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Formation of Alkyl Heteroaromatics in the Pyrolysis of Pyrazylethanol and Pyridylethanol Derivatives

Richard A. Kornfeld* and Yoram Houminer*

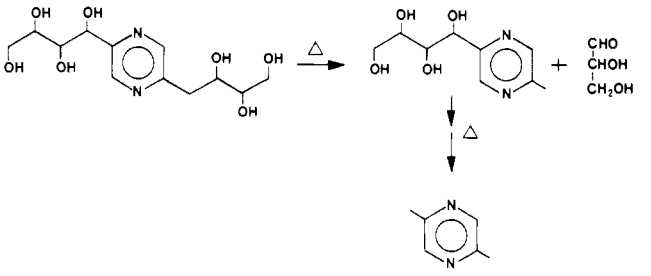
Several substituted pyrazylethanols (**1**–**15**) and pyridylethanols (**16**–**18**) have been prepared and their pyrolysis at 450 °C has been studied. Each of these compounds decomposes to yield the parent methyl heteroaromatic and the corresponding aldehyde or ketone by way of a retro-ene type mechanism. Characteristic also to the pyrolysis of the pyrazylethanols is the formation of small amounts of 1,2-dipyrazylethanes (**19**–**23**), as well as small amounts of dehydration products. The isomeric 2-, 3- and 4-pyridylethanols differ strongly in their thermal reactivities.

Alkyl heteroaromatics such as alkylpyridines and, in particular, alkylpyrazines have desirable flavor properties. These compounds have been detected in a wide variety of food products, especially ones that have undergone cooking or roasting (Ohloff and Flament, 1979). The mechanisms by which these important flavors are formed are still under extensive study. Several pathways have been proposed for the formation of alkylpyrazines in the systems mentioned above. One mechanism involves the reaction of 1,2-dicarbonyl compounds, formed from sugars, with ammonia. A second proposed pathway is the dimerization of α-amino ketones, the latter being formed from the reaction of sugars with amino acids (Garnero, 1980).

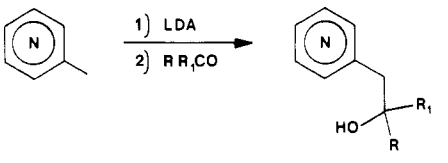
A number of possible intermediates in these reaction schemes have been isolated. One of these compounds, 2,5-deoxyfructosazine has been isolated from natural products such as tobacco leaves (Green et al., 1980; Shigematsu and Kitami, 1978). This compound is also known to be formed in the dehydration of 2-amino-2-deoxy-D-glucose (Eitelman and Feather, 1979). The deoxyfructosazine is proposed to undergo thermal decomposition to form 2,5-dimethylpyrazine in a multistep reaction. One part of this decomposition may involve a retro-ene type reaction as shown in Scheme I.

The role of this retro-ene reaction in the formation of alkyl heteroaromatics has been demonstrated in a few systems (Houminer, 1980; Ohsawa et al., 1979). All of these studies were performed in solution and at relatively low temperatures (<200 °C). The investigations reported here focus on the formation of alkylpyrazines from a large variety of 2-pyrazylethanols as model compounds. The reactions were carried out in the molten state and at a relatively high temperature (450 °C). These studies have also been extended to isomeric pyridylethanols in an attempt to obtain basic pyrolysis data and to correlate structure and reactivity.

Scheme I



Scheme II



RESULTS AND DISCUSSION

The preparations of the pyrazyl- and pyridylethanols were carried out by reacting the alkyl heteroaromatic anion

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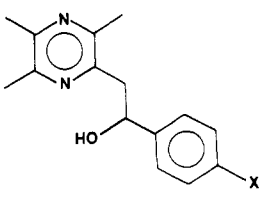
Table I. Yields of 1,2-Dipyrazylethanes in the 450 °C Pyrolysis of Various Pyrazylethanols[a]

pyrazylethanol	1	2	3	5	6	7	8	9	10	11	12	13	14
yield of 1,2-dipyrazylethane, %	4	2	1	2	9	2	2	8	7	2 (19), 3 (20), 2 (23)	<1	<1	<1

