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REVIEW

Heterocyclic Compounds Found in Cooked Meats

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Heterocyclic compounds occurring in cooked meat products (boiled beef, canned beef, cooked chicken, canned beef stew, cooked pork liver, roast beef, cooked ovine fat, shallow-fried beef, ground beef, roasted lamb fat) are reviewed. The compounds reviewed include thiophenes, furans, pyrazines, thiazoles, thiazolines, pyrroles, cyclic polysulfides, oxazoles, oxazolines, and pyridines. The odors of these chemicals in relation to cooked meat flavors are discussed.

Many cooked meat constituents have been isolated and identified over the last 20 years. Some fatty acids were found in raw meat and reported by early researchers (Hornstein and Crowe, 1960; Hornstein et al., 1961; Hornstein and Crowe, 1963). Around the same time some low boiling point compounds (hydrogen sulfide, acetone, acetaldehyde, methyl mercaptan, etc.) were identified in cooked beef (Pearson et al., 1959; Kramlich and Pearson, 1960; Pippen and Nonaka, 1960).

Following the development of gas chromatographic techniques and other instrumental methods (MS, NMR, GC/MS), more information concerning cooked meat constituents began to appear. Fifty-five compounds had been reported as volatile compounds in heat-treated meat by the end of 1966 (Herz and Chang, 1970). In the late 1960's, the introduction of the capillary column to gas chromatographic analysis made it possible to make a more comprehensive analysis of cooked meat volatiles. Nonaka et al. (1967) identified 62 of the approximately 227 compounds evident on the chromatogram of the isopentane extract of cooked chicken meat. The compounds identified included 2-methylthiophene and seven alkylfurans.

The trace heterocyclic compounds in meat volatiles began to be identified from that time. Recently, heterocyclic compounds, including, pyrazines, thiophenes, thiazoles, and furans, have received much attention as producers of characteristic cooked meat aromas.

Thiophenes. The first thiophene compound reported in cooked meat volatiles was 2-methylthiophene (Nonaka et al., 1967). Thiophenes are responsible for the mild sulfurous odor of cooked meat. Table I summarizes the thiophenes identified in cooked meats.

The formation of thiophenes in cooked meat has been described by several researchers. The sulfur in a thiophene ring may come either from amino acids (cysteine, cystine, methionine) or from a vitamin B₁ (thiamin). Dwivedi and Arnold (1973) obtained some thiophene derivatives (2-methylthiophene, 4,5-dihydro-2-methylthiophene) from a

thiamin solution maintained at 120 °C for 1 h. This is good evidence that thiamin could serve as a thiophene precursor. Hydrogen sulfide, which is formed during the Strecker degradation of cysteine with a diketone (Kobayashi and Fujimaki 1965), has been considered as a precursor of various compounds associated with meat aroma (Pippen and Mecchi, 1969; Brinkman et al., 1972; Shibamoto and Russel, 1976). Shibamoto (1977) obtained 2-thiophene-carboxaldehyde from the reaction of furfural (sugar caramelization product) and hydrogen sulfide. This indicates there was an exchange of S and O in the furan ring during heat treatment. Many thiophene derivatives were formed in the reaction of D-glucose and hydrogen sulfide (Sakaguchi and Shibamoto, 1978). These experimental results indicate that the thiophene derivatives form from a sugar or carbohydrate and hydrogen sulfide or amino acid in meat during heat treatment (cooking).

Furans. It is well known that various furans are produced from sugar caramelization or degradation (Hodge, 1967). Some furan derivatives have been thought, therefore, to be present in cooked meat. Table II shows the furans found in cooked meat products. The presence of a furan in raw chicken meat was reported in 1967 (Grey and Shrimpton, 1967). A series of alkylfurans was found in cooked chicken soon thereafter (Nonaka et al., 1967). Herz (1968) reported that a small GC peak which had a meaty flavor was identified as 5-thiomethylfurfural. It was the first furan compound recognized as a meaty-flavor-giving constituent. Various furan compounds which do not contain sulfur possess a wide variety of aromas, none of them meaty (Herz and Chang, 1970). Tonsbeek et al. (1968) isolated two furan compounds from beef broth. They were 4-hydroxy-2,5-dimethyl-3(2*H*)-furanone, which has a caramel-like odor (Hodge, 1967), and 4-hydroxy-5-methyl-3(2*H*)-furanone. Persson and von Sydow (1973) identified nine alkylfurans in a headspace sample obtained from canned beef using gas chromatographic-mass spectrometric techniques. The furans identified included unsubstituted furan and 2-methylfuran, which has a sickly, nasty smell and gives an off flavor to canned beef. Musinan and Walradt (1974) identified 179 volatile compounds, including 23 furan derivatives in pressure-cooked

