

This effect was especially pronounced with flakes made from defective raw material and from mash accumulating on drum drier applicator rolls (Table IX) which contained unusually high levels of 2- and 3-methylbutanal (Sapers et al., 1974).

The selection of packaging materials for air-packed potato flakes has been an area of controversy for the potato processing industry. A comparison of flakes packaged in two widely used containers, the metal can and the polyethylene bag, indicated no differences in storage stability at 32° (Table X). Low flavor scores received by these samples after 12 months probably reflect nonenzymatic browning resulting from the high storage temperature used in this comparison. The equivalent performance of metal and polyethylene containers in this study is a consequence of the low bulk density of potato flakes. At this density, the package headspace contains a large excess of oxygen over that required for flake oxidation; the oxygen permeability of the packaging material is not a limiting factor. Of course, this would not apply to nitrogen packed products or to products having a substantially higher bulk density than flakes, both of which would require an oxygen impermeable package.

CONCLUSIONS AND OUTLOOK

The flavor quality of dehydrated potato products is determined by nonenzymatic browning reactions which occur primarily during processing and by oxidative reactions which take place during storage. The extent to which these reactions affect product flavor depends on raw material quality and composition, processing conditions, packaging, the use of additives, and storage conditions.

What are the prospects for materially improving the flavor quality of dehydrated potatoes? Obviously, processors should avoid those practices which result in flavor problems, overdrying being a prime example. Beyond this, an effort should be made to improve the retention of natural potato flavor through process modification. Precooking, cooling, and cooking conditions might be modified to reduce the leaching and degradation of flavor precursors. The development of new drying procedures which minimize heat damage and improve retention of volatile constituents would be advantageous. The addition of synthetic mixtures of important flavor compounds and precursors might be beneficial. Finally, more effective means to prevent oxidative rancidity during storage are needed. A reduction in the cost of nitrogen packing or the development of more effective antioxidants and synergists might serve this end.

Improvements in these areas might have broad application and would benefit both the food processing industry and the consumer.

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A Review of Thermally Produced Imitation Meat Flavors

Richard A. Wilson

The evolution and current state-of-the-art of thermally produced imitation meat flavors are reviewed and discussed with particular emphasis on

the patent literature with respect to flavor precursors and possible routes of formation of flavor components.

Thermally produced imitation meat flavors are often described in the patent literature as "processed meat flavors" because they are the result of the thermal processing of a

mixture of food components which possess to varying degrees the organoleptic properties of cooked meat. They arose as a response to a need in the food industry for inexpensive, stable products of consistent, controllable quality which would provide flavors suggestive of cooked meats. These products have enjoyed an increasingly wide application as consumer acceptance and food legislation have per-

International Flavors and Fragrances, Inc., Union Beach, New Jersey 07735.

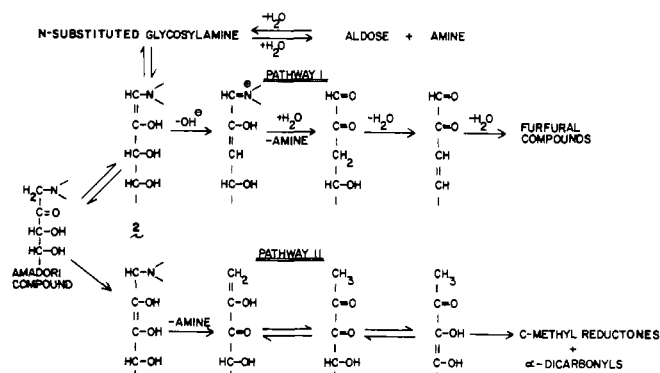


Figure 1. Pathways of flavor chemical production from nonenzymatic browning (Hodge, 1967).

mitted their use as partial or total meat replacement items in processed foods. The growing demand throughout the world for high protein dietary supplements and food extenders has also engendered a need for flavors which will render these materials palatable. Where quality flavors were already available, as in the fruits and chocolate areas, a small but steadily increasing volume of these products has been marketed. However, to the vast majority of people in the so-called "Developed World", protein is synonymous with meat, and even in less affluent societies, where meat is not a dietary staple, some form of meat-like flavor assistance is often used to perk up an otherwise bland meal of rice, millet, or casava.