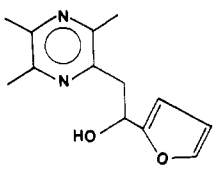
[a] Yields are accurate to ±1%.

with a variety of aldehydes or ketones (see Scheme II) (Houminer, 1980). Compounds 1–18 were subjected to 450



1 X = H
2 X = CH_3
3 X = OCH_3
4 X = $N(CH_3)_2$
5 X = Cl
6 X = NO_2

1–6



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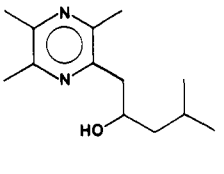

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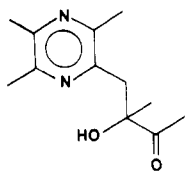

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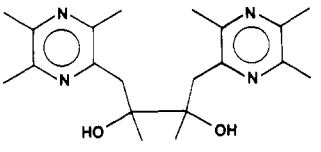

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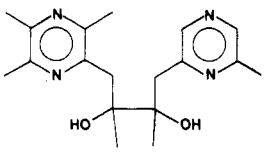

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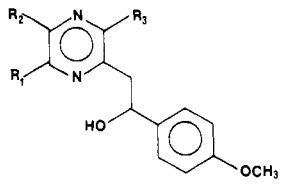
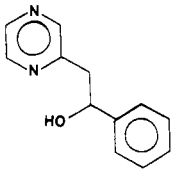


12 R_1 = CH_3, R_2 = R_3 = H
13 R_2 = CH_3, R_1 = R_3 = H
14 R_3 = CH_3, R_1 = R_2 = H



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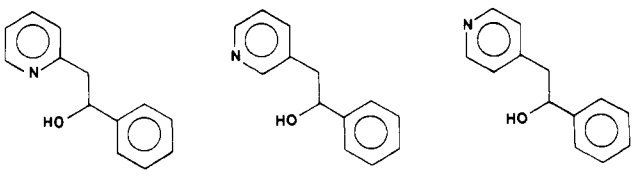
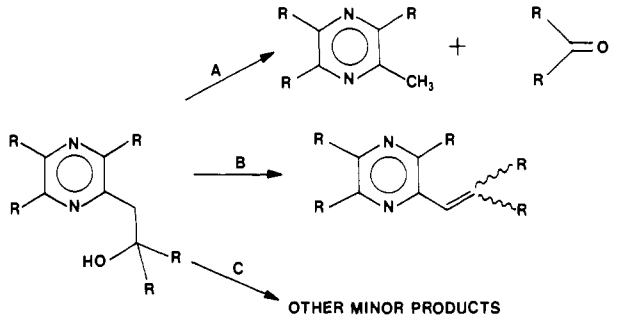


16 17 18

°C pyrolysis for 2 min in a helium atmosphere. The pyrolyzates were analyzed by using GC/MS. Products were identified from their mass spectral fragmentation patterns and, in most cases, by comparison of their GC retention time with authentic materials.

Except for compound 4, all of the pyrazylethanols de-

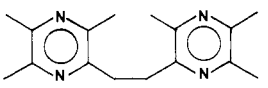
Scheme III



composed to form the corresponding alkylpyrazines and carbonyl compounds as the major products (each above 40%). This reaction is illustrated by pathway A in Scheme III. The formation of these products is assumed to proceed via a concerted retro-ene mechanism as was established in the solution thermolysis of some of the above substrates (Houminer, 1980). This suggested mechanism is consistent with the pyrolytic behavior of the 1-*O*-acetate of compound 1, in which blocking the hydroxyl group dramatically changes the pyrolytic pattern. The only observed reaction (about 70%) is elmination of acetic acid (pathway B, Scheme III) to form olefinic products. None of the products from pathway A are formed in this reaction, thus indicating the requirement for a free hydroxyl group in this retro-ene type reaction. The generality of the above reaction suggests that it may be an important pathway for alkylpyrazine formation in cooked or roasted food.

