, activation equaled or exceeded degradation. In rabbit microsomes, degradation equaled or exceeded activation (Nakatsugawa and Dahm, 1967).

Neal (1967) reported that with rat liver microsomal metabolism of parathion, the effects of enzyme inhibitors, stimulators, and substrate concentration were quantitatively different for metabolism to DEPTA and to paraoxon. He concluded that the differences in the two reactions may either be due to two separate mixed-function oxidase enzyme systems or two different binding sites for parathion which share a common electron transport pathway. It is not known whether similar differences may also occur in insect microsomal metabolism of parathion.

There are also soluble enzyme systems metabolizing phosphorothionate insecticides. They are reduced glutathion (GSH)-dependent *S*-alkyl transferase (Fukami and Shishido, 1966) and *S*-aryl transferase (Shishido *et al.*, 1972), as well as esterases which require no cofactors. When a crude homogenate is used as a microsomal enzyme preparation in this assay procedure, the aqueous layer may contain a small amount of the reaction products of the above enzymes. The contribution of these reaction products to the aqueous layer count would, however, be the same for both the sample and blank which in this method also contains the enzyme preparation. Therefore, the net result of the microsomal parathion metabolism measured by this procedure will not be affected by the soluble enzymes.

Although the recommended method does not measure total microsomal parathion metabolism *in vitro,* the results obtained by the method still represent degradative metabolism plus activation in part. Relative activities determined by this procedure are comparable with those obtained by the more commonly used but slower method of measuring cyclodiene epoxidation.

ACKNOWLEDGMENT

The authors wish to thank Dr. T. Nakatsugawa, State University of New York, Syracuse, N. Y., for his gift of phenyl-^{14}C-labeled paraoxon.

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Comparative Study of Flavor Properties of Thiazole Derivatives

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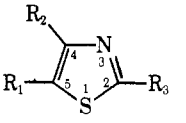
A series of mono-, di-, and trisubstituted thiazoles containing alkyl, alkoxy, and acetyl functional groups was synthesized and their mass spectra, gc retention indices (I_E values), and organoleptic properties were determined. Significant flavor correspondence was found between the thiazoles and derivatives of pyrazine and pyridine possessing comparable functional groups. These similarities tended to be greater with the 2- and 4-substituted thiazoles than the 5-substituted thiazoles, which were more sulfury in character. The variations in odor quality in these N-containing heterocycles are discussed in terms of structure and charge distribution.

Although thiazole derivatives have been known to synthetic organic chemists for almost a century (Hoffman, 1879), little interest was shown in these heterocyclic compounds from a nutritional point of view until Williams (1935) demonstrated that vitamin B_1 contains a thiazole ring. The potential of thiazole derivatives as flavorants became evident through the work of Stoll *et al.* (1967a), who found that the strong nutlike odor of a basic fraction obtained from a cocoa extract was due to a trace amount of 4-methyl-5-vinylthiazole. Since then an increasing number of volatile thiazole derivatives has been isolated from a wide range of food products. Although some thiazoles, *e.g.*, 2-isobutylthiazole in tomato, probably arise biogenetically (Kazeniac and Hall, 1970), the majority of the thiazole derivatives to date have been isolated from foods which have undergone heat processing or Maillard-type reactions. These include cocoa (Stoll *et al.*, 1967a), coffee (Stoll *et al.*, 1967b), roasted peanuts (Walradt *et*

International Flavors and Fragrances, Inc., R&D Center, Union Beach, New Jersey 07735.

al., 1971), and filberts (Kinlin *et al.*, 1972), cooked beef (Wilson *et al.*, 1973), and stale dried milk (Ferretti and Flanagan, 1972). However, it has been demonstrated that benzothiazole can arise as a contaminant from rubber tubing used in distillation techniques (Ferretti and Flanagan, 1973). Only a limited amount of information on the odor qualities of thiazole derivatives is available; these range from the objectionable pyridine-like odor of thiazole itself (Webster, 1964) and quinoline-like benzothiazole (Merck, 1968) through the strong tomato leaf odor of 2-isobutylthiazole (Viani *et al.*, 1969) to the pleasant bread-crust flavor of 2-acetyl-2-thiazoline (Tonsbeek *et al.*, 1971).