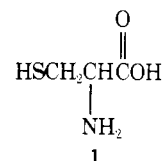
Unfortunately, meat flavors have not as yet attained the degree of sophistication enjoyed by other flavors. This is not a result of lack of effort or incentive but rather reflects the relative complexity of the problem, and the frequency of documentation of research reports in this field attests to the intensity of effort being applied to the providing of unique flavoring agents which are closing the gap between the obviously artificial and the pleasingly natural-tasting.

The first synthetic meat flavors were, undoubtedly, skillfully blended spices that were, and still are, used in processed meats. Once the importance of monosodium glutamate and the 5'-nucleotides was recognized and these materials became commercially available, they were combined with spices to supply a portion of the brothiness of meat and to enhance the flavor of the natural meat. The introduction of high quality hydrolyzed vegetable proteins which were then combined with the nucleotides and spice blends represented the first formulations which exhibited characteristic meaty notes. There is no doubt that flavors based on hydrolyzed vegetable protein are far from duplications of meat extract, but they have served their purpose and were the obvious products of an industry reliant upon subjective evaluation and operating from a limited analytical data base. The subsequent need for improved meat flavors elicited an extensive research effort which has assumed one or more of the following approaches: (A) analysis of the flavor components of cooked meat; (B) analysis of precursor components; (C) analysis of the flavor components of heated model systems; (D) systematic evaluation and application of heated model systems, resulting in processed meat flavors.

Early investigations of meat flavor, lacking many of the sophisticated tools and techniques we take for granted today, often resulted in conflicting and confusing observations. But one thing on which almost everyone has been in agreement is that raw meat must be heated before it develops any organoleptically acceptable flavor. The quality of that flavor is dependent on many factors, the interrelationships of which are as complex as the aroma composition of the product. Additionally, it has been shown that the pre-

cursors of cooked meat flavor are water soluble, of low molecular weight, and, when partially purified, rather unstable, spontaneously undergoing reactions suspiciously suggestive of Maillard browning.

Since meats were known to be excellent sources of potential Maillard reactants, it was only a matter of time before a report of one of the apparently many possible flavor contributing combinations appeared in the patent literature. The flood of grantings and applications which followed the disclosure (May, 1960) of the reaction of cysteine (1) with reducing sugars is well known, and the purpose of this presentation is to discuss some of the possible chemistry involved in these reactions with regard to the formation of aroma compounds which may contribute to the claimed meatiness.



Hodge (1967), in his review on the chemistry of nonenzymatic browning, states that flavor production proceeds via three pathways. The reaction sequence is initiated by the formation of the glycosylamine as shown in Figure 1. Enolization to the 1,2-enamine (2) then permits either pathway I resulting in furfural compounds or pathway II, via the Amadori rearrangement, which yields a variety of compounds including α -dicarbonyls. Both routes thus provide active reagents for pathway III, the Strecker degradation of α -amino acids, resulting in aldehydes of one less carbon atom and nitrogen-containing heterocyclics such as pyrazines. The flavor chemicals resulting from the first two pathways are believed to be derived primarily from the carbohydrate source with the amino moiety functioning in the capacity of a catalyst (Hodge, 1967).

It is noteworthy that the Unilever scientists chose cysteine as their preferred Maillard reactant. Of the α -amino acids known to occur in meats cysteine and its dimer cystine appear to yield the meatiest odors when subjected to thermal processing. The detailed role of individual amino acids and sugars in the production of meat flavor in situ remains to be determined; however, in view of the proposed Maillard mechanisms, the unique role of cysteine must be due to (1) its Strecker products per se; (2) the reaction of these products with themselves or with other species; (3) products and their subsequent reactions resulting from the thermolytic decomposition of the amino acid itself, (4) combinations of these.

