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MEAT FLAVOR GENERATION IN EXTRUDED SOY PROTEIN PRODUCTS

By

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ABSTRACT

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Meat flavor generation in extruded soy protein products via pre-extrusion addition of flavor precursors was investigated. The extrudates were comparatively examined for their sensory properties, volatile components, and their application in ground beef loaves.

The synthetic meat flavors (HH, SW) thermally generated from flavor precursor systems were found to be superior to the commercial beef samples (BV, MM, HO, GG) and comparable to the natural beef flavor (BE). The dominant nonmeaty aroma qualities of HH, HO, and BE, were "Toasted/Burnt", "Spicy/Fragrant" and "Cooked Vegetables", and "Flat/Dull", respectively and were higher than ideally desirable. The precursor system of HH and HO were selected for subsequent extrusion study.

The pre-extrusion addition of flavor precursors in the soy extrudate (15HH) resulted in a moderate, but significant improvement in "Meaty" flavor when compared to the unflavored product (UFC). No difference in meatiness was found between 15HH and the commercial beef flavored extrudate (15HO). Neither flavor systems was entirely successful in masking the off-flavors of soy protein products. Except for saltiness, no differences in "Roasted", "Sweet", "Green", "Beany" and "Bitter" notes were found among the extrudates. They were scored lower in "Meaty" flavor but higher in "Green"/"Beany" notes than ideally desirable. Subtle differences in some physicochemical

properties were observed among the samples.

By gas chromatography-mass spectrometry, the volatile components of 15HH (59 identified) was found to consist mainly of aldehydes, ketones, thiols, and pyrazines, of UFC (55) was predominantly pyrazines, and of HH (29) was aldehydes, alcohols, and acids. When compared to UFC, substantial increases in 2-/3-methylbutanal, 2-pentanone, and dimethyltrisulfide and the generation of several new heterocyclics were evident in 15HH and their implications to the perceived meaty flavor were discussed.

When compared to the UFC-substituted products, substitution with 15HH at 30-60% had a significantly positive effect on the aroma and color, but a limited effect on the flavor of ground beef loaves. The juiciness and mouthfeel of the products were adversely affected by increasing levels of soy-substitution. In contrast to the all-beef control, all soy-substituted products had higher cooking yields and moisture, lower fat, and enhanced oxidative stability.

Dedicated to
my daughter, Samantha

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INTRODUCTION

Textured soy protein products (TSPs) are protein-rich items that have been modified in appearance, texture and flavor to simulate conventional foods, especially meat items (Kinsella, 1983). They are available today as extruded granules or chunks, spun fibers, and heat-coagulated protein pieces (Wolf, 1970; Ritter, 1978; Kinsella, 1983). It is estimated that 95% of TSPs are currently made by the extrusion process (Kinsella, 1983). Therefore, it is generally assumed that TSPs refer to structured protein products produced by various extrusion processes.

Basically, extrusion involves metering moistened proteinaceous material via a screw, through a heated barrel ending in a restricted aperture termed a die. During extrusion, proteinaceous material is cooked and plasticized by a combination of pressure, heat, and mechanical shear. Extrudate emerging from the die undergoes an exothermic expansion yielding a relatively dry, porous product which assumes a chewable texture upon hydration in water (Williams et al., 1977).

TSPs are widely used as meat extenders in comminuted meat items (such as sausages, frankfurters, and bologna), and other meat products (for example, meat patties, meat loaves, and salisbury steak) (Kinsella, 1983). Advantages of extending ground meat with TSPs include lower fat content, increased moisture retention, improved

tenderness, reduced shrinkage during cooking, inhibition of rancidity, and considerably lower cost (Schweigert, 1974; Langsdorf, 1981; Berry et al., 1985; Kotula and Berry, 1986). Because of these beneficial properties, the USDA's National School Lunch Program has permitted the use of up to 30% of hydrated TSP with 70% of ground meat as an acceptable meat alternative since 1971 (Rakosky, 1974; Bodwell, 1983).

Hammonds and Call (1970) forecasted that TSPs would account for 10% of domestic meat consumption, that is, around 2 billion lbs/year by 1985. In 1972, it was predicted that 2 to 4 billion lbs of hydrated ground meat extenders would be in use by 1980 (Bird, 1974). In retrospect, this prediction was grossly over-inflated, and since 1972, there has been relatively little movement in volume (Kinsella, 1983).

The major factor preventing the widespread use of TSPs as meat extenders has been attributed to its unsatisfactory flavor (Cowan, 1973; Sutton, 1978; van den Ouweland and Schutte, 1978; Rackis et al., 1979; Kinsella, 1983; Kinsella et al., 1985). Soy protein products often have a characteristic off-flavor, which has been described as green/grassy and beany. When the meat formulation is prepared with insufficient seasonings to mask the off-flavors, consumers often find these foods objectionable (Kinsella, 1983).

This research was undertaken to investigate the use of thermal extrusion of defatted soy flour containing meat flavor precursors as a means of improving the flavor of soy protein products. This study was based on the hypothesis that since extrusion uses heat, the flavor precursors should react during processing to produce the desirable

flavor components. The objectives of this study were:

- (a) To select a meat flavor precursor system for the extrusion study by sensorially evaluating the aroma qualities of selected meat/beef flavors;
- (b) To investigate the effects of pre-extrusion addition of meat flavor precursors on the sensory properties of soy extrudate;
- (c) To examine the effects of added meat flavor precursors on the formation of desirable flavor components in soy extrudate; and
- (d) To evaluate the application of the flavored soy extrudate on the quality characteristics of ground beef loaves at increasing levels of soy-substitution.

LITERATURE REVIEW

Soy protein products (SPPs) (soy flours/grits, concentrates and isolates), particularly, textured soy protein products (TSPs), have received major attention as potential substitutes for meat proteins (Kinsella, 1983). However, flavoring is still a major obstacle to more widespread use of SPPs (Kinsella, 1983).

Meat flavors added to TSPs as meat extenders/analogues must not only impart the desired positive meat-like flavor while allowing for uneven adsorption or release during processing, storage and consumption, they must also mask the formidable assortment of off-flavors associated with SPPs (van den Ouweland and Schutte, 1978; Heinze et al., 1978; Schutte and van den Ouweland, 1979; Kinsella and Damodaran, 1980; Palkert, 1980; Kinsella, 1983).

Due to the diversity of the aforementioned subjects, this review will attempt only to cover the pertinent information and significant/current findings of these interrelated topics.

Off-flavors in Soy Protein Products

Numerous authors have reviewed the off-flavors present in SPPs (Maga, 1973; Cowan et al., 1973; Wolf, 1975; Eskin et al., 1977; Sessa and Rackis, 1977; van den Ouweland and Schutte, 1978; Heinze et al., 1978; Rackis et al., 1979; Kinsella and Damodaran, 1980; Kinsella, 1983). Thus far, there has been only one published sensory and

analytical report which examined the compounds responsible for off-flavors in TSPs (Palkert, 1980). Generally, it is assumed that the off-flavors of TSPs and soy flours are identical and derived from the same compounds.

Some of the off-flavors in SPPs are associated with the carbonyls and scission products of the hydroperoxides formed via the action of lipoxygenase on polyunsaturated fatty acids, especially linoleic and linolenic acids (Wolf, 1975; Sessa et al., 1979; Rackis, 1979; Kinsella and Damodaran, 1980).

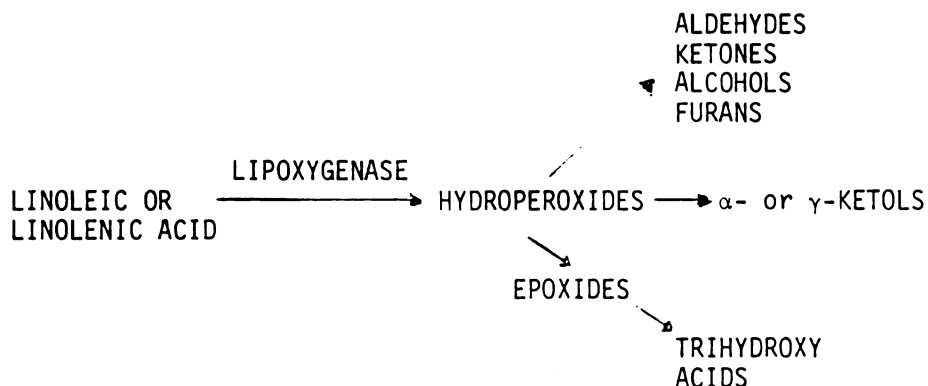


Figure 1. Off-flavors in soy protein products from linoleic or linolenic acids as catalyzed by lipoxygenase (adapted from Kinsella and Damodaran, 1980).

The descriptors most commonly associated with off-flavors in SPPs are green/grassy, beany, and bitter (Kalbrenner et al., 1971). Processing may accentuate or cause the development of off-flavors described as toasted, astringent, cardboardy and mealy (Kalbrenner et al., 1971). Other off-flavors which have been noted in SPPs include sweet, cooked soybean, burnt, catty, and fusel (Schutte and

van den Ouweland, 1979). The important sensory notes in TSPs are beany, cereal, and roasted (aroma), and cereal, beany, and sweet (flavor) (Palkert, 1980). These descriptors are listed in order of importance.

Green, Grassy and Beany Flavor

It is generally felt in the food industry that green, grassy and beany flavor of TSPs is perhaps its most important flavor defect (Palkert, 1980). This off-flavor apparently arises primarily from the oxidation of linoleic acid in the soy flour (Rackis et al., 1979).

Isopentanol, hexanol, heptanol, hexanal, cis-3-hexenal, 2-heptenal, 2,4-decadienal, ethyl vinyl ketone, n-pentylfuran, cis- and trans-2-(1-pentenyl)furan have all been credited with contributing to the green/beany flavor of SPPs (Goossens, 1974; Dutton, 1978; Rackis et al., 1979; Kinsella and Damodaran, 1980) (Table 1). During thermal processing, cis-3-hexenal can readily isomerize to trans-3-hexenal which possesses an oily grassy flavor (Sessa and Rackis, 1977).

The flavor thresholds of the contributors to green/beany flavor in SPPs are presented in Table 1. These values may be an order of magnitude less when tested in a non-oily medium (Rackis et al., 1979; Kinsella and Damodaran, 1980). For example, Kinsella (1969) reports a 3-fold difference in flavor threshold values of cis-3-hexenal in oil (0.15 parts per million (ppm)) versus milk (0.05 ppm) and a 25-fold difference for trans-2-hexenal with 2.5 ppm in oil versus 0.1 ppm in skim milk. The threshold value for the grassy, beany flavor associated with raw defatted soy flour in aqueous dispersion is approximately 300 ppm (Kalbrenner et al., 1971) which seems high, but may reflect its

Table 1. Compounds that produce green-beany flavor in soy protein products: their contributions and flavor thresholds^a.