We have now synthesized a series of thiazole derivatives in which a limited number of functional groups, namely alkyl, alkoxy, and acetyl, were incorporated into the 2, 4, and 5 positions of the thiazole ring and determined the effect of substitution on their flavor properties.



R_1 = H, alkyl, alkoxyl, acetyl
R_2 = H, alkyl, acetyl
R_3 = H, alkyl, alkoxy, acetyl

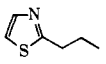
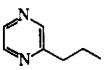
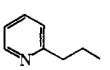
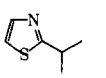
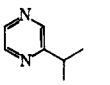
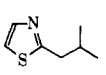
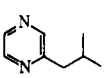
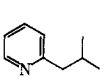
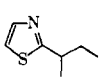
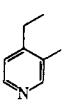
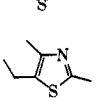
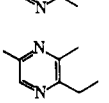
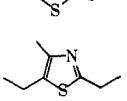
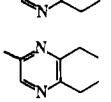
Where possible, organoleptic comparisons were made with pyrazine and pyridine derivatives of analogous substitution. These compounds were chosen because many of them are already of flavor interest and because pyrazines and pyridines are structurally related to the thiazoles;

Table I. Chromatographic Retention Indices (I_E Values) and Mass Spectra

Thiazole	Purity, %	Mp, °C	Bp, °C (mm Hg)	Retention index CBW	Retention index SE 30	Mass fragmentation, *m/e*
2-Methyl	>96			6.15	3.81	58 (100), *99 (57)*, 45 (9), 59 (8), 42 (6)[a]
2-Ethyl	>95			6.83	4.87	58 (100), *113 (81)*, 112 (63), 57 (20), 45 (20), 98 (19)
2-Propyl	>95			7.65	5.91	99 (100), 58 (55), 112 (22), 98 (20), 45 (14), 59 (13), *127 (12)*
2-Isopropyl	>99			6.99	5.51	112 (100), 58 (53), *127 (41)*, 59 (29), 126 (23), 27 (17)
2-Isobutyl	96.5[c]			7.89	6.41	99 (100), 58 (38), 27 (20), 126 (17), 41 (17), 113 (15)
2-*sec*-Butyl	>98			7.79	6.37	113 (100), 112 (81), 58 (53), 126 (43). 59 (40), 99 (19)
4,5-Dimethyl	>99			7.55	5.31	*113 (100)*, 71 (73), 45 (40), 86 (39), 85 (30), 27 (28)
5-Ethyl-4-methyl	>95			8.17	6.19	112 (100), *127 (70)*, 45 (47), 85 (36), 43 (26), 39 (24)
2,4,5-Trimethyl	>98			7.60	5.94	*127 (100)*, 86 (97), 71 (90), 59 (42), 85 (35), 27 (29)
5-Ethyl-2,4-dimethyl	>98			8.25	6.80	126 (100), *141 (74)*, 85 (55), 54 (31), 113 (24), 59 (23)[b]
2,5-Diethyl-4-methyl	>95			8.85	7.64	140 (100), *155* (75), 85 (32), 45 (30), 154 (24), 100 (22)
2-Acetyl	>99			10.15	6.27	43 (100), *127 (41)*, 99 (40), 58 (40), 57 (32), 112 (26)
4-Acetyl	>99			11.56	6.50	112 (100), *127 (60)*, 43 (40), 45 (30), 57 (29), 84 (23)
4-Acetyl-2,5-dimethyl	>99	38–39.6		11.00	7.96	140 (100), *155 (97)*, 43 (70), 59 (55), 45 (43), 99 (40)[b]
5-Acetyl-4-methyl	>95			12.46	7.62	126 (100), 43 (78), *141 (67)*, 45 (48), 71 (29), 98 (22)
5-Acetyl-2,4-dimethyl	>99			12.47	8.40	43 (100), *155 (69)*, 140 (61), 45 (38), 71 (36), 112 (29)
2-Methoxy	98.3			7.18	4.80	*115 (100)*, 56 (74), 45 (64), 100 (54), 58 (39), 114 (27)
2-Ethoxy	>97		32–33 (2)	7.74	5.60	101 (100), 73 (79), *129 (50)*, 27 (49), 29 (41), 45 (41)
2-Butoxy	>95			9.64	7.65	101 (100), 29 (56), 41 (35), 27 (30), 57 (24), 73 (21), *157 (19)*
5-Methoxy	>95			9.51	5.62	45 (100), *115 (64)*, 57 (12), 72 (10), 73 (10), 44 (9)[b]
5-Ethoxy	>95		94–96 (30)	9.95	6.49	45 (100), 29 (83), 101 (75), 27 (40), 46 (38), *129 (34)*[b]
5-Methoxy-2-methyl	>95		33 (0.5)	9.42	6.27	*129 (100)*, 45 (81), 59 (66), 88 (27), 57 (26), 73 (25)
4-Isobutyl-5-methoxy	98.7		92–93 (10)	10.83	8.41	128 (100), 129 (39), 101 (36), 45 (31), *171 (20)*, 27 (19)
4-Isobutyl-5-methoxy-2-methyl	98.2		69–70 (2.2)	10.43	8.77	142 (100), 101 (46), *185 (40)*, 59 (28), 143 (24), 41 (22)[a]
4-Isobutyl-5-ethoxy	95		80–81 (10)	11.00	9.02	114 (100), 142 (44), 27 (36), 45 (35), 29 (32), *185 (24)*
4-Isobutyl-5-ethoxy-2-methyl	>95		126–127 (30)	10.65	9.40	59 (100), 128 (98), 156 (57), *199 (37)*, 27 (35), 29 (31)