It must be stated at this point that any attempt to extrapolate from the chemistry of model systems to that of meat is difficult to substantiate due to the obvious complexity of the latter. But it is reasonable to suggest that reactions and their products observed in the one may occur in the other, though they may not predominate or may require different temperatures.

Wasserman (1972) has pointed out that "The aroma of stewed or braised meat heated at 100° differs from that of the same meat roasted with dry heat at 190°." Recent reports from our laboratory (Mussinan et al., 1973; Wilson et al., 1973) also indicate that in a sealed system an aqueous stirred beef slurry must attain a temperature of approximately 160° before the aroma can be described as "roasted". Wasserman (1972) goes on to say "... that when meat is roasted at 190° the internal temperature varies from about 60° for rare meat to 80° for well-done meat." He concludes that "The flavor of roast meat ... is derived essentially from the surface."

Fujimaki et al. (1969) and Kato et al. (1973a), studying the pyrolysis of cysteine, observed no odor at 150° and a weak popcorn, sesame-like odor at 200° and higher. The

Table I. Cysteine Pyrolysis Products

Ammonia	2-Ethyl-5-methylpyridine
Hydrogen sulfide	2-Ethylthiazole
Ethylamine	Thiophene
Cystamine	2-Methylthiophene
Acetaldehyde	3-Methyltetrahydrothiophene
Ammonium carbonate	2, 3- and 2, 5-Dimethylthiophene
Orthorhombic sulfur	2(3)-Ethylthiophene
Alanine	2, 3-Dihydro-4(5)-ethylthiophene
Isoleucine	2-Methyl-3(4)-ethylthiophene
Methionine	2, 3, 5-Trimethylthiophene
2-Methylthiazolidine	3-Methyl- <i>n</i> -propylthiophene
2-Methylthiazoline	2, 4-Dimethyl-5-ethylthiophene
α -Picoline	

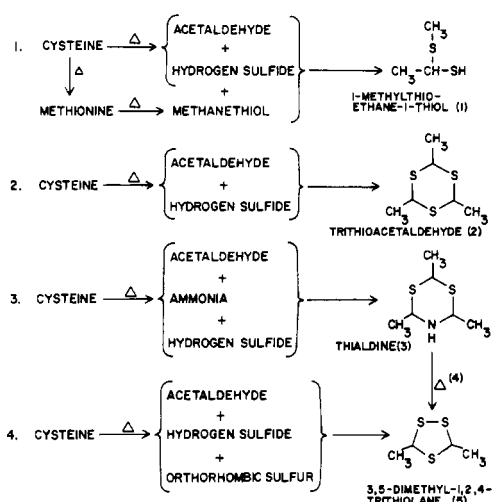


Figure 2. Possible routes of formation from cysteine of volatile beef flavor components: (1) Schutte and Koenders, 1972; (2) Wilson et al., 1973; (3) Brinkman et al., 1972; Wilson et al., 1973; (4) Wilson and Katz, 1974; (5) Chang et al., 1963.

compounds which occurred between 270 and 300° are listed in Table I. Although any food system heated to these temperatures would be organoleptically unacceptable, one cannot reject the possibility that at normal processing temperatures in a more complex system sufficient quantities of some of these reactive species are formed to initiate a chain of reactions culminating in the production of flavor chemicals. Some simple examples yielding highly odorous substances which have been reported in the recent literature as components of cooked beef volatiles are shown in Figure 2.