Compound	Flavor Description	Threshold (ppm in oil)		
		Odor	Taste	Reference
n-Hexanal	Green, grassy	0.32	0.15	Grosch (1975)
cis-3-Hexenal	Green, grassy	0.11	0.11	Chang et al. (1966)
Ethyl vinyl ketone	Green, beany	5(milk)		Mattick and Hand (1969)
n-Pentylfuran	Beany	2	1-10	Chang et al. (1966)
2-(cis-1-Pentyl)furan	Beany	8	8	Ho et al. (1978)
2-(trans-1-Pentyl)furan	Beany	1	1	Ho et al. (1978)
n-Pentanol ^b				Arai et al. (1970)
Isopentanol ^b				
n-Hexanol ^b				
n-Heptanol ^b				

^aAdapted from Rackis et al. (1979).

^bPostulated to contribute or enhance the green-beany flavor of soy protein products.

binding to the protein.

Although the triglycerides in soybeans undergo considerable transformation in composition during maturation, the characteristic green, grassy, and beany flavor does not vary in intensity (Rackis et al., 1972). This would indicate that minimal oxidation of the highly unsaturated lipids by lipoxygenase may be enough to initiate formation of this flavor.

Recently, supercritical carbon dioxide (SC-CO₂) has been used in the extraction of soybeans and full-fat soy flakes (Friedrich et al., 1982, 1984; Friedrich and Eldridge, 1985; Eldridge et al., 1986). The usual grassy, beany and bitter flavors of hexane-defatted soy flours were only minimally detectable in the optimally SC-CO₂ (at least 375 kgf/cm² about 85°C, and moisture levels of 10.5 to 11.5%) extracted materials (Eldridge et al., 1986). Conditions could be selected to produce defatted soy flours with acceptable nitrogen solubility indices (>70%) and flavor scores (>6.5 on a scale of 1-strong to 10-bland) (Eldridge et al., 1986).

Bitter Taste

An intensely bitter taste developed when oil-free soy phosphatides were irradiated with ultraviolet light (Sessa et al., 1969). Purified soy phosphatidylcholine (SPC) oxidized in an aqueous suspension developed a bitter taste, whereas hydrogenated SPC similarly treated did not (Sessa et al., 1974). The bitter threshold level of oxidized SPC in charcoal-filtered tap water was calculated to be about 60 ppm (0.006%).

Three oxidized SPCs designated SPC-A, SPC-B, and lyso-SPC were isolated from the residual lipids of hexane-defatted soy flakes (Sessa et al., 1976). A seven-member taste panel found that 0.05% suspensions of SPC-B and lyso-SPC from defatted flakes stored 1 year at 4°C were strongly bitter, whereas SPC-A was rated weakly bitter (Sessa et al., 1976). Based on the above studies and the fact that defatted soy flakes contain at least 0.08% oxidized SPC, Sessa et al. (1976) concluded that oxidized phospholipids was a major cause of the bitter taste of SPP.

Oxygenated (keto, epoxy, hydroxy) derivatives of fatty acids isolated from lipoxygenase-catalyzed oxidation of linoleic acid (Bauer and Grosch, 1977) and dimers formed from acylhydroperoxides also impart a bitter taste. Taste threshold of the various unsaturated tri- and tetrahydroxy derivatives are in the range of 200-1500 ppm (Bauer and Grosch, 1977). The presence of a double bond in these polyhydroxy acids enhances the bitter taste three-fold (Bauer and Grosch, 1977). Since SPC contains a complex mixture of oxygenated fatty acids (Sessa et al., 1977), the content of esterified polyhydroxy fatty acid may account for the range in bitterness of the various SPCs. However, whether soybeans contain free oxygenated fatty acids has not been determined.

During maturation, bitterness in soybeans increases 3- to 4-fold, particularly in the latter stages of maturity. There is also a significant correlation between lipoxygenase activity and the formation of a bitter flavor (Rackis et al., 1979).

Cooked Soybean Odor

Soy flour contains several phenolic compounds with ferulic, coumaric, syringic and vanillic acids being most prevalent (Maga, 1978). Phenolic acids may contribute bitter astringent flavors to soy flour (Arai et al., 1966). However, Rackis et al. (1967) stated that phenolic compounds had little significance in flavor of soy products. Nevertheless, when wet defatted soybean meal is sterilized or heated to high temperature (cooking, retorting), a very unpleasant cooked odor that many consumers find repulsive is generated. The cooked soybean odor is also characteristic of extruded soy flour and canned retorted TSPs (van den Ouweland and Schutte, 1978). This has been attributed to the formation of 4-vinylphenol and 4-vinylguaiacol by the thermal decarboxylation of p-coumaric acid and ferulic acids, respectively (Greuell, 1974). 4-Vinylphenol has a strong smoky aroma and 4-vinylguaiacol tastes phenolic or bitter. These have flavor threshold of around 10-90 ppm (Maga, 1978) and contribute an unpleasant flavor to heated SPP.

Sweet Taste

A significant amount of sucrose (12%) present in defatted soy flour can influence the perceived flavor and, of course, on cooking can give rise to different flavors via the Maillard reaction. Pinitol, a sweet tasting alcohol has been found at a level of 0.3% in defatted soy flakes, and may also contribute to sweetness in TSPs (Honig, 1971).

Burnt Flavor

Under excessive heating and extrusion with high temperatures, a burnt flavor may be formed (van den Ouweland and Schutte, 1978). This

probably arises from the Maillard reaction between the amino acids and sugars (particularly the oligosaccharides) present in defatted soy flour. Qvist and von Sydow (1974) identified a host of compounds including aldehydes, ketones, furans, sulfur containing-compounds, and pyrazines in heated soy protein isolate. It is interesting to note that the concentration of almost all volatiles increases on heating, except for sulfur-containing compounds. All of these compounds could contribute burnt, cereal, nutty and toasted off-flavors to TSPs (Palkert, 1980). Alkyl-substituted pyrazines in deep fat-fried soybeans have been suggested to be responsible for their nutty aroma (Wilkins and Lin, 1970).

Contaminant Flavors

Contaminant flavors may also form in SPPs, particularly in solvent-extracted preparations. Thus, off-flavors like sweet fusel notes or catty odors may arise from the formation of mesityl oxide from traces of acetone and hydrogen sulfide derived from sulfur-containing amino acids. These can be avoided by using purified solvents (van den Ouweland and Schutte, 1978). The myriad of volatile compounds (carbonyls, furans, alcohols, phenolic compounds, browning products and amines) found to be associated with SPPs are compiled and compared with cooked beef volatiles in a later section.

Table 2 presents a condensed version of the significant research findings on the origin, nature, and control of off-flavors in SPP.

Table 2. Origin, nature, and control of off-flavors in soy protein products^a.

Off-flavors	Compounds responsible	Precursors	Prevention/removal
Green, grassy or beany	Carbonyl compounds ^b	Polyunsaturated fatty acids + lipoxygenase	Heating intact beans, hexane extraction
Bitter	Esterified poly-hydroxy fatty acids, fatty acid dimers, oxidized phosphatidylcholine	Phosphatidylcholines	Alcohol extraction
Cooked soybean	p-Vinylphenol, p-vinylguaiacol	p-Coumaric acid, ferulic acid (lignin)	Low heat treatment, alcohol extraction
Sweet	Sucrose, pinitol		Water extraction
Burnt, cerealy, nutty, roasted	Maillard reaction products	Amino acids + carbohydrates	Low heat treatment, water extraction
Catty	4-methyl-4-mercapto-pentanone	Acetone + hydrogen sulfide	Solvent removal
Fusel note	Long chain alcohols		Solvent removal

^aAdapted from Schutte and van den Ouweland (1979).^bSee Table 1.

Flavor Binding in Soy Protein Products

The ability to mask undesirable flavors and simulate the desired meat flavor is significantly influenced by the flavor binding capacity of the protein used (Kinsella and Damodaran, 1980). Better understanding of the binding and release of off-flavors from aqueous and dry soy systems is essential to the development of methods/processes to remove/minimize this flavor and increase the acceptability of SPPs in the marketplace (Kinsella and Damodaran, 1980; Aspelund and Wilson, 1983). In addition, this could aid in the retention of desired flavors in SPPs and could significantly improve the human consumption of SPPs (Schutte and van den Ouweland, 1979; Lyon, 1980).

Soy Protein-flavor Interactions

The problem of binding of flavors to proteins has received limited attention (Gremli, 1974; Beyerly and Solms, 1974; Franzen and Kinsella, 1974; Aspelund and Wilson, 1979, 1983; Damodaran and Kinsella, 1981a,b). Gremli (1974) was the first to systematically study the interaction of saturated and unsaturated aldehydes, phenolic alcohols, and phenolic and heterocyclic ketones with a 5% aqueous soy protein solution. Although all of the aldehydes and most of the ketones studied were bound to some extent by soy protein components, none of the alcohols examined were bound (Gremli, 1974).

The percent retention of the aldehydes increased with increasing molecular weight and unsaturation. The ketones showed a different pattern of binding affinity. For the homologous series of 2-hexanone to 2-decanone binding to soy protein increased with molecular weight, but ketones larger than 2-decanone, showed a reduced affinity for soy

protein. Phenolic ketones were bound by soy protein while low molecular weight ketones containing a furan ring were not bound. Among the compounds examined, only the aldehydes were retained irreversibly to some extent (25-51%). When measuring flavor retention by a 50% soy dough subjected to a high vacuum as a model for a mild drying process, all of the compounds tested including aldehydes, ketones, and even alcohols were strongly retained. However, when the dough was diluted to a 5% solution with water and then vacuum distilled, the ketones and alcohols were quantitatively removed, while the aldehydes were partially removed (Gremli, 1974).

Gremli (1974) rightly points out that his data are not strictly applicable to TSP as TSP is only 50% protein and contains about 35% carbohydrates and 2% lipid which may bind flavor compounds. Secondly, the high temperatures and pressures involved in extrusion likely result in considerable losses of reversibly bound flavors. Thirdly, the denaturation and restructuring of proteins as well as other soy component interactions which occur during extrusion have an unknown effect upon soy protein-flavor interactions.

Arai et al. (1970) quantitatively studied the interaction of hexanal and n-hexanol with native denatured and enzymatically hydrolyzed soy protein. The interaction of hexanal and n-hexanol increased with the degree of denaturation of soy protein and these flavors were not removed by vacuum distillation. The increased binding of these carbonyls by denatured soy protein, compared to native protein, was attributed to the greater exposure of hydrophobic regions in the denatured protein. Arai et al. (1970) further showed that proteolysis of the denatured

protein decreased the amount of hexanal and n-hexanol retained by the protein. These results suggest that the interaction of flavor compounds with proteins is not via mere surface adsorption but through interaction with specific hydrophobic regions in the protein. Using a gel filtration technique, Arai et al. (1970) obtained the binding constants, 173.4 M^{-1} and 80.3 M^{-1} , for hexanal and n-hexanol respectively. These values suggest that the binding is relatively weak, and that the resistance to vacuum distillation cannot be interpreted in terms of strong interactions but possibly to entrapment of these compounds in the solid protein matrix. At saturation levels, the amounts of hexanal and n-hexanol bound to partially denatured soy protein was about 0.847 mg/g and 0.889 mg/g respectively (Arai et al., 1970). Assuming that the molecular weight of soy protein is 100,000, the total number of binding sites, calculated from the above values, in partially denatured soy protein is about one. For an oligomeric protein such as soy protein this value seems to be very low and cannot fully explain the inherent flavor problem in soy protein (Kinsella and Damodaran, 1980).