[a] AEI MS 9. [b] Hitachi RMU-6E. [c] 3.5% 2-*sec*-butylthiazole.

Table II. Flavor Properties of Alkyl Heterocycles

	Green vegetable		Nutty, roasted		Green
	Green, nutty		Nutty, roasted		Green
	Green, herby, nutty		Green vegetable		Sweet, green
	Green vegetable		Green, nutty		Green vegetable
	Green, tomato vine		Green, fruity		Green pepper
	Raw, green, herby				
	Roasted, nutty, green		Green, nutty		Green
	Nutty, green, earthy		Nutty, roasted		Sweet, nutty
	Cocoa, nutty		Nutty, roasted		
	Nutty, roasted, meaty		Nutty, roasted		
	Green, nutty		Nutty, roasted		

they have planar rings of comparable size and tertiary nitrogen atoms as part of the heteroaromatic system.

EXPERIMENTAL SECTION

Chemicals. 2-Aminothiazole was purchased from Aldirch Chemical Co., Milwaukee, Wis. Chloroacetaldehyde was obtained from Montrose Chemical Co., Newark, N. J., as a 40% aq solution. The anhydrous material was obtained by distillation and drying with calcium sulfate.

3-Bromo-2-butanone was obtained from Eastman Kodak, Rochester, N. Y.

Ammonium dithiocarbamate was prepared by the method of Redemann *et al.* (1955).

Methods. Acid amides not commercially available were prepared from the corresponding acids *via* their respective chlorides (Kent and McElvain, 1955). Where necessary, α-chloro ketones were prepared by the method of Buchman and Richardson (1945).

The majority of the alkyl- and acetylthiazoles were prepared by the addition of the halodicarbonyl compound to the thioamide formed *in situ* from the corresponding amide (Kurkjy and Brown, 1952a).

4,5-Dimethylthiazole was synthesized by the procedure of Buchman *et al.* (1941) from ammonium dithiocarbamate and 3-bromo-2-butanone.