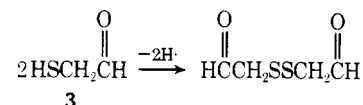
In the presence of reducing sugars or α -dicarbonyls, however, reaction can be initiated at much lower temperatures. Kobayashi and Fujimaki (1965) identified hydrogen sulfide, acetaldehyde, and mercaptoacetaldehyde in refluxed aqueous cysteine-ninhydrin. At 160°, in the reaction with glucose, Kato et al. (1973b) isolated several alkylated pyrazines, furan derivatives, and other products of Maillard process I as well as carbohydrate thermal decomposition products. They commented on the weak, "sesame", "rice-cracker" odor of the product instead of the anticipated meatiness. It is possible that their results are due to the conditions of reaction for they heated only 5 min in the dry state. Palamand et al. (1970), on the other hand, heated 40% aqueous solutions of cysteine with methyl glyoxal for 30 min. They observed "meaty", "popcorn", and "fried onion" aromas at 100° and wood spirit, pyrazine, onion odors at 200°. It is interesting that they found most of the reaction products to be high boiling though completely ethanol soluble and yet not easily gas chromatographed. Re-

Table II. Heterocyclic Classes Identified in Cysteine-Sugar Reactions

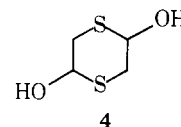
Oxygen	Nitrogen	Sulfur
Furans	Pyroles	Tetrahydrothiophenes
Lactones	Pyridines	Dihydrothiophenes
	Pyrazines	phenes
Sulfur-nitrogen	Mixed bicyclic	Thiophenes
Thiazolidines	Bis(2, 2'-furyl-thiazole)	Thiolactones
Thiazolines	<i>n</i> -Furfurylpyrrole	Dithiolanes
Thiazoles		Trithiolanes
Dithiazines		Dithianes
		Trithianes

cent publications (Ledl and Severin, 1973, 1974; Kleipool and Tas, 1973, 1974; Mulders, 1973) have greatly expanded the list of volatile heterocyclic compounds identified in cysteine-sugar reactions. Some of the classes of chemicals which they reported are shown in Table II.

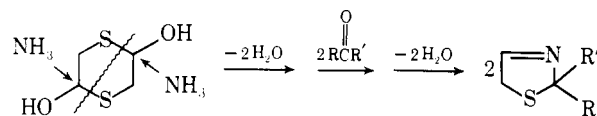
Palamand et al. (1970) suggested that the key to flavor formation lay in the high reactivity of the cysteine Strecker products, mercaptoacetaldehyde (3) and the enaminol. He



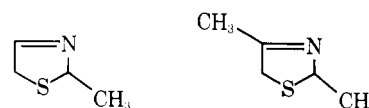
postulated that the former might readily dimerize and he predicted that this dimer would also possess a high degree of reactivity.



An alternate dimer, 2,5-dihydroxy-1,4-dithiane (4), is the subject of a patent (Broderick and Linteris, 1960) which also utilizes acetal and mercaptal forms of mercaptoacetaldehyde for synthetic meat flavors. A particularly interesting version is the hemimercaptal of xylose and mercaptoacetaldehyde. The cyclic dimer can be prepared in the laboratory (Hromatka and Haberl, 1954), presumably via mercaptoacetaldehyde, in high yield. It is stable at its melting point of 151° but dissociates to the monomer during distillation redimerizing on cooling (Hesse and Jörder, 1952). However Assinger and Thiel (1958) discovered that, at room temperature, it behaves essentially as the monomer to nucleophilic attack resulting in 2-substituted- Δ^3 -thiazolines in the presence of ammonia.



Dubs and Pesaro (1974) have patented a series of 2-alkyl- Δ^3 -thiazolines for use as flavoring agents. They are described as generally "green vegetable"-like. C. J. Mussinan (1973, unpublished data), in our laboratories, has reported what is believed to be the first identification in foods of representatives of this species.



One wonders, faced with the reported high yields of the synthetic products, why the Δ^3 -thiazolines are not more prominent in roasted meat and processed cysteine flavors.