In a different approach, Beyeler and Solms (1974) calculated the binding constants of a wide variety of flavor compounds to soy protein and bovine serum albumin (BSA) using equilibrium dialysis. They found that the binding constants decreased in the order: aldehydes, ketones, and alcohols. Carboxylic acids, dimethylpyrazine, aniline, and phenylalanine exhibited no affinity for soy protein. Vanillin and p-amino-benzoic acid, which contain more than one functional group, showed complex binding properties. These authors further demonstrated

that temperature (20-60°C) and pH (3.0-7.0) had little influence on the strength of binding. They believed this indicated that both ionic and hydrophobic forces were responsible for soy protein-flavor interactions, with hydrophobic forces being predominant.

The binding constant for 2-butanone to a soy protein isolate at 20°C and pH 7.0 was estimated to be 5174 M^{-1} (Beyeler and Solm, 1974). This value seems to be very high when compared to that for hexanal obtained by Arai et al. (1970). This may be attributed to inadequate methods and inappropriate systems used by Beyeler and Solm (1974) (Kinsella and Damodaran, 1980).

Beyeler and Solm (1974) surprisingly also found that BSA and soy protein showed very similar affinities for the same flavor compounds. They attributed this to the fact that both proteins have the same average hydrophobicity, and thus, infer that binding is primarily due to hydrophobic interactions. However, since the molecular structure of two different proteins can never be the same, the hydrophobicity of the binding sites and hence the magnitude of the hydrophobic interaction with the ligand varies (Kinsella and Damodaran, 1980). Therefore, it is unlikely that the binding constants for BSA and soy protein would be similar as reported (Beyeler and Solms, 1974).

In 1974, Franzen and Kinsella studied the interaction of soy isolate and soy concentrate with C_6 - C_8 aldehydes and ketones using headspace analysis. They found that all the flavor compounds except 2-heptanone interacted with the soy fractions, resulting in a decrease in their headspace concentration. In general, soy concentrate bound the flavor compounds more strongly than the soy isolate. They attributed

this to the higher carbohydrate and lipid content of the concentrate.

More recently, Damodaran and Kinsella (1981a) studied the interaction of carbonyls (2-heptanone, 2-octanone, 2- and 5-nonanone, and nonanal) with soy protein, using equilibrium dialysis. They found that at saturation level, soy protein exhibited four binding sites for all the carbonyls studied. The binding constant increased with the chain length of the ligand by 3 orders of magnitude for each methylene group increase in the chain. The favorable change in the hydrophobic free energy was 550 cal/mol of CH_2 residue. The position of the carbonyl group decreased the hydrophobic free energy by 105 cal/mol for each shift from the terminal 1 position to the middle of the chain. The order of the binding affinity to soy protein is nonanal>2-nonanone>5-nonanone. This could be due to steric hindrance introduced by the presence of the carbonyl group as it is shifted to the center of the chain. While the binding affinity was independent of temperature above 25°C, a drastic increase in the binding affinity was observed at 5°C. Partial denaturation of soy protein increased the binding constant. Thermodynamic analysis of the binding of carbonyls with soy protein revealed that the interaction is relatively weak.

The effect of urea and succinylation of soy protein on the binding of 2-nonanone were studied by Damodaran and Kinsella (1981b). The addition of urea caused a decrease in the binding affinity of 2-nonanone for soy protein. The binding affinity decreased by about 50% in the presence of 1.5 M of urea. This is due to the interaction of urea with the hydrophobic region of the soy protein resulting in the separation of subunits into their constituent polypeptide chains. Succinylation of

soy protein also resulted in conformational changes in the protein which destroys half of the four binding sites originally present for 2-nonanone. However, the intrinsic binding constants of 930 M^{-1} and 850 M^{-1} for the respective native and succinylated soy proteins are almost identical. The decrease in the binding constant in the presence of urea and succinylation was due to structural changes in the protein as evidenced by the changes in the fluorescence behavior of soy protein.

Damodaran and Kinsella (1981b) also examined the binding affinities of 11S and 7S fractions of soy protein for 2-nonanone. While the binding affinity of the 7S fraction was the same as that of whole soy protein, the 11S fraction exhibited almost no affinity for 2-nonanone. These differences are interpreted in terms of the structural differences in these two proteins.

Aspelund and Wilson (1983) reported the thermodynamic properties of the reversible adsorption of off-flavor compounds (homologous series of alcohols, aldehydes, ketones, hydrocarbons and methyl esters) onto soy protein isolate using gas chromatography and statistical linear analysis of triplicate samples ran at 80, 90, 100°C . The heat of adsorption of aldehydes, ketones, and methyl esters were not statistically significant from each other but were significantly different from the hydrocarbons and the alcohols. The hydrocarbons adsorbed the weakest and the alcohols adsorbed the strongest onto dry soy protein. Aspelund and Wilson (1983) concluded that the functional group of the ligand plays a significant role in binding of flavor compounds to soy protein in the dry state.

Palkert (1980) examined the TSP-flavor compound interactions with meat flavor system consisting of sulfides (C_3 - C_4), disulfides (C_2 - C_4), heterocyclics (2,4-dimethylthiazole, 2,5-dimethylthiophene, furfural and pyrrole), and aldehyde (undecanal). The extent of TSP-flavor compound interactions was found to vary widely for different compounds. Using a Tenax trapping system for isolation of flavor compounds, recovery of the compounds in the presence of TSP ranged from 30% for undecanal to 88% for pyrrole when the model system was added at a level of 50 ppm. Increasing the concentration to 100 ppm increased the amount of flavor bound to TSP, indicating that additional binding was still occurring. The Tenax trapping system used was unsuitable for recovering compounds (2,5-dimethylfuran, 2,5-dimethylpyrazine, caprolactone, and octalactone) of high polarity and solubility in water. The former property slowed the migration of the compounds out of the aqueous phase while the latter acted to reduce the retention of the compounds by the Tenax column.

TSP may interact with flavor compounds and lower their volatility in several ways. Franzen and Kinsella (1974) attributed the decrease in volatility of intermediate chain length aldehydes and ketones in the presence of TSP to a reduction in surface area and increase in solubility. Arai et al. (1970) believed hexanol and hexanal interacted with soy protein via hydrophobic forces, while Beyeler and Solms (1974) indicated that both hydrophobic and ionic forces may bind flavor compounds to soy proteins.

Much research effort is needed to examine the binding phenomena of desired meat flavor compounds (especially nitrogen-, oxygen- and/or

sulfur-containing heterocyclics, sulfides, and thiols) with SPPs, particularly, TSPs.

Flavor Release in Soy Protein Products

van den Ouweland and Schutte (1978) studied the taste threshold values for some meat flavor components in four different media (Table 3).

Table 3. Taste threshold values of meat flavor components^a.

Compound	Taste threshold value (ppm) in			
	water	oil/water emulsion	textured soy protein	meat
2-Heptanone	0.08	1.00	1.00	5.00
1-Octen-3-ol	0.05	0.70	0.50	2.30
1,5-Dodecalactone	0.06	3.00	3.00	6.50
Benzaldehyde	0.05	0.40	0.60	2.00
2(H)-3-Furanone, 4-hydroxy-2,5-dimethyl-	0.03	0.20	0.10	5.70

^aAdapted from van den Ouweland and Schutte (1978).

For all the compounds tested, the threshold values are higher in the oil/water (O/W) emulsion than in water. The threshold values of the components in the O/W emulsion are of the same order of magnitude as those found for the TSP. In bland-tasting freeze-dried meat pieces rehydrated with the same emulsion, the threshold values are in all cases higher than in the TSP.

An explanation for this interesting phenomenon seems to be that during mastication of TSP, the flavors are expelled during the first bites, whereas in the meat system, the release is much more gradual (van den Ouweland and Schutte, 1978; Schutte and van den Ouweland,

1979). This is particularly true for water soluble flavor compounds, and unfortunately many meat volatiles and certainly the taste compounds are water soluble (Schutte and van den Ouweland, 1979).

The practical solution for the release of flavor constituents as proposed by Schutte and van den Ouweland (1979) are: (a) developing meat flavor blends adaptable to the quick release of water from material, (b) restricting TSP to small particle size to avoid prolonged chewing, and (c) intensive blending with other ingredients in the food, for example, comminuting or mincing together with meat.

Chemistry of Meat Flavor: An Overview

Flavors for meat extenders or analogs must be far superior to the traditional blend of flavors used for imparting meat flavors to soups and gravies (Kuramoto and Katz, 1975). When the addition of TSPs in comminuted meats exceeds 20%, the flavor generated by the meat cannot mask the natural, undesirable flavors of the extender. Thus, there is a real demand for meat flavor precursor systems whose potency is thermally generated. A complete appreciation of all meat aroma chemicals and the appropriate use of precursors is the only way to ensure a wide range of processed and novel foods which will be attractive to the consumer (Schutte, 1976). Hence, a brief overview of the chemistry of meat flavor is presented.

The scope of the background literatures in the fields of natural and simulated meat flavor is vast. Review articles worthy of particular note are those by Herz and Chang (1970), Dwivedi (1975), MacLeod and Seyyedain-Ardebili (1981), and Shahidi et al. (1986).

Meat composes a wide variety of foods originating largely from beef, pork, lamb, and chicken. Flavor is one of the most important quality attributes which contributes to the acceptability of meat. Raw meat has little odor and only a metallic, blood-like taste, whereas cooking develops its flavor (Crocker, 1948). A meaty flavor is believed to originate from the lean portion of meat and a species flavor from fat (Hornstein and Crowe, 1960; Allen and Foegeding, 1981). It has been suggested that the meaty flavor derived by heating the water-soluble precursors in the lean portion is the same regardless of the type of meat from which the precursors are obtained (Hornstein and Crowe, 1960).

The early work on meat flavor which began during the 1950s was almost exclusively concerned with the identification of the water-soluble, non-volatile precursors of meat flavor and was reviewed by MacLeod and Seyyedain-Ardebili (1981).