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Table I. Thiophenes Identified in Cooked Meat

compound	cooked meat system	references
thiophene	canned beef pressure-cooked beef fried chicken canned beef boiled beef	Persson and von Sydow (1973) Wilson et al. (1973) Janney and Hale (1974) Qvist et al. (1976) Garbusoy et al. (1976)
2-methylthiophene	cooked chicken cooked chicken canned beef pressured-cooked beef canned beef pressure-cooked pork liver cooked chicken boiled beef canned beef	Nonaka et al. (1967) Hobson-Frohock (1970) Persson and von Sydow (1973) Wilson et al. (1973) Persson and von Sydow (1973) Mussinan and Walradt (1974) Horvat (1976) Garbusoy et al. (1976) Qvist et al. (1976)
3-methylthiophene	canned beef canned beef	Persson and von Sydow (1973) Qvist et al. (1976)
2,3-dimethylthiophene	canned beef	Persson and von Sydow (1973)
2,5-dimethylthiophene	canned beef	Persson and von Sydow (1973)
2-ethylthiophene	pressure-cooked beef canned beef	Wilson et al. (1973) Qvist et al. (1976)
2-n-butylthiophene	pressure-cooked beef	Wilson et al. (1973)
2-n-pentylthiophene	canned beef pressure-cooked beef	Persson and von Sydow (1973) Wilson et al. (1973)
2-n-hexylthiophene	beef fat	Crawford and Kretsch (1976)
2-n-octylthiophene	pressure-cooked beef	Wilson et al. (1973)
2-n-tetradecylthiophene	pressure-cooked beef	Wilson et al. (1973)
2-tert-butylthiophene	boiled beef	Garbusoy et al. (1976)
3-tert-butylthiophene	boiled beef	Garbusoy et al. (1976)
2-n-propyl-5-isopentylthiophene	cooked chicken	Horvat (1976)
2-methyltetrahydrothiophene	boiled beef	Garbusoy et al. (1976)
2,5-dimethyltetrahydrothiophene	boiled beef	Garbusoy et al. (1976)
2-thiophenecarboxaldehyde	boiled beef canned beef pressure-cooked beef pressure-cooked pork liver canned beef stew	Hirai et al. (1973) Persson and von Sydow (1973) Wilson et al. (1973) Mussinan and Walradt (1974) Peterson et al. (1975)
3-thiophenecarboxaldehyde	pressure-cooked beef pressure-cooked pork liver pressure-cooked pork liver	Wilson et al. (1973) Mussinan and Walradt (1974) Mussinan and Walradt (1974)
3-methyl-2-thiophenecarboxaldehyde	pressure-cooked pork liver	Wilson et al. (1973)
5-methyl-2-thiophenecarboxaldehyde	pressure-cooked beef pressure-cooked pork liver	Mussinan and Walradt (1974) Wilson et al. (1973)
2,5-dimethyl-3-thiophenecarboxaldehyde	pressure-cooked beef pressure-cooked pork liver	Wilson et al. (1973) Mussinan and Walradt (1974)
2-acetylthiophene	pressure-cooked beef pressure-cooked pork liver cooked chicken	Wilson et al. (1973) Mussinan and Walradt (1974) Horvat (1976)
3-acetylthiophene	pressure-cooked beef pressure-cooked pork liver	Wilson et al. (1973) Mussinan and Walradt (1974)
2-acetyl-5-methylthiophene	pressure-cooked beef pressure-cooked pork liver	Wilson et al. (1973) Mussinan and Walradt (1974)
1-(2-thienyl)-1-propanone	pressure-cooked beef	Wilson et al. (1973)
1-(2-methyl-5-thienyl)-1-propanone	pressure-cooked beef	Wilson et al. (1973)
2-thiophenemethanol	pressure-cooked beef	Wilson et al. (1973)
tetrahydrothiophen-3-one	pressure-cooked beef	Wilson et al. (1973)
2-methyltetrahydrothiophen-3-one	pressure-cooked beef	Wilson et al. (1973)

pork liver. Furan esters (seven derivatives) were found for the first time in cooked meat in this study.