Table III. Potentially Reactive Thiamine Degradation Products

Elemental sulfur	3-Acetyl-3-mercaptopropanol
Hydrogen sulfide	4-Methyl-5-vinylthiazole
3-Mercaptopropanol	

A possible explanation is the observation by Assinger et al. (1960) that they can be thermally dehydrogenated in the presence of elemental sulfur to the corresponding thiazoles, many of which have been recently identified in these systems. Assinger's studies on the chemistry of α -mercapto-carbonyls and Δ^3 -thiazolines suggest several additional interesting reactions the products of which await identification in flavor research.

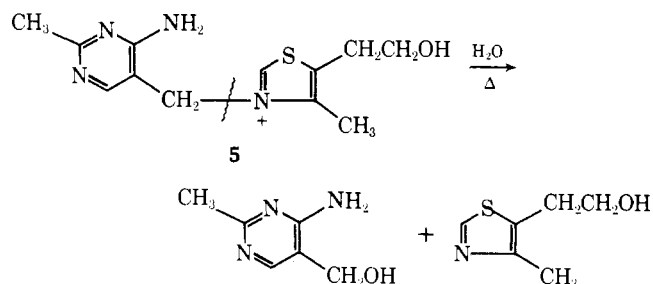
Another possibility was proposed by Mulders (1973) to account for the formation of 5-methyl-2-thiophenecarboxaldehyde and 3-methyl-2-thiophenecarboxaldehyde in the reaction between cysteine and ribose. Roasted beef and high temperature cysteine-sugar reactions yield a large number of thiophene derivatives as well as the compounds already discussed. An additional likely source might be attack by hydrogen sulfide on carbonyls generated from carbohydrates during Maillard browning (Schutte, 1974) to form the thio analogs of the well-known furan derivatives.

It is thus obvious that a great variety of potential flavor chemicals, including many which have appeared in recent reports on the analysis of cooked meat volatiles, can arise from cysteine based systems. It is the author's conviction that, as analytical procedures improve, disclosures of potent new substances derived from pyrolyzed cysteine and cysteine-sugars will closely parallel analytical results of cooked meat flavor.

Many combinations of ingredients and cooking parameters based around the central component of cysteine have been formulated subsequent to the initial disclosure and are the subject of recent patents (Wilson and Katz, 1974). It is readily demonstrable that the inclusion of reducing sugars supplies a characteristic roasted-burnt note which is both highly desirable and, at the same time, difficult to obtain in their absence. In the continuing search for substitute materials which might contribute some of these desirable flavor notes, some very interesting reaction products have been proposed.

Several patents seek to provide carbohydrate from other sources such as ribose 5-phosphate (Kyowa Hakko Kogyo Co., Ltd., 1968), 5'-nucleotides (Tonsbeek, 1971; Perret and McMahan, 1966; O'Hara et al., 1970), or yeast autolysate (Mosher, 1973). Others, recognizing the unique contribution to meat flavor of sulfur compounds, have sought alternate means of providing these reactive and/or odorous agents. Among these are the patents (Giacino, 1968; Bidmead and Giacino, 1968) based upon cysteine and thiamine in a carbohydrate-free system.

Investigations of the thermal decomposition products of thiamine (5) were stimulated in the 1950's primarily out of concern regarding retention of its vitamin activity. This and subsequent work have been recently reviewed by Dwivedi and Arnold (1973). When thiamine is simmered in water under acid or neutral conditions it undergoes simple



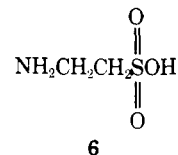
cleavage. The pyrimidine moiety apparently does not play an important role in flavor production. At least no chemical of potential flavor value which could be traced to it has, as yet, been reported. The thiazole alcohol portion, however, is quite interesting. Depending upon its state of purity and age the author has found it to have organoleptic properties describable as smooth, meaty, sweet, woody, smokey, sharp, pungent, biting, harsh, or disagreeable. The decomposition products responsible for these flavor characters are extremely potent, organoleptically detectable at quite low levels, and not amenable to gas-liquid chromatographic analysis.