The formation of olefins (pathway B) is also observed in the decomposition of most of the pyrazylethanols studied. In the case of 4 at least 50% of the product mixture is olefins. A similar observation was made in the solution thermolysis of 4 and is attributed to the *p*-dimethylamino group, a substituent that accelerates an E1-type elimination (Houminer, 1980). Substituent effects on olefin formation are observed in 1–6. Dehydration products are 0% in 6, 1% in 5, 12% in 2, and 19% in 3. Each of the observed olefinic products is a mixture of both cis and trans isomers.

The most interesting and unexpected products observed in these pyrolyses are 1,2-dipyrazylethanes (19–23). Their



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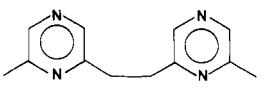

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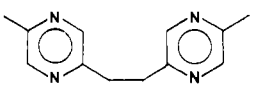

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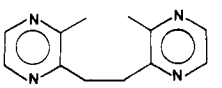

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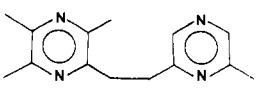

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Scheme IV

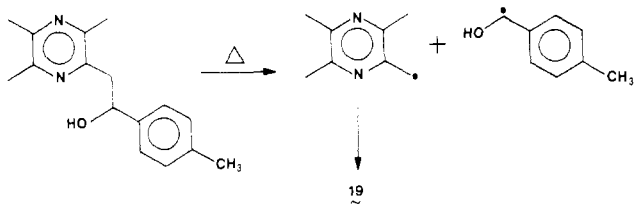

Table II. Products from the 450 °C Pyrolysis of Various Pyridylethanols

	products, %			
pyridyl-ethanol	methyl-pyridine	benz-aldehyde	dehydration product[a]	unreacted material
16	43	49	1	6
17	<1	<1	20	79
18	17	21	3	59

[a] Mixture of cis and trans isomers.

presence was confirmed by mass spectral and GC retention time comparisons with authentic compounds (Houminer et al., 1980). Each of the above pyrazylethanols (except **4** and **15**) gave the corresponding dimers. Quite interestingly, **11** gave a mixture of all three possible dimers (**19**, **20**, and **23**). Table I shows the yields of dimer formation from the various pyrazylethanols. Several observations can be made from the data in Table I. Generally, electron-withdrawing groups attached to the 1 position of the ethanol increase the formation of dimers. The large amount of dimer produced from **10** is the result of its rapid pyrolysis to form **9**, a compound producing relatively large amounts of dimer. Similar pyrolytic behavior is observed for **11**. It also appears that increased methyl substitution on the pyrazine ring increases the dimer yield.

The formation of these dimers can be rationalized by invoking a radical mechanism. The carbon–carbon bond in the ethanol moiety is homolytically cleaved to form a methylpyrazyl radical. Combination of these radicals leads to the formation of the dimer as seen in Scheme IV for the case of **2**. A radical mechanism for the formation of these dipyrazines is supported by the detection of the three possible dimer products from the pyrolysis of **11**.

In order to further explore the role of the nitrogen functionality in the thermal retro-ene reaction, three isomeric pyridylethanols were investigated (**16**–**18**). The results obtained at 450 °C are presented in Table II. The 2-substituted pyridine isomer follows the general behavior shown in Scheme III for the pyrazylethanols. The absence of 1,2-dipyridylethane in the pyrolyzate resembles the behavior of the unsubstituted pyrazyl analogue, **15**.

The thermal behavior of **17** is quite different. It does not undergo the retro-ene reactions. The major route is dehydration; however, most of the starting material remains unchanged. This behavior is very similar to that of 1,2-diphenylethanol where we find only starting material plus a small amount of dehydration products in the pyrolyzate.