N-Pentylfuran seems to be distributed in various kinds of cooked meats (chicken, beef, pork liver, etc.). Furans are mainly produced from sugars or carbohydrates present in meat by the heat treatment. They may contribute some cooked flavor but are not important flavor materials for cooked meat. Furfural can, however, be a precursor of various flavor materials (Shibamoto, 1977).

Pyrazines. Pyrazines are one of the main components of meat volatiles. They comprise, for example, over 40% of the volatile compounds found in cooked pork liver (Mussinan and Walradt, 1974). There have already been two comprehensive reviews of pyrazines (Maga and Sizer, 1973a,b).

Watanabe and Sato (1971a) identified 65 compounds in heated beef fats, among which were five pyrazines. This was the first report of pyrazines present in cooked meat.

They postulated that pyrazines formed from a reaction of the degraded nitrogenous substances (NH_3 , RNH_2) from proteins, peptides, amino acids, and phospholipids, and the α -dicarbonyl compounds in beef fats. Table III shows the pyrazines in pressure-cooked beef. The pyrazines identified included polycyclic pyrazines (dihydro-5*H*-cyclopentapyrazines, tetrahydroquinoxalines) which were listed for the first time as beef volatiles. Mussinan and Walradt (1974) identified 179 compounds in the diethyl ether extract of pressure cooked pork liver. They reported 36 pyrazines, including furylpyrazines: 2-furylpyrazine and 2-(2-furyl)-5(or 6)-methylpyrazine. Compounds containing two heterocyclic moieties (furan and pyrazine) were reported for the first time as meat volatile components. Some alkylpyrrolo[1,2-*a*]pyrazines have been identified in roasted meat aroma obtained by thermolysis of the water-soluble flavor precursors of raw meat (Flament et al., 1977). Prior to this report, the structure of these ni-

Table II. Furan Derivatives Identified in Cooked Meat

compound	cooked meat system	references
furan	chicken ^a	Grey and Shrimpton (1967)
2-methylfuran	canned beef	Persson and von Sydow (1973)
	chicken	Nonaka et al. (1967)
	canned beef	Persson and von Sydow (1973)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
3-methylfuran	canned beef	Persson and von Sydow (1973)
2,5-dimethylfuran	canned beef	Persson and von Sydow (1973)
2-ethylfuran	chicken	Nonaka et al. (1967)
	chicken	Hobson-Frohock (1970)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
2-ethyl-5-methylfuran	canned beef	Persson and von Sydow (1973)
2-n-propylfuran	chicken	Nonaka et al. (1967)
	canned beef	Persson and von Sydow (1973)
2-n-butylfuran	chicken	Nonaka et al. (1967)
	canned beef	Persson and von Sydow (1973)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
2-n-pentylfuran	chicken	Nonaka et al. (1967)
	beef	Herz (1968)
	chicken	Hobson-Frohock (1970)
	roast beef	Liebich et al. (1972)
	canned beef	Persson and von Sydow (1973)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
	cooked chicken	Horvat (1976)
	cooked ovine fat	Caporaso et al. (1977)
3-pentylfuran	pressure-cooked pork liver	Mussinán and Walradt (1974)
2-hexylfuran	chicken	Nonaka et al. (1967)
	canned beef	Persson and von Sydow (1973)
2-n-heptylfuran	roast beef	Liebich et al. (1972)
	chicken	Nonaka et al. (1967)
	roast beef	Liebich et al. (1972)
2-n-octylfuran	roast beef	Leibich et al. (1972)
2-furaldehyde	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
2-acetyl-furan	shallow-fried beef	Watanabe and Sato (1972b)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl alcohol	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
5-methyl-2-furaldehyde	pressure-cooked pork liver	Mussinán and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
2-propionylfuran	pressure-cooked pork liver	Mussinán and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
furfuryl methyl ketone	pressure-cooked pork liver	Mussinán and Walradt (1974)
	shallow-fried beef	Watanabe and Sato (1972b)
	canned beef stew	Peterson et al. (1975)
2-acetyl-5-methylfuran	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl formate	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl acetate	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl propionate	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl butyrate	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl pentanoate	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl hexanoate	pressure-cooked pork liver	Mussinán and Walradt (1974)
ethyl furoate	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl ether	pressure-cooked pork liver	Mussinán and Walradt (1974)
2,2'-methylenedifuran	pressure-cooked pork liver	Mussinán and Walradt (1974)
5-methyl-2,2'-methylenedifuran	pressure-cooked pork liver	Mussinán and Walradt (1974)
5-thiomethyl-2-furaldehyde	beef	Herz (1968)
	boiled beef	Hirai et al. (1973)
furfuryl methyl sulfide	pressure-cooked pork liver	Mussinán and Walradt (1974)
furfuryl methyl disulfide	pressure-cooked pork liver	Mussinán and Walradt (1974)
2-methyltetrahydrofuran-3-one	beef	Herz (1968)
	pressure-cooked pork liver	Mussinán and Walradt (1974)
4-hydroxy-2,5-dimethyl-3(2H)-furanone	beef	Tonsbeek et al. (1968)
4-hydroxy-5-methyl-3(2H)-furanone	beef	Tonsbeek et al. (1968)