The 5-alkoxy- and 5-alkoxyalkylthiazoles were prepared by reaction of the appropriate *N*-acylamino acid esters with phosphorous pentasulfide (Tarbell *et al.*, 1950). The unsubstituted 5-alkoxythiazoles were also prepared from 2-aminothiazole by successive bromination and deamination (Beyerman *et al.*, 1954) and treatment with the appropriate alkoxide.

2-Alkoxythiazoles were prepared from 2-bromothiazole (Ganapathi and Venkataraman, 1945) which was synthesized from 2-aminothiazole (Ganapathi and Kulkarni, 1953).

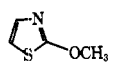
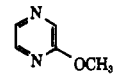
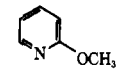
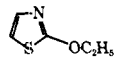
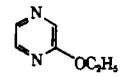
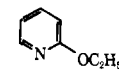
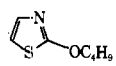
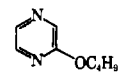
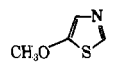
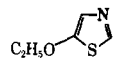
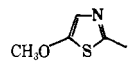
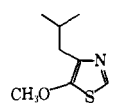
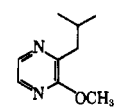
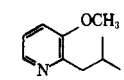
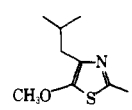
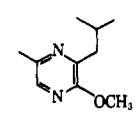
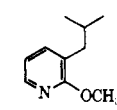
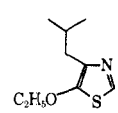
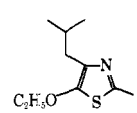
2-Acetylthiazole was prepared from 2-bromothiazole *via* the 2-lithio derivative (Kurkjy and Brown, 1952b) which was treated with acetyl chloride.

2-Isobutyl-3-methoxypyridine. A mixture of 123.2 g of isobutyl-2-furyl ketone (prepared by acylation of furan with isovaleric anhydride) and 1500 ml of ammonium hydroxide (11 *N*) was placed in a Parr bomb and heated at 150° with stirring for 18 hr. After cooling and saturating the reaction mixture with salt, it was extracted with 3 × 500 ml of methylene chloride. The combined extracts were dried (anhydrous sodium sulfate) and filtered and the solvent was evaporated to yield a semicrystalline black residue (82 g) which was redissolved in ethanol, decolorized (Norit A charcoal), and the solvent evaporated. Pale brown crystals were obtained, part of which were recrystallized (carbon tetrachloride) to afford white needles (20.6 g) of 2-isobutyl-3-hydroxypyridine: mp 155.6–157.2°; *m/e* 109 (100), 94 (99), 39 (58), *151* (*31*), 27 (30), 66 (28); nmr 0.92 (d, 6 H), 2.14 (m, 1 H), 2.68 (d, 2 H), 4.86 (s, 1 H), 7.10 (m, 2 H), 7.88 (m, 1 H). The 2-isobutyl-3-hydroxypyridine was methylated with diazomethane to yield 2-isobutyl-3-methoxypyridine: bp 91–92° (5 mm); *m/e* 123 (100), 122 (43), 39 (37), 93 (33), 150 (24), *165* (*6*); nmr 0.88 (d, 6 H), 2.11 (m, 1 H), 2.67 (d, 2 H), 3.75 (s, 3 H), 7.03 (d, 2 H), 8.07 (t, 1 H).

The thiazoles were isolated by fractional vacuum distillation and the purity of the products was determined by gc analysis. The structure and purity of the compounds were confirmed by nmr analysis.

Gas chromatographic retention indices (I_E values) were

Table III. Flavor Properties of Alkoxy Heterocycles

	Sweet, roasted, phenolic		Sweet, nutty		Phenolic
	Phenolic, burnt, nutty		Sweet, nutty		Phenolic
	Green vegetable		Green vegetable		
	Roasted, meaty, onion				
	Cooked onion				
	Cabbagy, sulfury, vegetable				
	Green pepper		Green pepper[a]		Green pepper
	Green vegetable		Green pepper, minty[b]		Camphoraceous[b]
	Cucumber, green potato				
	Green vegetable, onion				

[a] Buttery *et al.* (1969). [b] Seifert *et al.* (1972).

determined on Carbowax 20M and SE-30 columns using programmed gc by the method of van den Dool and Kratz (1963) utilizing ethyl esters of *n*-aliphatic acids as standards.