Under varying conditions of degradation, researchers have shown (Dwivedi and Arnold, 1973) that thiamine can yield the potentially reactive species shown in Table III. Little need be said concerning the flavor value of hydrogen sulfide and its role in the formation of potent sulfur compounds. Elemental sulfur has been shown to be essential for the creation of many cyclic and acyclic di-, tri-, and polysulfides. 3-Acetyl-3-mercaptopropanol may be expected to possess to some degree the chemical properties of its simplest homolog, mercaptoacetaldehyde, as well as the extremely potent aroma character of simple α -mercapto ketones. 4-Methyl-5-vinylthiazole, isolated by Stoll et al. (1967) from 4-methyl-5-(β -hydroxyethyl)thiazole and roasted cocoa distillate, was described as having a strong nut-like aroma.

That much remains to be resolved with regard to the role of thiamine in these processed flavors is evident. One example of a flavor component derived from thiamine is a crystalline substance described by Morfee (1969) as possessing a pleasant cooked odor. It would also be of interest to determine if thiamine supplies any reactive nitrogen-containing species.

Other potential sulfur-containing precursors which have found application in processed meat flavors include egg protein (CPC International Inc., 1973; Theron et al., 1970), 5-acetylmercaptosuccinic acid (Mosher, 1973), methionine (van Pottelsberghe de la Potterie, 1973; Toyoda et al., 1973), taurine (Hack and Konigsdorf, 1969; Giacino, 1970), alkyl mercaptans (Yamamoto et al., 1970), mercaptoalkylamines or amine sulfides (Ohwa et al., 1972), thiocarbonates, thioamides, and 2-mercaptoalkanoic acids and their amides (Schutte, 1974).

The use of methionine would appear to be limited to flavors in which the "potato skin" odor of methional and the "green vegetable" odor of methyl mercaptan and methyl disulfide are either suppressed, covered, tolerable, or desired. An example of the last may be found in its use by Takeda Chemical Industries Ltd. in conjunction with trimethylamine oxide, serine, and threonine to produce a roasted, dried cuttlefish flavor (Toyoda et al., 1973).



Taurine's (6) role in flavor production is somewhat of a mystery. Although it is found in a wide variety of foods, no sulfur containing flavor components can be traced to it. Mecchi et al. (1964) reported that it is not a precursor of hydrogen sulfide. Hack and Konigsdorf (1969) describe a processed flavor comprising a cysteine-free amino acid mixture, taurine, and reducing sugars as a replacement for natural meat extract. If cysteine and thiamine are added to this system a product results which is described as characteristically "cooked chicken" (Giacino, 1970). The invention also states that taurine may act as a partial replacement for cysteine which implies that it functions as a precursor.