Thermal behavior of the 4-pyridyl isomer (**18**) is similar to that of the 2 isomer. However, there is a major difference in reactivity, as indicated by the presence of a large amount of unreacted starting material from the pyrolysis of **18**. It is obvious from the above results that the proximity of the nitrogen functionality and the hydroxyl group is required for an effective retro-ene reaction, further supporting the previously proposed concerted mechanism for this reaction. In **18**, the formation of 4-methylpyridine and benzaldehyde suggests that other mechanisms, for example, a base-autocatalyzed retro-aldol reaction, may be operating. This is possible in the 4 isomer (**18**) and not in the 3 isomer (**17**) because of the much greater stabilization of the anion of 4-methylpyridine formed in such a base-catalyzed retro-aldol reaction.

EXPERIMENTAL SECTION

All reactions involving organometallic reagents were carried out under N_2 atmosphere. Melting points were determined with a Thomas-Hoover capillary melting point apparatus and are uncorrected. IR spectra were recorded with a Perkin-Elmer 621 spectrophotometer. NMR spectra were recorded with a Varian XL-100 or a Brucker WP80 spectrometer, and the chemical shifts are given in δ values downfield from internal Me_4Si. UV spectra were taken in 95% EtOH with a Beckman Acta-CV spectrophotometer. Mass spectra were recorded with a CEC21-104 spectrometer. Elemental analyses were performed by Galbraith Laboratories, Inc. TLC was carried out on silica gel GF plates with hexane containing 15–30% acetone as the eluent. Compounds **1**–**6** and **12**–**15** were prepared by the method described previously (Houminer, 1980).

2-(2-Acetoxy-2-phenylethyl)-3,5,6-trimethylpyrazine (1-OAc). A solution of **1** (3 g) in dry pyridine (80 mL) was treated with acetic anhydride (10 mL), and the mixture was left at room temperature overnight. Water was added, and the solution was stirred for 2 h. The product was extracted with ether (3 × 50 mL), and the solution dried ($MgSO_4$) and evaporated under reduced pressure to give an oil (2.9 g) of pure **1-OAc**; IR (neat) 1740, 1415, 1370, 1230, 1020, 760, 695 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.97 (3 H, s, CH_3), 2.41 (3 H, s, CH_3), 2.46 (6 H, s, 2 CH_3), 3.26 (2 H, m, CH_2), 6.23 (1 H, m, CH), 7.33 (5 H, m, Ph); MS *m/e* (rel intensity) 284 (16), 241 (31), 136 (51), 107 (37), 105 (14), 79 (11), 77 (14), 53 (38), 43 (100), 42 (26). Anal. Calcd for $C_{17}H_{20}N_{20}O_2$: C, 71.80; H, 7.09; N, 9.85. Found: C, 71.66; H, 7.15; N, 10.04.

2-[2-Hydroxy-2-(2-furyl)ethyl)]-3,5,6-trimethylpyrazine (7). A solution of tetramethylpyrazine (13.6 g, 0.1 mol) in Et_2O (100 mL) was added slowly with stirring to a solution of phenyllithium in 150 mL of 7:3 benzene–ether (0.1 mol) at 0 °C. The mixture was stirred at room temperature for 2 h and then heated under reflux for 1.5 h. The red suspension so obtained was cooled to 0 °C, and a solution of 2-furaldehyde (9.6 g, 0.1 mol) in Et_2O (50 mL) was added dropwise. The reaction mixture was stirred at room temperature for 1 h. Water was added, and the organic layer was separated, washed with water, and dried (Na_2SO_4). The solvent was evaporated under reduced pressure to give an oil (6.2 g). Preparative TLC gave **7** (5.0 g, 22%). Recrystallization from Et_2O–hexane (1:1) gave pure **7** as needles: mp 69–71 °C; IR (CCl_4) 3390, 1445, 1415, 1065, 1005, 725 cm^{-1}; UV λ_{max} 300 nm (sh, ϵ 4600) 281 (ϵ 8300), 216 (ϵ 15000); ^1H NMR ($CDCl_3$) δ 2.44 (3 H, s, CH_3), 2.47 (6 H, s, 2 CH_3), 3.18 (2 H, d, J = 6 Hz, CH_2), 5.15–5.40 (2 H, m, CH + OH), 6.18–6. 38 (2 H, m, furan), 7.35 (1 H, m, furan); MS *m/e* (rel intensity) 232 (12), 215 (18), 214 (100), 186 (15), 185 (9), 171 (14), 160 (16), 136 (44), 123 (24), 96 (16). Anal. Calcd for $C_{13}H_{16}N_2O_2$: C, 67.22; H, 6.94; N, 12.06. Found: C, 67.47; H, 6.86; N, 12.16.