^a In raw chicken breast muscle.

trogen heterocyclic compounds was in doubt because of the similarity of their mass spectra to those of other diazaindene and diazanaphthalene derivatives such as benzimidazoles, indazoles, cyclopenta[b]pyrazines, and dihydroquinoxalines. Alkylpyrrolo[1,2-a]pyrazines were now positively identified as new components of cooked meat in this report.

Pyrazines have been used to create imitation meat fla-

vors (Evers et al., 1972; Pittet et al., 1972). Pyrazine flavor patent applications are summarized by Maga and Sizer (1973b).

Thiazoles and Thiazolines. In 1935, it was discovered that thiamin, or vitamin B₁, contains a thiazole ring nucleus. Dwivedi and Arnold (1973) obtained three thiazole derivatives [4,5-dimethyl-, 2-vinyl-3-methyl-, and 4-methyl-5-(β-hydroxyethyl)thiazole] from heated thiamin

Table III. Pyrazines Identified in Cooked Meat

compound	cooked meat system	references
pyrazine	pressure-cooked beef	Mussinan et al. (1973)
2-methylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
	shallow-fried beef	Watanabe and Sato (1971b)
	chicken broth	Wilson and Katz (1972)
	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
	chicken broth	Horvat (1976)
2,5-dimethylpyrazine	roasted lamb fat	Buttery et al. (1977)
	shallow-fried beef	Watanabe and Sato (1971b)
	beef fat	Watanabe and Sato (1971a)
	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2,3-dimethylpyrazine	roasted lamb fat	Buttery et al. (1977)
	boiled beef	Liebich et al. (1972)
	shallow-fried beef	Watanabe and Sato (1971b)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2,6-dimethylpyrazine	roasted lamb fat	Buttery et al. (1977)
	shallow-fried beef	Watanabe and Sato (1971b)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2,3,5-trimethylpyrazine	roasted lamb fat	Buttery et al. (1977)
	boiled beef	Liebich et al. (1972)
	shallow-fried beef	Watanabe and Sato (1971b)
	beef fat	Watanabe and Sato (1971a)
	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
tetramethylpyrazine	roasted lamb fat	Buttery et al. (1977)
	shallow-fried beef	Watanabe and Sato (1971b)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-ethylpyrazine	roasted lamb fat	Buttery et al. (1977)
	shallow-fried beef	Watanabe and Sato (1971b)
	beef fat	Watanabe and Sato (1971a)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-ethyl-3-methylpyrazine	shallow-fried beef	Watanabe and Sato (1972a)
2-ethyl-5-methylpyrazine	shallow-fried beef	Watanabe and Sato (1971b)
	beef fat	Watanabe and Sato (1971a)
	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-ethyl-6-methylpyrazine	roasted lamb fat	Buttery et al. (1977)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
	roasted lamb fat	Buttery et al. (1977)
2,5-diethylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
2,6-diethylpyrazine	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked beef	Mussinan et al. (1973)
2-ethyl-3,6-dimethylpyrazine	boiled beef	Liebich et al. (1972)
	shallow-fried beef	Watanabe and Sato (1971b)
	shallow-fried beef	Watanabe and Sato (1972a)
	shallow-fried beef	Watanabe and Sato (1972a)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
5-ethyl-2,3-dimethylpyrazine	roasted lamb fat	Buttery et al. (1977)
2-ethyl-3,5-dimethylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
	roasted lamb fat	Buttery et al. (1977)
2-ethyl-5,6-dimethylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
3,6-diethyl-2,5-dimethylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
2,5-diethyl-3-methylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
	roasted lamb fat	Buttery et al. (1977)
2,6-diethyl-3-methylpyrazine	shallow fried beef	Watanabe and Sato (1971b)
	pressure-cooked beef	Mussinan et al. (1973)
	roasted lamb fat	Buttery et al. (1977)
2,3-diethyl-5-methylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
	roasted lamb fat	Buttery et al. (1977)
3,5-diethyl-2-methylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
triethylpyrazine	pressure-cooked beef	Mussinan et al. (1973)