Hornstein and Teranishi (1967) summarized the early work on meat flavor precursors as follows:

- (1) Only low molecular weight water-soluble materials are meat flavor precursors;
- (2) The high molecular weight proteins (muscle fibrils and sarcoplasmic proteins) do not contribute to the formation of meat flavor;
- (3) The free amino acids and carbohydrate components of lean pork, beef, and lamb are similar, and this is reflected in the similarity of their lean meat flavor;
- (4) A specific glycoprotein and inosinic acid may be precursors of beef flavor or parts thereof; and,
- (5) Browning-type reactions may not be the sole mechanism responsible for the production of lean meat flavor.

According to Dwivedi (1975) the flavor of cooked meat is due to a mixture of compounds which include: (a) non-volatile, water soluble

compounds with taste and tactile properties, (b) potentiators and synergists such as L-amino acids containing five carbon atoms and/or 5'-nucleotides, and (c) volatile components with odor properties. Of these, the volatile or aroma compounds are by far the most important. Their formation and relative contribution to cooked meat aroma will be discussed.

Maillard Reaction Products and Meat Aroma

The main types of heat-induced reactions leading to the formation of meat flavor volatiles from non-volatile precursors have been summarized by van den Ouweland et al. (1978) as follows:

- (1) Pyrolysis of peptides and amino acids,
- (2) Degradation of sugars (particularly reducing sugars),
- (3) Interactions involving sugars, peptides, amino acids, or their degradation products (Maillard reaction),
- (4) Degradation and reaction of ribonucleotides,
- (5) Reaction of hydrogen sulfide, ammonia, and thiols, with volatile and non-volatile components,
- (6) Oxidation, hydrolysis, dehydration, and decarboxylation of lipids, and,
- (7) Thiamin degradation.

Because of its importance in flavor propagation, the Maillard reaction has recently been reviewed by many workers including Tressl et al. (1979), Tressl (1979), Baltes (1980), Nursten (1980), and Danehy (1986). Only those aspects of the reaction which are best understood and are likely to be important in their contribution to meat aroma will be discussed.

The Maillard or non-enzymic browning reaction is induced by heating a free amino group (amino acids, amines, peptides, proteins, ammonia) with carbonyl compounds (aldehydes, ketones, reducing sugars) (MacLeod and Seyyedain-Ardebili, 1981). It is an open ended complex reaction consisting of a series of interactions and decompositions and resulting in numerous products frequently including mono- and dicarbonyls, furans and derivatives, alcohols, cyclic ethers, and heterocyclics.

Factors Affecting the Maillard Reaction

The reaction can occur at 90°C, is inhibited by water, and increases with time and temperature (Wang and Odell, 1973). Chuyen et al. (1973) have reported that peptides are more reactive than amino acids in non-enzymic browning. The effect of water content of the food is important (van den Ouweland et al., 1978). For example, optimal formation of Amadori products (APs) from glucose/amino acid occurs at a water content of 25 to 30% (model system 100°C/1 hr) (van den Ouweland et al., 1978), a region often encountered during cooking and processing. van den Ouweland et al. (1978) reported that during frying of meat, approximately 60% of the water is lost. In the surface layers, this loss is even higher, and conditions are created at which the Maillard reaction is favored (van den Ouweland et al., 1978). A considerable decrease in amino nitrogen and in glucose, fructose, and ribose concentrations occurred when a beef diffusate was heated (125°C/1 hr; Wasserman and Spinelli, 1970) and the glucose/glycine APs have been isolated from roasted meat (van den Ouweland et al., 1978).

Nursten (1980) summarized the important factors such as temperature and time of reaction, proportion and nature of reactants, and water

activity. The effect of temperature on browning is marked, Q_{10} values being 3-6. There are some clear effects on the nature of the reactants: pentoses react more quickly than hexoses; thiazoles are specific to cysteine, and pyrroles to pyrroline. As regard to proportion of reactants, there is a general tendency for model systems not to be moved away from a 1:1 ratio of sugar:amino acid.

Reaction Mechanisms

In order to understand the wealth of compounds generated, the current mechanistic proposals will therefore be briefly reviewed. The Maillard reaction is best divided into three stages (Hodge, 1953, 1967; Mills et al., 1969) and the overall reaction scheme is outlined in Figure 2 (Hodge, 1967).

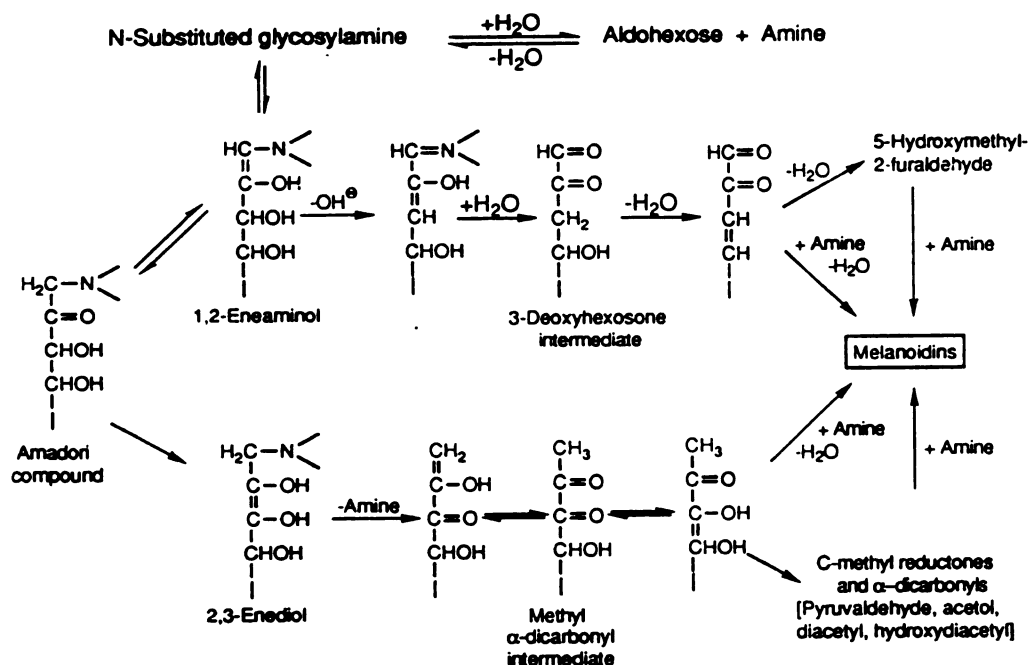


Figure 2. Sugar-amine (Maillard) browning reactions: Two pathways to melanoidins and by-products (Hodge, 1967).

The first stage comprises glycosylamine formation and subsequent rearrangement. This involves an addition reaction of the amine to the carbonyl group, followed by elimination of water to form a Schiff base. The Schiff base cyclizes producing an N-substituted glycosylamine, which undergoes an acid-catalyzed Amadori rearrangement forming the Amadori product N-substituted-1-amino-1-deoxy-2-ketose.

The intermediate stage comprises dehydration, either by loss of three molecules of water to furfurals or by loss of two to reductones, fission (mainly by dealdolization), and Strecker degradation (the interaction of amino acids and dicarbonyl compounds which may either be dehydroreductones or dehydration/fission products).

The final stage consists of the conversion of carbonyl compounds (dehydroreductones, dehydration/fission products, or Strecker aldehydes) into high molecular weight products, the melanoidins, with further involvement of amines where these are available.

Its Role in Meat Aroma Production

The aroma volatiles produced by the Maillard reaction are best classified into three groups (Nursten, 1980):

- (1) "Simple" sugar dehydration/fragmentation products (furans, pyrones, cyclopentenones, carbonyls, acids);
- (2) "Simple" amino acid degradation products (aldehydes, sulfur compounds); and,
- (3) Volatiles produced by further interactions (pyrroles, pyridines, imidazoles, pyrazines, oxazoles, thiazoles, compounds from aldol condensations).

The formation of some of these compounds, especially the latter ones which may be significant contributors to meat aroma (see following section), are herein reviewed. To aid in subsequent

discussions, the parent structures of some of the heterocyclics are presented in Figure 3.

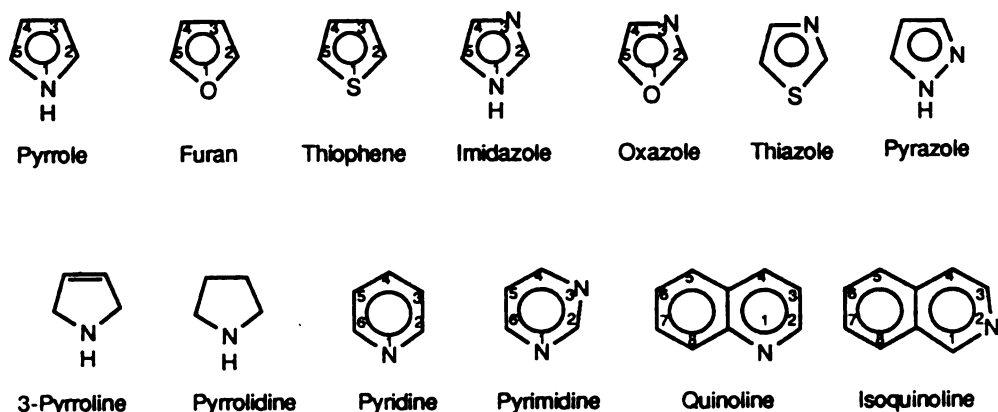
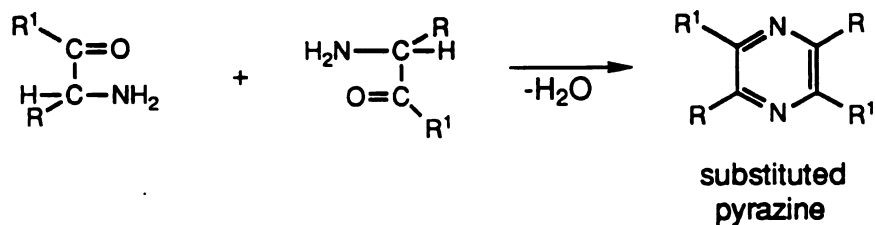


Figure 3. Parent structures of some heterocyclics (Morrison and Boyd, 1976).

The non-volatile APs are the key compounds in that they are heat-labile and, on low temperature thermolysis, decompose forming volatile flavor compounds via 1-deoxysones and 3-deoxysones, respectively (Tressl et al., 1977). The former may be transformed into decarbonyls with which amino acids can undergo Strecker degradation. The amino ketones simultaneously formed may be transformed into pyrazines. For example,



Some simple reactions of APs are presented in Figure 4 (Hodge, 1953; Tressl et al., 1977).