2-(2-Hydroxy-4-methylpentyl)-3,5,6-trimethylpyrazine (8). The reaction of tetramethylpyrazine (13.6 g, 0.1 mol) with isovaleraldehyde (8.6 g, 0.1 mol) was carried out as described for **7**. Distillation of the crude product gave 7.7 g (35%) of pure **8**: bp 98–100 °C/0.05 mmHg; IR (neat) 3410, 1450, 1415, 1195, 1170, 1070, 990 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.95 (6 H, d, J = 7 Hz, 2 CH_3), 1.13–2.03 (3 H, m, CH + CH_2), 2.46 (9 H, s, 3 CH_3), 2.79 (2 H, m, CH_2), 4.20 (1 H, m, CH), 4.85 (1 H, m, OH); MS

m/e (rel intensity) 222 (1), 220 (1), 204 (3), 189 (5), 161 (9), 136 (100), 54 (25), 53 (10), 43 (10), 42 (18), 41 (11), 39 (11). Anal. Calcd for $C_{13}H_{22}N_2O$: C, 70.23; H, 9.97; N, 12.60. Found: C, 70.37; H, 9.86; N, 12.50.

Reaction of Tetramethylpyrazine with 2,3-Butanedione. *n*-BuLi (0.1 mol) in hexane (50 mL) was added with stirring to a solution of diisopropylamine (10.1 g, 0.1 mol) in Et_2O (100 mL) at 0 °C. The mixture was stirred at 0 °C for 15 min. A solution of tetramethylpyrazine (13.6 g, 0.1 mol) in Et_2O (80 mL) was added slowly, and the resulting red suspension was stirred at 0 °C for 20 min and then cooled to −78 °C. A solution of 2,3-butanedione (8.6 g, 0.1 mol) in ether (20 mL) was added rapidly with stirring, and the mixture was left stirring at −78 °C for 30 min, at which time the red color disappeared. The solution was then allowed to warm up to room temperature. Water was added, and the Et_2O layer was separated, washed with water, and dried ($MgSO_4$). The solvent was evaporated under reduced pressure to give an oil. Separation by column chromatography (using 300 g of silica gel and hexane containing 5–15% acetone as the eluant) gave 5.2 g (23%) of 2-(2-hydroxy-2-methoxy-3-oxobutyl)-3,5,6-trimethylpyrazine (**9**). Crystallization from hexane gave pure **9** as needles: mp 75–77 °C; IR (Nujol) 3455, 1705, 1450, 1415, 1365, 1225, 1170, 1115, 1060, 1005 cm^{-1}; UV λ_{max} 298 nm (sh, ϵ 3300, 280.5 (ϵ 5900), 211 (ϵ 7100); ^1H NMR ($CDCl_3$) δ 1.39 (3 H, s, CH_3), 2.32 (3 H, s, CH_3), 2.42 (3, H, s, CH_3), 2.44 (3 H, s, CH_3), 2.47 (3 H, s, CH_3) 2.88 and 3.41 (2 H, ABq, J = 16 Hz, CH_3), 5.85 (1 H, s, OH); MS *m/e* (rel intensity) 222 (<1), 204 (2), 179 (100), 137 (20), 136 (61), 54 (27), 53 (35), 43 (50), 42 (36), 41 (15), 39 (16). anal. Calcd for $C_{12}H_{18}N_2O_2$: C, 64.84; H, 8.16; N, 12.60. Found: C, 64.81; H, 8.14; N, 12.55.