Mass spectra were determined, unless otherwise stated, on a C.E.C. 21-103 C (Consolidated Electrodynamics Corp., Pasadena, Calif.) using an ionizing voltage of 70 eV and an inlet temperature of 150°.

Organoleptic Data. All the thiazoles evaluated were at least 95% pure by gc analysis (area normalization); see Table I. The compounds were smelled on blotters and tasted in water at appropriate dilutions by a panel of expert flavorists.

RESULTS

The retention indices (I_E values), mass spectra, and purity of the thiazoles synthesized are given in Table I; in the case of new derivatives melting point or boiling point data are included. It is hoped that the above information will assist other research workers in identifying thiazoles in natural products. It is noteworthy that thiazoles are particularly amenable to gc detection using a chromatograph equipped for recording simultaneously nitrogen, sulfur, and flame ionization detector signals (Kinlin *et al.*, 1972). Since the preparation of this manuscript, Buttery *et al.* (1973) have published ms data on additional alkylthiazoles.

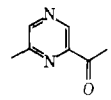
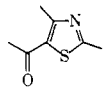
The flavor properties of the thiazole derivatives are given in Tables II–IV. The lower 2-alkylthiazoles have green, vegetable-like flavors. The 2-*sec*-butylthiazole was judged to be inferior to 2-isobutylthiazole, which has a typical tomato vine-like character. The monoalkylpyridines too have green odors and the higher homologs again are more pleasant. The monoalkylpyrazines, in comparison, tend to be more nutty in flavor. In the case of the di- and trialkylthiazoles, increased substitution conveys added nutty, roasted, meaty notes and these thiazoles correspond more closely with the di- and trialkylpyrazines, although the latter as a group tend to be more roasted in character. Unfortunately, an insufficient number of di- and trialkylpyridine derivatives was available for meaningful conclusions to be drawn.

The flavor properties of 2-methoxy- and 2-ethoxythiazoles are intermediate between the sweet, nutty characteristics of the pyrazine derivatives and the rather unpleasant phenolic odor of the 2-alkoxypyridines. The 2-butoxy derivatives of both thiazole and pyrazine are green and vegetable-like. On the other hand, the 5-alkoxythiazoles are more sulfury in character than the 2-substituted compounds.

The 4-isobutyl-5-methoxythiazole has a strong characteristic green pepper odor. This compound may be regarded as the thiazole analog of 2-isobutyl-3-methoxypyrazine and 2-isobutyl-3-methoxypyridine, both of which have a typical green pepper note; the isomeric 3-isobutyl-2-methoxypyridine has been reported to have a somewhat camphoraceous odor (Seifert *et al.*, 1972).

The replacement of the C-2 proton of 4-isobutyl-5-methoxythiazole by a methyl group produced a less characteristic and less potent odor. A similar effect was observed by Seifert *et al.* (1972), who found that the substitution of either or both of the C-5 and C-6 protons of 2-

Table IV. Flavor Properties of Heterocyclic Methyl Ketones

	Nutty, cereal, popcorn		Popcorn, nutty[a]
	Nutty, cereal		Popcorn
	Roasted, meaty, sulfury		
	Roasted, nutty, sulfury		Popcorn[a]
	Roasted, nutty, meaty		

[a] Roberts (1968).