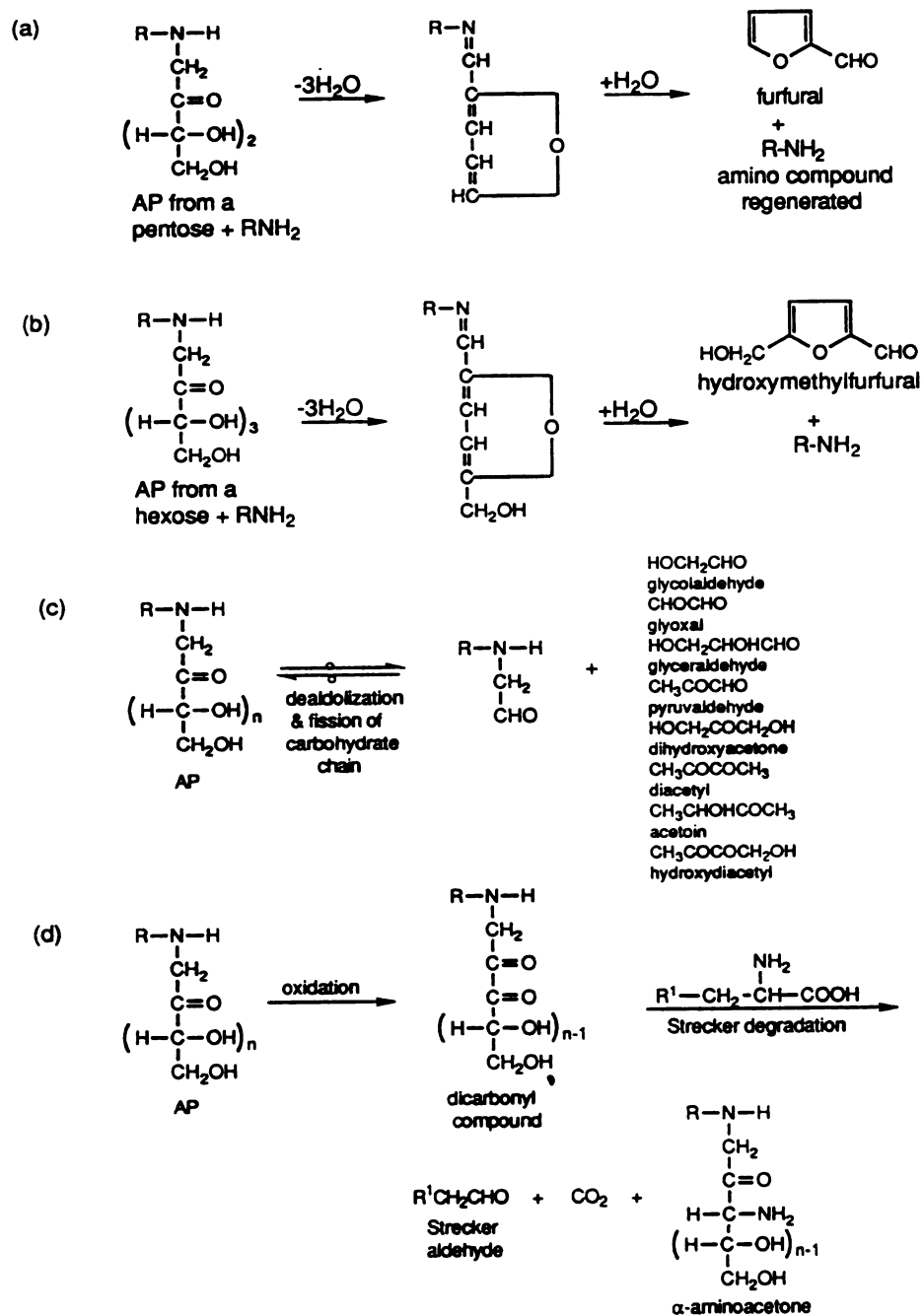


Figure 4. Some simple reactions of Amadori products (Hodge, 1967; Tressl et al., 1977).

Further reactions of the unstable APs on heating have been reported (Tressl et al., 1979; Mills et al., 1969; 1970; Mills and Hodge, 1976). The reaction conditions and the character of the amino compound determine the range of aroma components formed (Tressl et al., 1979).

A. Furan and Derivatives. A scheme for the formation of several furan derivatives identified in beef aroma has been presented by Tressl et al. (1979) and is summarized as Figure 5.

While hexoses form 5-methylfurfural and 4-hydroxy-2,5-dimethyl-3(2H)-furanone, pentoses give rise to furfural and 4-hydroxy-5-methyl-3(2H)-furanone, respectively. This latter compound has been synthesized by heating amines with xylose, ribose, ribose-5-phosphate or incidentally, glucuronic acid (Hicks and Feather, 1975; Hicks et al., 1974). During these reactions, the oxygen of the furan ring may be substituted by nitrogen or sulfur, forming the corresponding pyrroles and thiophene derivatives (Tressl et al., 1979). Shibamoto et al. (1977) identified several pyrroles in the reaction mixture of furfural, ammonia, and hydrogen sulfide showing that exchange of nitrogen for the oxygen in the furan ring does occur on heating.

B. Maltol. Maltol, in beef aroma, may arise from decomposition of a hexose AP. Its immediate precursor is probably 5-hydroxy-5,6-dihydromaltol, an important precursor of caramel compounds (Tressl et al., 1979) and identified in sugar-amine model reactions by Mills et al. (1970). This compound, together with smaller amounts of cyclo-tene, 2,5-dimethyl-2,4-dihydroxy-3(2H)-furanone and 5-hydroxymaltol, were formed on decomposition at 140°C of 1-deoxy-1-L-proline-D-fructose as shown by Mills and Hodge (1976) in Figure 6.

Figure 5. Formation of furan derivatives from glucose Amadori products (Tressl et al., 1979).

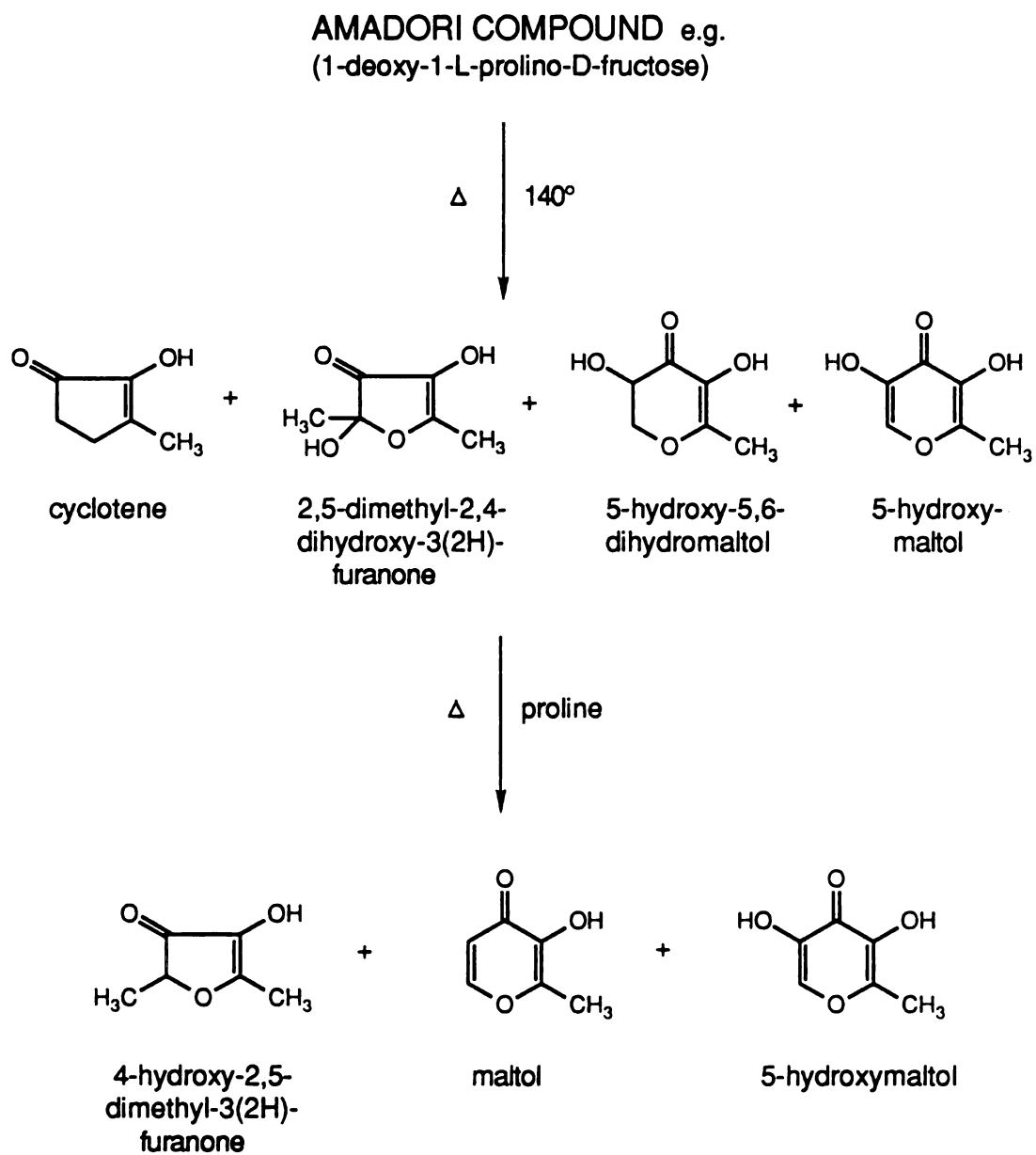


Figure 6. Formation of maltol and derivatives from Maillard reaction (Mills and Hodge, 1976).

On heating with proline, 5-hydroxy-5,6-dihydromaltol give rise to 5-hydroxymaltol, maltol and 4-hydroxy-2,5-dimethyl-3(2H)-furanone (Mills and Hodge, 1976). The latter two have been identified in cooked beef aroma. Proline and hydroxyproline have secondary amino groups and therefore do not undergo Strecker degradation.

C. Pyrroles, Pyridines. The formation of several pyrroles (pyrrole, 2- and 3-methyl-, 2-ethyl-, 2,5-dimethyl, N-methyl-, and N-propyl-pyrrole) and pyridines (pyridine, 2- and 3-methyl-, 2-ethyl-, 2,3-dimethyl-, and 2-formyl-pyridine) from the reaction of proline and glucose under roasting conditions has been reported (Tressl et al., 1979; Shigematsu et al., 1975). Several N-acyl-pyrrolidines and 2,3-dihydroindolines were also reported, but have not been identified in beef aroma. Bicyclic pyrrole compounds have also been isolated from a proline/glucose model reaction (Shigematsu et al., 1975). The similar reaction of hydroxyproline with glucose has produced over 50 nitrogen heterocycles and in contrast to the proline system, only N-substituted products were obtained (N-alkylpyrroles, N-acylpyrroles, and N-furfuryl-pyrroles). The 2,3-dihydroindolines were again identified, but no pyridines. Tressl et al. (1981) characterized 5,6,7,8-tetrahydro-indolizin-6-ones, 1-furfuryl-pyrroles, 1-(pyrrolyl)-2-butanones, 1-(pyrrolyl)-3-buten-2-one, 2- and 5-(1-pyrrolyl)cyclopentenones and 2-[(1-pyrrolyl)methyl]-cyclopentenones as specific compounds derived from hydroxyproline/glucose or arabinose (erythrose) model experiments. None of these compounds have been identified in cooked beef aroma.