Table III (Continued)

compound	cooked meat system	references
2-vinylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
2-methyl-5-vinylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-methyl-6-vinylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
2-methyl-3-vinylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-methyl-6-propylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
2-isopropylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
2-acetylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
5-acetyl-2-methylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
	pressure-cooked beef	Mussinan et al. (1973)
6-(or 5)-acetyl-2-ethylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-acetyl-3-methylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-acetyl-5-ethylpyrazine	pressure-cooked beef	Mussinan et al. (1973)
1-pyrazinyl-2-propanone	pressure-cooked beef	Mussinan et al. (1973)
2-methyl-6,7-dihydro-5 <i>H</i> -cyclopentapyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
5-methyl-6,7-dihydro-5 <i>H</i> -cyclopentapyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-(or 3),5-dimethyl-6,7-dihydro-5 <i>H</i> -cyclopentapyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
6,7-dihydro-5 <i>H</i> -cyclopentapyrazine	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
quinoxaline	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-methylquinoxaline	pressure-cooked pork liver	Mussinan and Walradt (1974)
6-methylquinoxaline	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-methyl-5,6,7,8-tetrahydroquinoxaline	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-furylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-furylmethylpyrazine	pressure-cooked pork liver	Mussinan and Walradt (1974)
pyrrolo[1,2- <i>a</i>]pyrazine	grilled beef	Flament et al. (1977)
1-methylpyrrolo[1,2- <i>a</i>]pyrazine	grilled beef	Flament et al. (1977)
3-methylpyrrolo[1,2- <i>a</i>]pyrazine	grilled beef	Flament et al. (1977)
4-methylpyrrolo[1,2- <i>a</i>]pyrazine	grilled beef	Flament et al. (1977)
1,3-dimethylpyrrolo[1,2- <i>a</i>]pyrazine	grilled beef	Flament et al. (1977)
1,4-dimethylpyrrolo[1,2- <i>a</i>]pyrazine	grilled beef	Flament et al. (1977)
3,4-dimethylpyrrolo[1,2- <i>a</i>]pyrazine	grilled beef	Flament et al. (1977)

Table IV. Thiazoles and Thiazolines Identified in Cooked Meat

compound	cooked meat system	references
thiazole	ground beef	Wilson et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-methylthiazole	ground beef	Wilson et al. (1973)
4-methylthiazole	ground beef	Wilson et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
2,4-dimethylthiazole	ground beef	Wilson et al. (1973)
2,4,5-trimethylthiazole	roasted lamb fat	Buttery et al. (1977)
5-ethyl-4-methylthiazole	ground beef	Wilson et al. (1973)
5-ethyl-2,4-dimethylthiazole	roasted lamb fat	Buttery et al. (1977)
4-ethyl-2-methylthiazole	ground beef	Wilson et al. (1973)
2,4,5-trimethylthiazole	ground beef	Wilson et al. (1973)
2,4-dimethyl-5-vinylthiazole	ground beef	Wilson et al. (1973)
2-acetylthiazole	ground beef	Wilson et al. (1973)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
benzothiazole	canned beef stew	Peterson et al. (1975)
	shallow fried beef	Watanabe and Sato (1972b)
	boiled beef	Liebich et al. (1972)
	ground beef	Wilson et al. (1973)
	canned beef stew	Peterson et al. (1975)
	roasted lamb fat	Buttery et al. (1977)
2-acetylthiazoline	beef broth	Tonsbeek et al. (1971)
2,4,5-trimethylthiazoline	roasted lamb fat	Buttery et al. (1977)