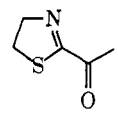
methoxy-3-isobutylpyrazine by methyl groups resulted in less potent and less characteristic smelling compounds. The 4-isobutyl-5-ethoxythiazoles possess a more cucumber green flavor rather than green pepper and, again, the insertion of a methyl group into the C-2 position gave a less characteristic and weaker odor. Although no threshold values were determined, a panel judged the two 5-alkoxy-4-isobutylthiazoles to be of approximately equal strength and about five to ten times stronger than the corresponding 5-alkoxy-4-isobutyl-2-methylthiazoles when the compounds were tasted at high dilution.

In the case of 2- and 4-acetylthiazoles in which the functional group is adjacent to the ring nitrogen, the compounds have nutty, cereal, popcorn odors similar to the corresponding pyrazine and pyridine derivatives. The 5-acetylalkylthiazoles, together with the 4-acetyl-2,5-dimethylthiazole, have more roasted, sulfury, meaty odors.

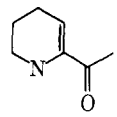
DISCUSSION

It may be seen from the flavor properties of the thiazoles described here that there are some significant similarities with the alkyl-, alkoxy-, and acetylpyridines and greater similarities with the corresponding pyrazine derivatives. These correlations are more evident when the functional group is in the 2 or 4 position of the thiazole ring, *i.e.*, adjacent to the ring nitrogen. In the case of the 5-substituted thiazoles, a more sulfury odor is obtained. The tendency for some of the thiazole compounds that we have synthesized to have odor properties closer to the pyrazine and pyridine derivatives containing the same functional group rather than to positional isomers within the thiazole series may be attributed in part to the role of both the nitrogen and sulfur heteroatoms of the thiazole ring.

Most of the compounds known to have nutty, corny, and bready odors are unsaturated heterocyclic compounds with either one or two nitrogen atoms in the ring (Hodge *et al.*, 1972). If the nitrogen atom plays a primary role in conveying these particular odor characteristics, then it is reasonable to expect that functional groups adjacent to the thiazole nitrogen will convey odor qualities closer to those of the equivalent 2-substituted pyridines and pyrazines than those of the 5-substituted thiazoles, where the functional group is at least one atom further removed from the ring nitrogen. This type of effect we have observed in the acetylpyridines where the 2-substituted compound has considerably more odor strength and character than the 3- or 4-acetylpyridine. It is noteworthy that the "bready" odor quality is exhibited by the 2-acetyl derivatives 2-thiazoline and 1,4,5,6-tetrahydropyridine; in both compounds the acetyl group and the nitrogen atom are in the same plane analogous to the planarity of 2-acetylthiazole and 2-acetylpyridine.

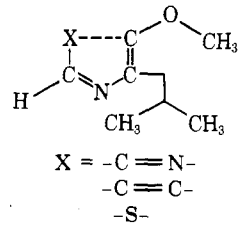


Tonsbeek *et al.* (1971)



Hunter *et al.* (1969)

The majority of compounds known to have "green pepper" odor are isobutylmethoxy derivatives of N-heterocycles. From the structures of the chemicals so far evaluated, it is now possible to postulate the probable functional moiety responsible for this particular odor. The 2-isobutyl-3-methoxypyrazine, naturally occurring in green bell peppers (Buttery *et al.*, 1969), may be regarded as possessing the most characteristic odor but, due to the symmetry of the molecule, it is not possible to conclude whether the proximity of the isobutyl or the methoxy group to the tertiary nitrogen is primarily responsible for this odor quality; indeed, a more complex functionality appears to be involved, since the protons on the pyrazine ring are also important for both potency and odor quality (Seifert *et al.*, 1972). In the thiazole series the green pepper quality of 4-isobutyl-5-methoxythiazole is also significantly modified by the substitution of the C-2 proton by a methyl group. These observations, together with the report that the odor of 3-isobutyl-2-methoxypyridine is camphoraceous (Seifert *et al.*, 1972), suggest that the basic functional moiety responsible for a strong green pepper odor in the N-heterocycles is:



To obtain more experimental data on this structure–odor relationship, we synthesized 2-isobutyl-3-methoxypyridine, anticipating that it would have a strong green pepper odor. This indeed was the case. The 2-isobutyl-3-hydroxypyridine intermediate also has a green pepper, green vegetable odor but is much weaker.