D. Pyrazines. The pyrazines most frequently produced thermally are the alkyl, alkenyl, and acyl pyrazines. Mechanisms of their formation

have been reported (Rizzi, 1969; 1972; Shibamoto and Bernhard, 1977; Dawes and Edwards, 1966). They can be formed as already described by dimerization of α -aminoketone Strecker products. Newell et al. (1967) using a model system of glucose/amino acid, and van Praag et al. (1968) using glucose/ammonia, both concluded that the reaction required free ammonia and that the same pyrazines were produced regardless of the amino acids since it only served as a source of free ammonia (Wasserman, 1979). Conversely, Koehler and coworkers (Koehler et al., 1969; Koehler and Odell, 1970) showed that the amino acid nitrogen reacts directly with the sugar system producing different pyrazines. The type and concentration of pyrazines formed depended on the carbon source (the particular sugar or sugar degradation products: glyoxal, acetaldehyde, glycerol, propanal, hydroxyacetone, and butane-2,3-dione, and also glucosamine). Shibamoto and Bernhard (1976; 1978) using sugar/ammonium hydroxide model systems, showed that glucose gave a series of alkylpyrazines, while rhamnose produced a series of dihydrocyclopentapyrazines and tetrahydroquinoxalines. Both of these classes of compounds have been identified in cooked beef aroma.

Shibamoto and Russell (1976; 1977) heated a solution of glucose, ammonia, and hydrogen sulfide. The volatiles produced resembled closely beef odor and included thiophenes, furans, 2,4-dimethyl-3-thiazoline, methanethiol, dimethylsulfide, alkylthiazoles, and pyrazines; several of the compounds formed have been identified in cooked beef aroma. Increasing the concentration of ammonia increased the total yield of pyrazines and also changed the ratio of the individual pyrazines formed, due partly to a greater amount of ammonia available

for reaction and partly to increased pH causing greater fragmentation of the sugar and the formation of more carbonyl compounds (Shibamoto et al., 1977; Shibamoto and Bernhard, 1976; Shibamoto and Russell, 1976; 1977). Wasserman (1979) explains that when meat is initially heated (normal pH 5.5 approximately) the mechanism for pyrazine formation, involving carbonyl-amino acid (or amine) reaction, is likely to be favored but as the concentration of ammonia increases on liberation from amino acids on continued heating, the pH increases and induces the reaction described above by Shibamoto and his co-workers. Using the same model system, Shibamoto and Russell (1976) determined the effects of temperature on pyrazine formation. Although some pyrazines were formed at -5°C (after 30 days) significant pyrazine formation began at 70°C and increased to optimum at $120^{\circ}\text{C}/2\text{ hr}$ (Shibamoto and Bernhard, 1978; Shibamoto and Russell, 1976). Reineccius et al. (1972) also showed that pyrazine formation occurred at time-temperature relationships as low as 30 min at 70°C . Other investigators have reported no pyrazine formation below 100°C (Wasserman, 1979). They were formed in greater concentrations during cooking of beef by microwave radiation than by conventional means (MacLeod and Coppock, 1976).

Alkyl-5H-6,7-dihydrocyclopenta-[b]-pyrazines, present in both boiled and roasted aromas of heated beef, arise from condensation of hydroxycyclopentenones with α -dicarbonyls in the presence of ammonia (Flament et al., 1976a,b). All these reactants are available in heated meat. Alkyl hydroxycyclopentenones are Maillard reaction products; a typical example is 2-hydroxy-3-methylcyclopent-2-enone (cyclozene). The series of reactions leading to the formation of the pyrazines is

shown in Figure 7.

Pyrrolo 1,2-a pyrazines probably arise by condensation of a sugar degradation product (α -dicarbonyl compound) with a Strecker degradation product (α -aminocarbonyl compound) in the presence of ammonia (Flament et al., 1977) as illustrated in Figure 8.

van den Ouweland et al. (1978) concluded that the majority of the volatile products evolved from heating the APs of glycine/glucose and of glycine/fructose above their melting points were furan and pyrrole derivatives.

E. Thiophenes. Maillard reactions involving cysteine and/or cystine have been extensively studied (Arroyo and Lillard, 1970; Kato et al., 1973; Scanlan et al., 1973; Mulders, 1973; Kleipool and Tas, 1973, 1974; Ledl and Severin, 1973; 1974). Possible reaction products are carbonyl compounds, amines, benzenoids, acids, lactones, thiols, furan derivatives, thiophene derivatives, thianes, thiolanes, pyrroles, pyridines, pyrazines, thiazoles, thiazolines, and thiazolidines. Kato et al. (1973) showed that far more thiophene derivatives arise from cysteine/pyruvaldehyde reaction than from the corresponding reaction involving cystine. They made similar comparisons of glucose/cysteine and glucose/cystine reaction products and showed that more thiophenes and pyrazines were identified in the cysteine system while more thiazoles and furan derivatives arose from cystine. Thiophene derivatives have also been eminent in the reaction products of cysteine/xylose, a model system approximating cooked meat (Mussinan and Katz, 1973), and in a cysteine/cystine-ribose system. Mulders (1973) proposed a scheme for the formation of 5-methylthiophen-2-carboxaldehyde from

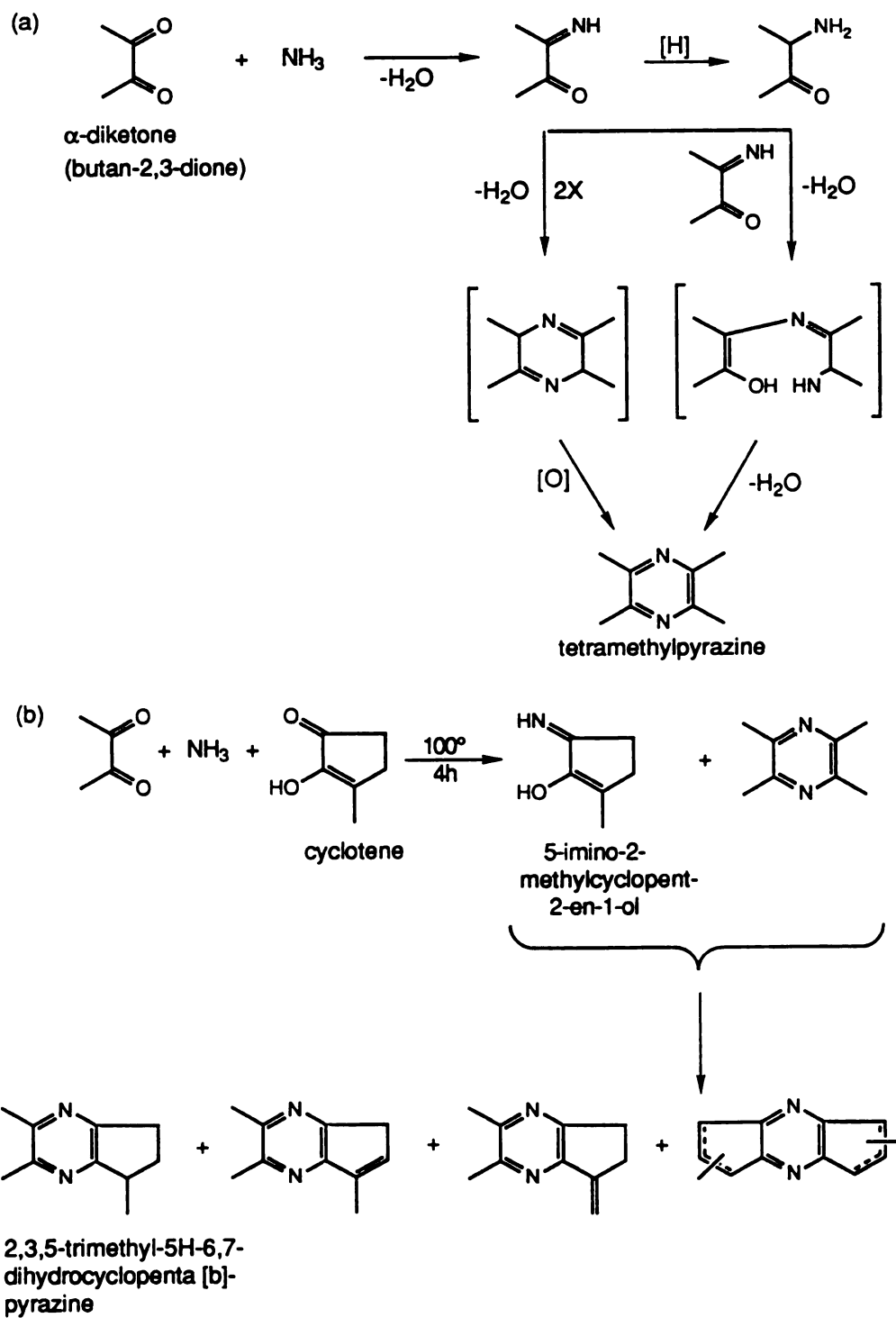


Figure 7. Formation of alkyl-5H-6,7-dihydroxycyclopenta[b]-pyrazines from Maillard reaction products (Flament et al., 1976).