solution at pH 6. Even before their experiments, flavor chemists had believed that volatile thiazoles would form in cooked foods because of the presence of thiamin. Arnold et al. (1966) identified benzothiazole in sterilized concentrated milk; this was the first thiazole derivative found in foods. It was rather later that thiazoles were identified in a cooked meat. After 2-acetyl-2-thiazoline was found in beef broth (Tonsbeek et al., 1971), a series of thiazole derivatives was found in cooked meat in the early 1970's (Wilson et al., 1973; Mussinan and Walradt, 1974). The thiazoles and thiazolines found in cooked meat are listed in Table IV. Thiazoles have been considered one of the

main constituents of the meaty flavor and are widely used in imitation meat flavors (Katz et al., 1969; Pittet et al., 1972). The odor properties of food-related thiazoles are well summarized by Maga (1975).

Pyrrroles. Pyrroles have been found in various foods [e.g., coffee; Stoll et al., (1967)], but have not received much attention as a flavor material. In the early 1970's, a pyrrole derivative (acetylpyrrole) was reported as a constituent of meat volatiles (Liebich et al., 1972). Soon thereafter, Watanabe and Sato (1972b) identified 2-acetylpyrrole in shallow fried beef. They postulated that this compound was a product of the aminocarbonyl reaction. They also

Table V. Pyrroles Identified in Cooked Meat

compound	cooked meat system	references
pyrrole-2-carboxaldehyde	pressure-cooked pork liver	Mussinan and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
2-acetylpyrrole	roast beef	Liebich et al. (1972)
	shallow-fried beef	Watanabe and Sato (1972b)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
5-methylpyrrole-2-carboxaldehyde	pressure-cooked pork liver	Mussinan and Walradt (1974)
1-acetylpyrrole	pressure-cooked pork liver	Mussinan and Walradt (1974)
2-propionylpyrrole	pressure-cooked pork liver	Mussinan and Walradt (1974)

Table VI. Miscellaneous Heterocyclic Compounds Identified in Cooked Meat

compound	cooked meat system	references
3,5-dimethyl-1,2,4-trithiolane	boiled beef	Herz and Change (1970)
	beef broth	Brinkman et al. (1972)
	pressure-cooked beef	Wilson et al. (1973)
	canned beef	Persson and von Sydow (1973)
	boiled beef	Hirai et al. (1973)
	cooked chicken	Horvat (1976)
2,4,6-trimethylperhydro-1,3,5-dithiazine (thialdine)	boiled beef	Garbusoy et al. (1976)
	beef broth	Brinkman et al. (1972)
2,4,6-trimethyl-s-trithiane	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked beef	Mussinan et al. (1973)
2,2,4,4,6,6-hexamethyl-s-trithiane	pressure-cooked beef	Mussinan et al. (1973)
	pressure-cooked beef	Mussinan et al. (1973)
1,3-dithiolane	boiled beef	Garbusoy et al. (1976)
2-methyl-1,3-dithiolane	boiled beef	Garbusoy et al. (1976)
1,4-dithiane	boiled beef	Garbusoy et al. (1976)
2,4,5-trimethyl-3-oxazoline	boiled beef	Chang et al. (1968)
	boiled beef	Hirai et al. (1973)
	canned beef stew	Peterson et al. (1975)
	boiled beef	Mussinan et al. (1976)
	boiled beef	Chang et al. (1977)
	boiled beef	Chang and Peterson (1977)
	pressure-cooked pork liver	Mussinan and Walradt (1974)
	canned beef stew	Peterson et al. (1975)
	boiled beef	Chang et al. (1977)
	boiled beef	Mussinan et al. (1976)
2,4-dimethyl-3-oxazoline	boiled beef	Mussinan et al. (1976)
	boiled beef	Mussinan et al. (1976)
2,4-dimethyl-5-ethyl-3-oxazole	boiled beef	Mussinan et al. (1976)
2,5-dimethyl-4-ethyl-3-oxazole	boiled beef	Mussinan et al. (1976)
pyridine	canned beef stew	Peterson et al. (1975)
2-methylpyridine	roasted lamb fat	Buttery et al. (1977)
	cooked chicken	Horvat (1976)
	roasted lamb fat	Buttery et al. (1977)
	roasted lamb fat	Buttery et al. (1977)
	roasted lamb fat	Buttery et al. (1977)
	roasted lamb fat	Buttery et al. (1977)
	roasted lamb fat	Buttery et al. (1977)
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	roasted lamb fat	Buttery et al. (1977)
	roasted lamb fat	Buttery et al. (1977)
	roasted lamb fat	Buttery et al. (1977)