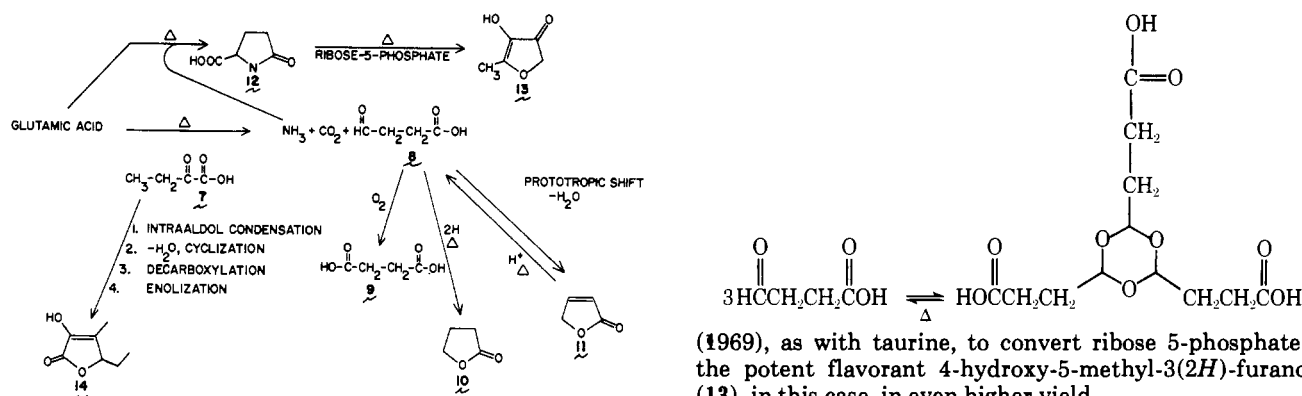


Figure 3. Possible pathways of flavor chemical formation in glutamic acid-nucleotide- α -ketobutyric acid system.

One possible role of taurine in thermally produced imitation meat flavors was alluded to in the report of the formation of 4-hydroxy-5-methyl-3(2H)-furanone, a beef flavor contributing component (Tonsbeek et al., 1969), in a heated ribose 5-phosphate- α -ketobutyric acid system. Not only have this product and its 2,5-dimethyl homolog turned out to be powerful flavoring agents with a wide range of applications, but they, in turn, may act as meat flavor precursors in processed flavors as exemplified by the patent (van den Ouweland and Peer, 1973) involving their reactions with hydrogen sulfide. It should be noted that taurine cannot function in this capacity in the system described in the Hack and Konigsdorf (1969) patent due to the absence of hydrogen sulfide or its precursor.

Along with the constituents described to this point, several patents utilize hydrolyzed vegetable protein. There are many varieties of this commodity commercially available, no two of which appear to possess the same flavor. Some are essentially free of reducing sugars, and therefore would contribute negligible Maillard-type flavors, while others are deeply roasted, almost burnt. All are characterized by high salt contents and a broad spectrum of amino acids including cysteine and glutamic acid. Therefore, it may be concluded that not only do hydrolyzed vegetable proteins serve as flavoring agents themselves, but they act as rich sources of flavor precursors for thermal processing in the presence of other reactants. One patent might be cited (Perret and McMahan, 1966) which, although it did not include hydrolyzed vegetable protein as a reactant, is of interest because it suggests itself as producing a hydrolyzed vegetable protein type of flavor. The reactants in this case are nucleotide, glutamate, and α -ketobutyric acid (7). If one accepts nucleotide as a source of ribose or its phosphate, some interesting chemistry can be postulated as outlined in Figure 3.

Glutamic acid may undergo Strecker degradation in the presence of α -ketobutyric acid to form succinaldehydic acid (8), carbon dioxide, and ammonia. That α -ketobutyric acid can perform as an effective α -dicarbonyl in the Strecker degradation can be inferred from the observation by Schönberg and Moubacher (1952) that its lower homolog, pyruvic acid, can so function. Although succinaldehydic acid occurs in several edible plants, no mention can be found of its isolation from flavor volatiles, quite possibly due to its tendency to reversibly trimerize (Tsybina et al., 1970). Aside from its unknown flavor contributions per se, it should be readily convertible to succinic acid (9) by oxidation, γ -butyrolactone (10) by reduction and lactonization, and crotonolactone (11) by prototropic shift and lactonization. The ammonia derived from the Strecker degradation permits the lactamization of glutamic acid via glutamine to pyrrolidone-5-carboxylic acid (12), which, although not of flavor value, has been shown by Tonsbeek et al.

(1969), as with taurine, to convert ribose 5-phosphate to the potent flavorant 4-hydroxy-5-methyl-3(2H)-furanone (13), in this case, in even higher yield.

α -Ketobutyric acid has been isolated from acid hydrolysates of proteins (Franck and Knoke, 1957) and has been traced to threonine (Wieland and Wiegandt, 1955). Several investigators in the 1950's regarded it as an essential contributor to hydrolyzed vegetable protein flavor; however, Sulser et al. (1967) showed that the flavor character developed only on aging and was due to the formation of α -hydroxy- β -methyl- $\Delta^{\alpha,\beta,\gamma}$ -hexenolactone (14), the flavor of which has been described as extraordinarily intense, typical of seasoning and bouillon preparations.