Also isolated was 4.8 g (26.8%) of 2,3-dihydroxy-2,3-dimethyl-1,4-bis(3,5,6-trimethyl-2-pyrazyl)butane (**10**). Crystallization from hexane–Et_2O gave pure **10** as fine needles: mp 119–123 °C; IR (Nujol) 3380, 1455, 1415, 1380, 1205, 1165 cm^{-1}; UV λ_{max} 300 nm (ϵ 15000), 282 (ϵ 24000), 211 (ϵ 26000); ^1H NMR ($CDCl_3$) δ 1.19 (6 H, s, 2 CH_3), 2.49 (12 H, s, 4 CH_3), 2.56 (6 H, s, 2 CH_3), 3.16 (4 H, m, 2 CH_2), 5.42 (1 H, br s, 2 OH); MS *m/e* (rel intensity) 358 (<1), 233 (8), 180 (41), 179 (100), 137 (22), 136 (58), 123 (18), 94 (8), 54 (13), 53 (21), 43 (11), 42 (12). Anal. Calcd for $C_{20}H_{30}N_4O_2$: C, 67.01; H, 8.44; N, 15.63. Found: C, 67.11; H, 8.59; N, 15.71.

2,3-Dihydroxy-2,3-dimethyl-1-(3,5,6-trimethyl-2-pyrazyl)-4-(6-methyl-2-pyrazyl)butane (11). A solution of 2,6-dimethylpyrazine (2.16 g, 20 mmol) in Et_2O (50 mL) was added with stirring to a solution of lithium diisopropylamide (20 mmol) in Et_2O (40 mL) and hexane (9 mL), at 0 °C. The dark red mixture was stirred at 0 °C for 20 min. A solution of **9** (2.0 g, 9 mmol) in Et_2O (60 mL) was added slowly and stirring at 0 °C was continued for an additional 1 h. Water was added, and the organic layer was separated, washed with water, and dried ($MgSO_4$). Evaporation of the solvent under reduced pressure gave an oil (1.6 g). Preparative TLC afforded 1.3 g (44%) of pure **11** as a thick oil: IR (neat) 3370, 1410, 1375, 1205, 1160 cm^{-1}; UV λ_{max} 300 nm (sh, ϵ 6400), 278, (ϵ 14500), 212 (ϵ 14300); ^1H NMR ($CDCl_3$) δ 1.19 (6 H, br s, 2 CH_3), 2.50 and 2.56 (12 H, m, 4 CH_3), 2.87–3.47 (4 H, m, 2 CH_2), 4.70 (1 H, m, OH), 6.00 (1 H, m, OH), 8.30–8.49 (2 H, m, pyrazine protons); MS *m/e* (rel intensity) 330 (1), 179 (100), 151 (68), 136 (100), 109 (52), 108 (65), 54 (85). Anal. Calcd for $C_{18}H_{26}N_4O_2$: C, 65.43; H, 7.93; N, 16.96. Found: C, 65.32; H, 8.05; N 16.69.

2-(2-Hydroxy-2-phenylethyl)pyridine (16). The reaction of 2-picoline (4.65 g, 50 mmol) with benzaldehyde (5.3 g, 50 mmol) was carried out as described in the case of **7**. Crystallization of the crude product from hexane–acetone (1:1) gave 4.1 g (40%) of pure **16** as plates: mp 105–107 °C [lit. mp 110 °C (Beyerman et al., 1956)]; IR (Nujol) 3200, 1600, 1570, 1480, 1455, 1445, 1060, 760, 695 cm^{-1}; UV λ_{max} 268 nm (ϵ 3300), 262 (ϵ 4550), 258 (sh, ϵ 4000), 210 (ϵ 13500); ^1H NMR ($CDCl_3$) δ 3.08 (2 H, d, J = 6 Hz, CH_2), 5.13 (1 H, t, J = 6 Hz, CH) 5.60 (1 H, m, OH), 6.96–7.74 (8 H, m, aromatic), 8.50 (1 H, m H-6 pyridine); MS *m/e* (rel intensity) 199 (4), 198 (5), 181 (23), 180 (77), 106 (23), 105 (25), 93 (100), 77 (16), 45 (11). Anal. Calcd for $C_{13}H_{13}NO$: C, 78.36; H, 6.58; N, 7.03. Found: C, 78.56; H, 6.70; N, 7.04.