reported that 2-acetylpyrrole, furfural, and furfuryl alcohol appeared to add a slightly caramel-like character to the flavor of cooked beef. The pyrroles found in cooked meat are listed in Table V. Mussinan and Walradt (1974) identified five acylpyrroles in the volatile constituents of pressure cooked pork liver. Peterson et al. (1975) identified 2-acetylpyrrole and 2-formylpyrrole, the odor of which was evaluated as GC effluents, in canned beef stew. They concluded that since both of the acylpyrroles found had rather unpleasant, heated plastic or antiseptic odors, these compounds may play a role in the objectionable "retort flavor" of the stew. Pyrroles seem to give an undesirable odor to cooked meat.

Miscellaneous. Table VI shows the miscellaneous heterocyclic compounds found in heated meat products. Some interesting sulfur-containing heterocyclic compounds (in addition to thiophenes, thiazoles, and thiazolines) have been isolated from cooked meat. Herz and Chang (1970) isolated 3,5-dimethyl-1,2,4-trithiolane; this compound has

a sulfide odor in concentrated form, but gives a meaty aroma when diluted. They suggest that this compound is an important contributor to the aroma of boiled beef. Brinkman et al. (1972) isolated and identified a six-membered ring heterocyclic compound which contains S and N in the same ring; 2,4,6-trimethylperhydro-1,3,5-dithiazine (thialdine). They point out that, in view of the ease with which it forms from NH_3 , H_2S , and CH_3CHO , thialdine is almost certainly present in the broth or the headspace and can be considered a contributor to beef broth flavor. Wilson et al. (1973) found two additional polysulfur heterocyclic compounds. Garbusoy et al. (1976) identified five polysulfur heterocyclic compounds (trithiolane, diethiolanes, and dithianes) and suggest that formation mechanism of sulfur compounds by heat-influenced browning reactions in cooked meat include numerous degradation-synthesis processes.

The first reported five-member ring with two hetero atoms, N and O, was 2,4,5-trimethyl-2-oxazoline (Chang

et al., 1968). Hirai et al. (1973) also found this compound but reported that the same compound synthesized in the laboratory did not possess the characteristic aroma of boiled beef. The dehydrogenated compound of an oxazoline (trimethylloxazole) was identified in cooked pork liver by Mussinan and Walradt (1974). The other oxazoles found in cooked meat are summarized by Maga (1978).

Reports on the identification of pyridines in cooked meat appeared rather late compared with those on other heterocyclic compounds. Peterson et al. (1975) identified pyridine for the first time as a meat volatile in canned beef stew. They state that pyridine has a vile odor when concentrated, but when diluted, it has a somewhat bitter, pleasant, roasted note and may play an important role in the more pleasing canned stew flavor notes. 2-Methylpyridine was identified in chicken broth the following year (Horvat, 1976). Buttery et al. (1977) identified 13 pyridines in the basic fraction from the steam volatile oil obtained from roasted lamb fat. They found that roasting the lamb fat at higher temperatures 200 °C gave higher concentrations of pyridine compounds relative to pyrazines. They also reported that the odor threshold of 2-pentylpyridine was 0.6 (0.5–0.7) parts per 10⁹ parts of water and that 2-pentylpyridine has a fatty- or tallowy-like odor in dilute solutions.

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