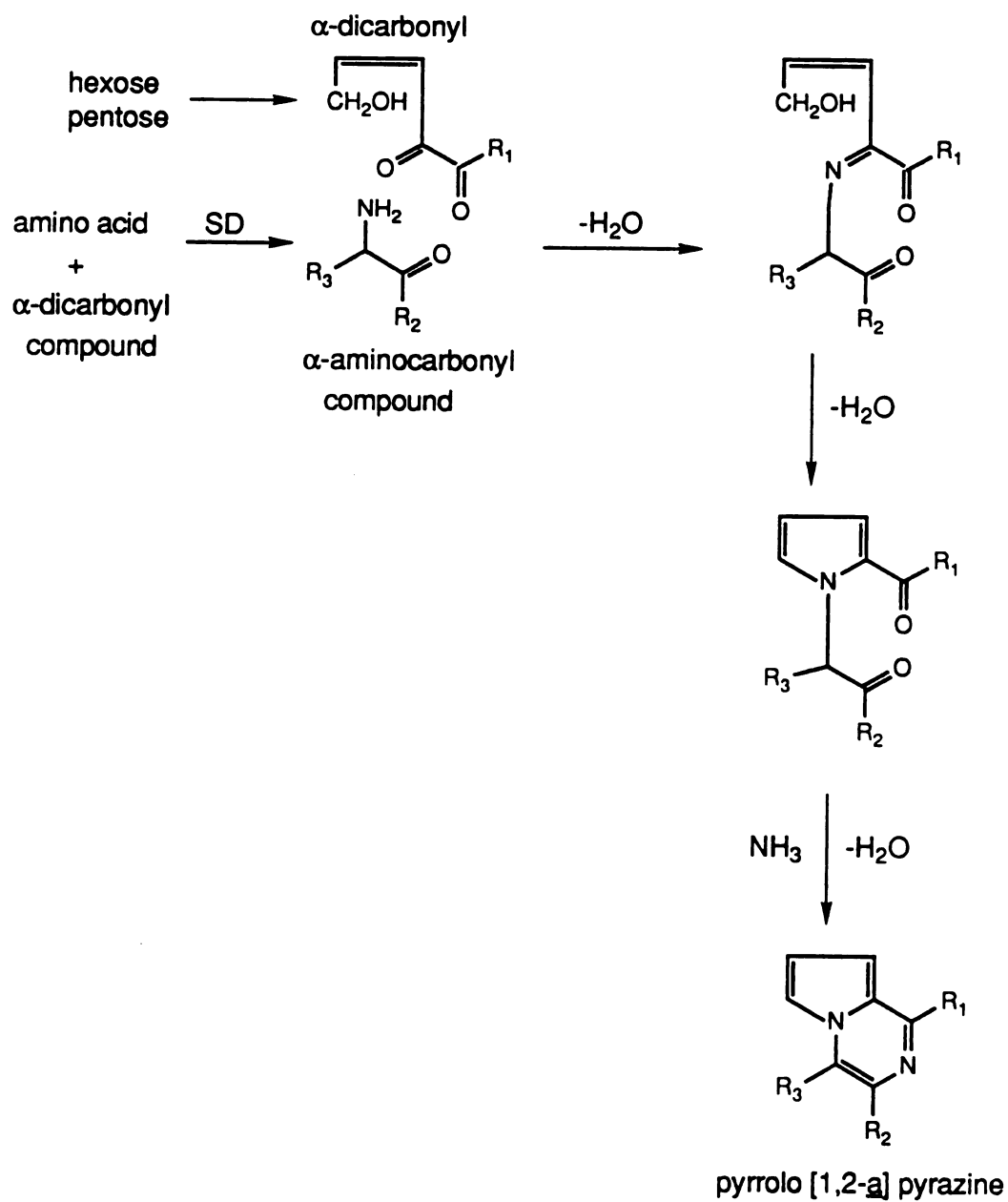


Figure 8. Formation of pyrrolo [1,2-a] pyrazines (Flament et al., 1977).

reaction of mercaptoacetaldehyde and but-2-enal which can arise from aldol condensation of acetaldehyde followed by dehydration. As far as foods are concerned, with the exception of American cranberries (Anjou and von Sydow, 1967), thiophenes and their derivatives have been identified exclusively in cooked or roasted foods (Ohloff and Flament, 1978), and so their formation from Maillard type reactions involving cysteine seems very likely. Interaction of glucose degradation products with hydrogen sulfide also produces thiophenes, including thiophene aldehydes and ketones (Shibamoto and Russell, 1976; 1977). Tetrahydrothiophen-2-one, tetrahydrothiophen-3-one and its methyl homolog have been identified in model reactions of cysteine with xylose (Mussinan and Katz, 1973), glucose (Scanlan et al., 1973), or pyruvaldehyde (Kato et al., 1973). Several mercaptothiophenes result from the reaction of hydrogen sulfide with 4-hydroxy-5-methyl-3(2H)-furanone or its 2,5-dimethyl homolog (van den Ouweland and Peer, 1975), but none of these have been identified in cooked beef aroma. Neither have thienothiophenes, known to arise from cysteine/cystine-ribose (Mulders, 1973) and cysteine/glucose (Scanlan et al., 1973; van den Ouweland and Peer, 1975) reactions. Recently, Shu et al. (1986) identified twenty-four volatile components including two novel compounds, 3-methyl-2-(2-oxopropyl)- and 2-methyl-3-propionylthiophene from the reaction of cysteine and 2,5-dimethyl-4-hydroxy-3(2H)-furanone.

F. Thiazoles. Alkylthiazoles and acylthiazoles have been isolated from model reactions of cysteine/cystine with xylose (Ledl and Severin, 1973), ribose (Mulders, 1973), pyruvaldehyde (Kato et al., 1973) or glucose (Kato et al., 1973). Alkenyl thiazoles were also identified in

the cysteine/xylose reaction (Ledl and Severin, 1973). 2,4-Dimethyl-5-vinylthiazole is easily formed by dehydration of the corresponding alcohol, 5-(2-hydroxymethyl)2-4-dimethylthiazole (Stoll et al., 1967). The acetylthiazole may arise from oxidation of 2-acetylthiazoline believed to arise from Strecker degradation of cysteine by pyruvaldehyde (Mulders, 1973) or from the addition of pyruvaldehyde to cysteamine and subsequent oxidation (Ohloff and Flament, 1978). Several 2-alkyl-thiazolines and 2-alkylthiazolidines have also been identified in cysteine/sugar reactions (Kato et al., 1973; Ledl and Severin, 1972), but have not been reported in beef aroma.

G. Oxazoles, Oxazolines. Oxazoles may arise by Strecker degradation of aminoketones resulting from the condensation of α -dicarbonyl compounds with amino acids (Ohloff and Flament, 1978). The model reaction of furfural, hydrogen sulfide, and ammonia produces 2,4-dimethyloxazole (Shibamoto et al., 1977). 2,4,5-Trimethyl-3-oxazoline is formed from reaction of alanine and butane-2,3-dione (Rizzi, 1969) and from the reaction of two carbonyl compounds (acetaldehyde and acetoin), in the presence of ammonia (Jassmann and Schulz, 1963).

H. S-containing Compounds. Several of the sulfur compounds identified in cooked beef aroma may arise from the Maillard reactions or Strecker degradation of cysteine and cystine. Hydrogen sulfide is a common heat-induced product, formed from interaction of cysteine with xylose (Ledl and Severin, 1974), ribose (Mulders, 1973) or α -diketones (Kobayashi and Fujimaki, 1965) and also on pyrolysis of sulfur-containing amino acids. Methanethiol is mainly formed by cleavage of methionine (Wainwright et al., 1972; Fujimaki et al., 1969). Short

chain aliphatic thiols are formed in cysteine/cystine-ribose reactions (Mulders, 1973). Benzylmethylsulfide has been isolated in a cysteine/xylose model system approximating cooked meat (Mussinan and Katz, 1973), although it has not been identified in beef aroma. The diastereoisomeric, 3,5-dimethyl-1,2,4-trithiolanes, thialdine, aliphatic disulfides and dimethyltrisulfide have also been identified in the cysteine/xylose model reaction (Mussinan and Katz, 1973).

Apart from contributing to meat flavor, hydrogen sulfide also acts as a precursor for other flavor compounds (van den Ouweland and Peer, 1975, 1978; Takken et al., 1976). It is evolved continuously on simmering beef; its release increases with time and cooking temperature, probably as a result of protein denaturation and reduction of disulfide linkages to thiol groups (Wasserman, 1979). Persson and von Sydow (1973) showed that as cooking time of canned beef increased from 15 to 75 min, hydrogen sulfide evolution increased 3-fold. Methanethiol and ethanethiol also increased in concentration in the aroma volatiles. On storage of the product, however, marked losses of both hydrogen sulfide and methanethiol occurred (Persson and von Sydow, 1974), possibly due to interactions with other components in the beef (Wasserman, 1979).

Beef Flavor Volatiles

To date, about 700 volatile compounds from various heated beef samples have been identified (Ching, 1979; Uralets and Golovnja, 1980; Yamaguchi et al., 1980; Lee et al., 1981; MacLeod and Seyyedain-Ardebili, 1981; Shahidi et al., 1986). These and some of their odor descriptions are listed together with the soy protein volatiles in Table 4.

Table 4. Chemical compounds and odor descriptions of beef and soy flavor volatiles.