3-(2-Hydroxy-2-phenylethyl)pyridine (17). A solution of 3-phenacylpyridine [prepared by the method of Miller and Levine (1959)] (0.5 g) in 95% EtOH (100 mL) was treated with a large excess of $NaBH_4$. The mixture was stirred at room temperature for 1 h. Water was added and the product was extracted with CH_2Cl_2. The solution was dried ($MgSO_4$) and evaporated under reduced pressure to give a solid. Recrystallization from hexane–Et_2O (1:1) gave 0.41 g (82%) of pure **17** as needles: mp 116–117 °C [lit. mp 121 °C (Miller and Levine, 1959)]; IR (Nujol) 3200, 1610, 1565, 1455, 1420, 1060, 1005, 795, 750, 695 cm^{-1}; UV λ_{max} 268.5 nm (ϵ (2450), 262.5 (ϵ 3400), 257 (ϵ 3100) nm; ^1H NMR ($CDCl_3$) δ 3.00 (2 H, d, J = 6.5 Hz, CH_2), 4.86 (1 H, t, J = 6.5 Hz, CH), 7.02–7.55 (7 H, m, aromatic), 8.35 (2 H, m, H-2 and H-6 pyridine); MS *m/e* (rel intensity) 198 (<1), 181 (20), 152 (4), 149 (3), 107 (20), 108 (15), 105 (40), 94 (100), 79 (33), 77 (60), 51 (47), 50 (30). Anal. Calcd for $C_{13}H_{13}NO$: C, 78.36; H, 6.58; N, 7.03. Found: C, 78.56; H, 6.78; N, 7.06.

4-(2-Hydroxy-2-phenylethyl)pyridine (18). The reaction of 4-picoline (9.3 g, 0.1 mol) with benzaldehyde (9.6 g, 0.1 mol) was carried out as described in the case of **11**. The crude product (11.1 g) as an oil was crystallized from ether to give 3.1 g (16%) of pure **18** as fine needles: mp 108–110 °C; IR (Nujol) 3200, 1610, 1565, 1455, 1420, 1060, 1005, 795, 750, 695 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.01 (2 H, d, J = 6.5 Hz, CH_2), 4.93 (1 H, t, J = 6.5 Hz, CH), 7.07 and 8.35 (4 H, ABq, J = 6 Hz, pyridine), 7.33 (5 H, br s, phenyl); MS *m/e* (rel intensity) 199 (<1), 181 (5), 180 (7), 152 (3), 107 (37), 105 (17), 93 (100), 79 (30), 77 (35), 64 (10), 51 (28), 39 (31). Anal. Calcd for $C_{13}H_{13}NO$: C, 78.36; H, 6.58; N, 7.03. Found: C, 78.44; H, 6.71; N, 6.91.

Pyrolysis–GC/MS Studies. Samples (25–75 μg) were weighed into clean ceramic boats and placed into the section of a quartz pyrolysis tube maintained at room temp. the remainder of the tube passed through a furnace and was connected to the injection port of a gas chromatograph (Bendix Model 2200). After purging air from the tube with an auxiliary helium supply (55 cm^3/min), the sample and boat were pushed into the pyrolysis zone maintained at 450 °C. The auxiliary helium swept the pyrolzate into the gas chromatographic column. The column was also swept by helium (20 cm^3/min) supplied in the usual manner.

The column (5.5 m × 2.2 mm i.d. stainless steel packed with 8% silicone oil W98 on 100–120-mesh Anakrom ABS) was maintained at 0 °C for 5 min after the onset of pyrolysis. During the first 2 min the auxiliary helium swept the pyrolyzate into the front of the column. At 2 min the auxiliary helium flow was stopped, the furnace cooled, and the column flow allowed to return to 20 cm^3/min for the next 3 min. After this 5-min span, the column temperature was increased at a rate of 10 °C/min until the upper limit, 275 °C, was reached. The column temperature was maintained at 275 °C for the duration of the analysis.