The organoleptic evaluation of additional compounds such as 5-isobutyl-4-methoxythiazole and the isobutylmethoxy derivatives of pyridazine and pyrimidine will assist in establishing a more complete structure–odor relationship within the nitrogen-containing heterocycles.

We conclude that from the compounds so far evaluated certain functional groups, for example acetyl, methoxy, and isobutyl, when appropriately located adjacent to the ring nitrogen of certain heterocycles of comparable size convey similar odor notes. As was mentioned above, the odors of thiazole and benzothiazole have been described as being pyridine- and quinoline-like, respectively. Erlenmeyer and Leo (1933) extended the concept of isosterism (Langmuir, 1919) to aromatic systems wherein the vinylene group H:C=C:H of benzene was interpreted as being electronically analogous to the -S- atom of thiophene and later applied this concept to the pyridine and thiazole series. They sought examples of similarity in physical, chemical, and biological properties of derivatives of thiazoles and benzothiazole with the corresponding pyridine or quinoline isosteres (see review by Sprague and Land, 1957). Although the concept of isosterism has been criticized (Bradlow *et al.*, 1947), the odor properties of several

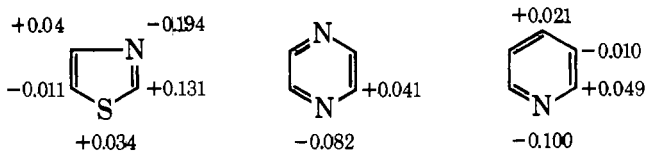


Figure 1. Charge distribution in nitrogen heterocycles. Electron density: −, excess; +, deficiency.

isosteric pyridines and thiazoles do exhibit distinct similarities.

Another factor influencing odor quality is charge distribution. Application of molecular orbital calculations to the unsubstituted thiazole molecule has shown that the charge distribution is nonuniform (Palmer, 1967). The carbon atoms in the 2 and 4 positions tend to be π-electron deficient and are separated by the electron-attracting nitrogen atom; the ring nitrogens of pyrazine and pyridine exert a similar effect (see Figure 1). However, the carbon atom of position 5 of the thiazole ring tends to be π-electron rich and is adjacent to an electron-deficient sulfur (due to its donation of two electrons to the π system). Thus, functional groups on C-5 of the thiazole ring are influenced by a different electron distribution or environment from those situated at C-2 or C-4, the latter positions approximating the C-2 positions of pyridine and pyrazine. The charge distribution undoubtedly plays an important role in determining the orientation of the thiazole ring and its substituent(s) at the nasal receptor site through the creation of a polarized odorant–receptor complex (Klopping, 1971), although the precise charge distribution and orientation of the odorant molecule in the transaction state must at present remain speculative.

ACKNOWLEDGMENT

The authors thank Anne Sanderson and Matt Drummond for obtaining mass spectra and I_E values, respectively.

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Flavor Properties of Phenylpentenals

William L. Schreiber,* Alan O. Pittet, and Manfred H. Vock

A number of phenylpentenals, isomeric with respect to double bond location and the position of phenyl substitution, have been prepared and their flavor properties have been described.

Phenylalkenals **1a, b,** and **c** were first isolated and identified from a steam distillate of cocoa nibs (van Praag *et al.,* 1968) and subsequently found in peanut (Johnson *et al.,* 1971; Walradt *et al.,* 1971) and in filbert (Kinlin *et al.,* 1972).

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It was suggested (van Praag *et al.,* 1968) that the phenylalkenals arose by aldol condensation of phenylacetaldehyde with acetaldehyde, isobutyraldehyde, and isovaleraldehyde, followed by dehydration to the respective enals **1a, b,** and **c** (Figure 1). In fact these materials were synthesized by classical aldol methods and proved to be of considerable value as flavoring agents (van Praag and Stein, 1971).