In summary, it may be concluded that thermally produced imitation meat flavors arise as the result of a diversity of chemical reactions many of which remain to be described. This chemistry, in many instances, may parallel that which operates in natural food systems, and its unraveling will permit the production of superior flavors for meat analogs.

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Chemical Changes Associated with Flavor in Irradiated Meat

Charles Merritt, Jr.,* Pio Angelini, Eugene Wierbicki, and Gary W. Shults

Chemical changes in meat that have been treated with ionizing radiations have been well documented. The recent development of new improved analytical methods employing combined gas chromatography and mass spectrometry systems with digital outputs permits computer processing of both qualitative and quantitative data. Precise determination of the variation in the amounts of components with various treatment conditions such as dose and temperature has now been made

and correlated with sensory observations. The irradiation flavor increased and overall acceptance decreased with an increase in dose and/or irradiation temperature. Correspondingly, analyses of volatile compounds show increases of amount with increases in dose or irradiation temperature. When the proper conditions of dose and temperature are employed, however, wholly acceptable products that are both safe and savory can be produced.

Irradiated foods are not yet commodities of the market place. Their development, however, has progressed so successfully that it is currently expected that they shall become commercial items. It is appropriate, therefore, that a paper dealing with the flavor of irradiated meat be included in this symposium.

In the early days of the development of irradiated meat products there were changes induced that were frequently described as "off" odors and flavors (Batzer and Doty, 1955; Batzer et al., 1957). It has been generally acknowledged that these changes are primarily due to the formation of volatile compounds from lipid (Merritt et al., 1966; Dubravcic and Nawar, 1968; Champagne and Nawar, 1969) and protein precursors (Merritt, 1966; Merritt et al., 1967a) and there has been a continuing study of these changes for several years (Josephson and Merritt, 1972), so that the nature of the chemical changes which occur due to irradiation processing is now very well known. The understanding of the basic chemistry has been achieved mainly by qualitative analysis of the trace volatile components by combined GC-MS techniques (Merritt, 1970, 1972). Recent developments employing a digital computer system to GC-MS output now provide accurate quantitative data as well (Merritt et al., 1974). The precise determination of the variation in the amounts of components with various processing conditions such as dose or temperature now permits the correlation of chemical changes with sensory observations.

The results of these studies have led to developments in processing techniques so that contemporary meat products

have very little so called irradiation flavor and are wholly acceptable consumer items.

EXPERIMENTAL SECTION

The techniques by which the chemical analyses are carried out have been described previously in detail in a number of publications (Angelini et al., 1967; Merritt et al., 1959, 1966, 1967a,b, 1970, 1972, 1974). The analytical scheme used in the current study may be summarized as follows. The trace volatile compounds are separated from the meat by a high vacuum distillation at room temperature into a receiver at liquid nitrogen temperature. The total condensate thus collected is further fractionated by high vacuum distillation at -80° into so called water and carbon dioxide fractions. Each of these fractions is then analyzed by combined GC-MS techniques. The output of the GC-MS system operating in a repetitive scan mode is digitized directly by a minicomputer to provide mass spectra for each successive scan. These data are transferred to a laboratory automation computer which performs component identifications, produces reconstructed chromatograms, computes component amounts, and carries out correlations or any other data processing that may be required. (The current system has been upgraded from that described by Merritt et al. (1974) and now utilizes a Digital Equipment Corp. PDP 15/76 system as the main processor.) The current results to be described later have been achieved largely through the use of this computer system.

RESULTS AND DISCUSSION

The knowledge and understanding of the chemical changes which occur in meat as a result of irradiation have been acquired through a large number of studies by many workers extending over several years (Merritt, 1966, 1970;

* Food Sciences Laboratory, United States Army Natick Laboratories, Natick, Massachusetts 01760.