Effluent from the column passed into a single-stage, glass, jet molecular separator (275 °C) and then into the ion source of a Finnigan Model 3300 mass spectrometer operated in the electron impact ionization mode. The mass spectrum was scanned every 4 s, and the data were acquired, stored, and manipulated by using a Finnigan Model 6110 data acquisition system. Compound peak areas were obtained by using standard software supplied by the manufacturer and were used to estimate products yields.

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On the Fate of Maleic Hydrazide in Tobacco Smokes

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Tobacco main-stream (MSS) and side-stream (SSS) smokes, butts, and ashes from commercial cigarettes and cigarettes made from tobacco treatments containing (1) maleic hydrazide (MH), (2) MH-30 (MH diethanolamine salt, DEA-MH), (3) Royal MH-30 (K-MH), (4) 1R1, and (5) 1968 and 1980 commercial cigarettes were analyzed for their MH contents. The MH transfer rates obtained for MSS ranged from 5.54% for MH-30 to 1.25% for K-MH and for SSS ranged from 3.33% for MH-30 to undetected for MH (acid forms). Further, analysis of MH in butts and ashes along with that in MSS and SSS indicates that there was greater MH destruction when MH in nonvolatile form was used. These results suggest the existence of the possibility of reducing the MH transfer rates in MSS and SSS by using the appropriate form of MH.

Like all commercial crops, various chemicals are also applied to tobacco. One such chemical, maleic hydrazide (MH), has been found to be the most effective substance known so far in tobacco sucker control (Seltmann, 1971). However, this compound is suspected to be a carcinogen (Epstein et al., 1967), and the German government has set a tolerance level of 80 ppm of this substance in cigarette tobacco (Spears and Jones, 1981). This would adversely affect the U.S. tobacco exports, since recent surveys have shown that a sizable amount of U.S. tobacco contains more then 80 ppm of MH residues (Hayes, 1979; Davis et al., 1979; Hunt et al., 1977; Spears and Jones, 1981).

However, as far as the smoker is concerned, the most important question is not how much pesticide is in tobacco but how much of the pesticide and its degradation products is present in cigarette main-stream smoke? Our investigations are, in part, an answer to that and, especially, the MH question.

In our investigations we have analyzed cigarette tobacco, cigarette main-stream and side-stream smokes, cigarette butts, and cigarette ashes for their MH contents and have calculated the transfer of MH into main-stream and side-stream smokes. Since it is a well-known fact that different formulations of the same amount of a pesticide will leave different amounts of pesticide residues in crops, we have also included in our study cigarettes made from tobacco treated with different forms of MH: i.e., MH, acid form [$C_4H_4N_2O_2$ (acid-MH)], Royal MH-30 (potassium salt of MH, K-MH), and MH-30 (diethanolamine salt of MH, DEA-MH). In this respect, as far as we could ascertain, ours is the first such study on any pesticide in tobacco smokes.

Also, although there have been some studies published on the transfer of pesticide residues into the main-stream smoke (Atallah and Dorough, 1975; Guthrie, 1968; Haeberer and Chortyk, 1974; Hengy and Thirion, 1970, 1971; Hoffmann and Rathkamp, 1968; Liu and Hoffmann, 1973), we have come across only one publication (Atallah and Dorough, 1975) dealing with the transfer of pesticide residues into the side-stream smoke. This study does not deal with MH. Further, in this study pesticides were applied to cigarettes by injecting their solutions into the cigarettes. In such application, according to the same authors, the concentration of pesticide in the cigarette is not uniformly spread over all of the cigarette. This adds to the importance of our study since our cigarettes had tobaccos in which the MH concentration was uniform throughout.

EXPERIMENTAL PROCEDURES

Materials. All cigarettes, whether purchased or made from tobacco specially grown for the study, were stored at 0 °C until required for use.

The 1R1 cigarettes were purchased in 1970, and the commercial cigarettes, all different brands, were purchased in 1968 and 1980 from local grocery stores on the day their shipment arrived at the stores.

Description of Tobaccos Specially Grown. (1) Tobacco, variety Coker 347, was planted on May 10, 1973, in a field at Chinqua Penn, NC. Royal MH-30 (active ingredient K-MH) was applied to the tobacco. A detailed description

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