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References) ^a
HYDROCARBONS			
Aiphatic, acyclic			
Methane, diisoproproxy		91 ^a	
Methane, methylidithia		85	
Butane	1 ^a		
Butane, 2-methyl	2		
Butane, dimethyl	3		Pleasant, sweet (3)
Pentane	1,70	84	
Pentane, 2-methyl	4,5		
Pentane, 3-methyl	5		
Pentane, 1,5-diamino		80	
1-Pentene, 2-methyl	6		
2-Pentene, 4-methyl	5		
1,4-Pentadiene		84	
Hexane	1,5-8,70		
Hexane, 2-methyl	5		
Hexane, 3-methyl	5		
Hexane, 2-methyl-3-ethyl	5,6		
1-Hexene	3		Dull, cardboard (3)
2-Hexene	6		
2,4-Hexadiene	6		
Heptane	1,3-6,9,70		Cooked meat (3)
Heptane, 2-methyl	3		Solvent-like (3)
1-Heptene	3,6,9		Sulfurous (3)
2-Heptene	6		
Octane (and isomers)	1,3-6,9,10	92	Meaty (3)
Octane, 2-methyl	4,5		
Octane, 3-methyl	5		
Octane, 2,6-dimethyl	5		
1-Octene	3,6,10		
3-Octene	6		
1,3-Octadiene	11	92	
2,4,6-Octatriene, 2,6-dimethyl	5		
Nonane	3,6,10,13		Strong, sour, harsh, burnt, unpleasant (3)
Nonane, 3-methyl	5		
Nonane, 4-methyl	5		
1-Nonene	3,6		Strong, grassy, onion, rancid (3)
3-Nonyne	12		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References) ^a
Decane	3,9,10,13	84	
Decane, 3-methyl		84	
1-Decene	3		Strong, cardboard (3)
2-Decene	6		
Decyne	11		
Undecane	3,6,10,13		
Undecane, 3-methyl	5		
1-Undecene	3,7		Unpleasant, old meat (3)
4-Undecene	3,9		
Dodecane	1,4-7,10,13	92	
Dodecane, 2-methyl	4,5		
1-Dodecene	3,5,6		Medicinal (3)
Tridecane	4-6,8,10,13,70		
Tridecane, 2-methyl	4,5		
Tridecane, 3-methyl	5		
Tridecane, 4-methyl	5		
1-Tridecene	3-5		
Tetradecane	4-6,9,13		
Tetradecane, 2-methyl	6,11,13		
Tetradecane, 6-methyl	13		
Tetradecane, 4-ethyl	5		
1-Tetradecene	5		
Pentadecane (and isomers)	4-9,13		
Pentadecane, 2-methyl	4,5		
Pentadecane, 3-methyl	11		
1-Pentadecene	5,7,8		
1-Pentadecene, 2-methyl	5		
Hexadecane (and isomers)	4,6-9,13		
Hexadecane, 2,6,10,14-tetramethyl (phytane)	5,14		
1-Hexadecene	5		
Heptadecane	4-6,8-10,13	92	
1-Heptadecene	4-6,13		
Octadecane	4-8,13		
Octadecene	15		
Nonadecane	15,16	92	
Eicosane	17		
Henicosane	15,16		
Docosane	15,16		
Tricosane	15,16		
Tetracosane	15,16		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Pentacosane	15,16		
Allo-ocimene	5		
Aliphatic, cyclic			
Cyclopentane, methyl	5		
Cyclohexane	4,5,18		
Cyclohexane, methyl	4,5		
Cyclohexane, trimethyl	5		
Cyclohexane, ethyl	4,5		
Cyclohex-1-ene, ethyl		84	
α -Pinene		92	
β -Pinene		92	
Limonene	5,6	92	
α -Terpinene	5	92	
β -Terpinene		92	
γ -Terpinene		92	
Terpinolene		92	
4-Terpineol		92	
β -Caryophyllene	4,5		
<i>p</i> -Cymene		92	
α -Phellandrene	5		
β -Phellandrene		92	
Aromatics			
Benzene	4,7-9,19-21	84,91,92	
Benzene, alkyl (MW 134)	10		
Benzene, methyl	3-7,9,10,13, 21,22,70	91,92,93	Strong, fruity, becoming dank, bitter (3)
Benzene, 1,2- dimethyl	9,10,13,21	91,92	Sweet (3)
Benzene, 1,3- dimethyl	4,5,13	91,92	
Benzene, 1,4- dimethyl	6,9,10,13,21	91,92	Fruity, solvent-like, sickly, fatty (3)
Benzene, trimethyl (3 isomers)	13		
Benzene, 1,2,3- trimethyl	10,21,23		
Benzene, 1,2,4- trimethyl	6,10,21,23		
Benzene, 1,2,5- trimethyl	5		
Benzene, 1,3,4- trimethyl	23		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Benzene, 1,3,5-trimethyl	6,10,21		
Benzene, 1,2,3,4-tetramethyl	6		
Benzene, 1,2,3,5-tetramethyl	6		
Benzene, ethyl	5,6,10	91,92	
Benzene, methylethyl	6,23		
Benzene, ethyl-2-methyl	5,6,10,21,23		
Benzene, ethyl-3-methyl	4,5,21,23,24		
Benzene, ethyl-4-methyl	21		
Benzene, diethyl	5,13		
Benzene, 1,2-diethyl	5		
Benzene, vinyl (styrene)	3,5,6,10	91	
Benzene, vinyl methyl	10		
Benzene, vinyl dimethyl	5,6		
Benzene, propyl		84	
Benzene, propyl-dimethyl	5-10		
Benzene, methyl-2-propyl	23		
Benzene, methyl-3-propyl	23		
Benzene, methyl-4-isopropyl	5,6,18		
Benzene, 2,4-dimethyl-1-isopropyl	11		
Benzene, ethyl-2-propyl	23		
Benzene, ethyl-3-propyl	23		
Benzene, butyl	6,13	84	
Benzene, pentyl	6,13		
Benzene, hexyl	6		
Benzene, heptyl	6		
Benzene, octyl	6		
Benzene, decyl	5		
Indane	3		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Indene	23		
Naphthalene	4-6,10	91,92	
Naphthalene, 2-methyl	5,10		
Phenanthrene, 9,10-		91	
dihydro-2-N-dodecyl			
Subtotal (%)	122 (17.5%)	34 (13.5)	
ALDEHYDE			
Aliphatic			
Methanal (formaldehyde)	2,25,26	78	
Ethanal (acetaldehyde)	2,21,25-32,70	78,82,84,87,89,90	Pungent (21)
Ethanal, phenyl	5,10,22	85,86,90,93	
Propanal	2,8,25,26,29-32,70	90	
Propanal, 2-methyl	2,9,21,26,29,31,33,70	84,95,90,92	Green, pungent, sweet (21)
Propanal, oxo	34		
Propenal (acrolein)	34	87	
Propenal, 2-methyl		90	
Butanal	4,5,18,21,23,26	84,90,91	Burnt, green, nasty-smelling (21)
Butanal, 2-methyl	2,9,6,13,21,26,29-31,70	90,92	Burnt, sickly (21)
Butanal, 3-methyl	3-5,7,8,13,21,26,29-31,39,70	90,92	Burnt, roasted (4), meaty, sulfurous (3) burnt, green, sickly (21)
Butanal, 2-ethyl	4,5		
Butenal (crotonaldehyde)	26,34,70		
2-Butenal, 2-methyl		90	
Pentanal	6-8,13,19-21,26	84,90-93	Burnt, green (21)
Pentanal, 2-methyl	26		
Pentanal, 3-methyl	26		
Pentanal, 3-methyl-4-oxo	5		
2-Pentenal	26	84	
2-Pentenal, 2-methyl		90,91	
4-Pentenal	26		
Hexanal	3-8,10,13,19-21,25,32,70	78,82,84,85,89,90-92,93	Strong, rancid, unpleasant (3), green, pungent, sickly (21)
Hexanal, methyl		90	

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
2-Hexenal	5,6,13,32	84	
2,4-Hexadienal	6,26	84,90	
Heptanal	4-8,10,13, 19-21,26,35	84,90-93	Green, burnt, sickly (21)
Heptanal, 2-methyl	5		
2-Heptenal	5,6,13,26,32	78,82,84,89,93	
4-Heptenal (cis)	36		Green, tallowy, creamy, butterscotch- like (36)
4-Heptenal (trans)	36		Green, tallowy, creamy, butterscotch- like (36)
2-Heptenal, 5-methyl	34		
2-Heptenal, 6-methyl	7,8,34		
2,4-Heptadienal	5-7,10,32,71	84,90	
Octanal	5,7,8,10, 13,19,26	84,90-93	
2-Octenal	5,7,8,13, 26,32	84	
2,4-Octadienal	13		
Nonanal	4,5,7,8,10, 13,19-21,32, 70,72	84,90,92	Green, moldy (21)
2-Nonenal	5,13,32	84	
2,4-Nonadienal	5,13	84,91	Pleasant, fried fat (5)
2,6-Nonadienal (trans, cis)	36		Green-cucumber-like (36)
2,6-Nonadienal (trans, trans)	36		Green-cucumber-like (36)
Decanal	5,10,13,26,37	90,92,93	
2-Decenal	5,13,32	84	
4-Decenal	11		
2,4-Decadienal	13,32	78,84,85,89	
Undecanal	5,10,13,20, 22,26		
2-Undecenal	5,13,19,20, 22,32		
2,4-Undecadienal	13		
Dodecanal	13,10	93	
2-Dodecenal	13		
2,4-Dodecadial	13		
Tridecanal	13,10		
2-Tridecenal	13		
Tetradecanal	10		
Tetradecenal	13,10		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Pentadecanal	4,5,13,10		
Hexadecanal	7,8,10		
Heptadecanal	13,8		
9-Octadecenal	11		
Aromatic			
Benzaldehyde	4,6-8,10,13,19-22	78,84,85,87 90-93	Sweet, almond-like (4), Strong, sweet, almond (5), sweet-metallic (21)
Benaladehyde, methyl	6		
Benzaldehyde, 3-methyl	7,13		
Benzaldehyde, methoxy	6		
Benzaldehyde, ethyl	6,9,10		
Benzaldehyde, 3-ethyl	28		
Benzaldehyde, 4-ethyl	6		
Benzaldehyde, 3-isopropyl	10		
Benzaldehyde, 4-isopropyl	11		
Cinnamaldehyde	13		
Subtotal (%)	65 (9.5)	31 (12.3)	
KETONES			
Aliphatic, acyclic			
2-Propanone (acetone)	3-6,9,21,26,29,30,32 40-42,70,72	78,82,85,89-92	Dull, meat-broth (3)
2-Propanone, 1-phenol	6	87,91	
2-Butanone	2,3,6,19-22,26,29,30,70	87,90,92	Strong, grassy, sweet, sickly, doughy (3), Sickly (21)
2-Butanone, 3-methyl	3,26,28	90	
2-Butanone,3,3-dimethyl		91	
2-Butanone, 3-hydroxy (acetoin)	4-8,10,13,20,22,26,70		Buttery (4)
2-Butanone, 4-phenyl	6		
3-Buten-2-one, 4-phenyl		87	
2,3-Butanedione	1,3-7,10,13,21,41,70	90,92	Buttery (4), butter, sickly (21)
2-Pentanone	3,5,6,21,23,26,70	78,89,90,91	Buttery, sweet, sickly, meaty (3), burnt, green (21)
3-Pentanone	22,23		Burnt, sickly (21)
2-Pentanone, 3-methyl	21,34	90	

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
2-Pentanone, 4-methyl	11,21	90,91	Cooked cabbage (21)
3-Pentanone, 2-methyl		90	
1-Penten-3-one		84	
2,3-Pentanedione	13,21,39	84,85,92	
2-Hexanone	6,21,23,26	78,89,90,92	
3-Hexanone		90	
2-Hexanone, 3-methyl	4,5		
2-Hexanone, 5-methyl	4,5,26		
3-Hexanone, 5-methyl	26		
2-Hexanone, 1-phenyl	26		
4-Hexen-3-one	15		
2-Heptanone	5,13,21	84,85,90-93	Green, pungent, sickly (21)
3-Heptanone	13,21	90	
2-Heptanone, methyl	10		
2-Heptanone, 6-methyl	18		
5-Hepten-2-one, 6-methyl	23		
2-Octanone	4,5,10,13,21	84,85,90,91, 93	Green, mushroom (21)
3-Octanone	13,21	84,90,92,93	
4-Octanone	6-8,23		
Octenone	6		
3-Octen-2-one	11		
1-Octen-3-one		84	
3,5-Octadien-2-one		92	
2,3-Octanedione	13	84	
2-Nonanone	5,6,10,13,21	90,91	Fatty (66), green (21)
3-Nonanone	7,8,26		
4-Nonanone	28,26		
5-Nonanone	26		
2-Decanone	4,5,10,13, 21,70	90,91	Citrus (66)
5-Decanone		90	
2-Undecanone	5,13	90	Fruity (66)
4-Undecanone	5,6,13		
2-Dodecanone	13		Waxy (66)
3-Dodecanone	7,8,13		
2-Tridecanone	6,13		
2-Tetradecanone	11		
2-Pentadecanone	4,5,13,15		
2-Hexadecanone	15		
2-Heptadecanone	15		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Aliphatic, cyclic			
Cyclopentanone, methyl	43		
4-Cyclopentene, 1,3- dione-4,5-dimethyl	4,43		
Cyclohexanone	10		
Cyclohex-2-enone, 2-methyl	43		
Cyclohex-2-enone, 4-methyl	43		
Cyclohex-2-enone, 2,6-dimethyl	43		
Cyclohex-2-enone, 3,5,5-trimethyl	43		
Ionone (isomers)	4,5		Woody-berry, violet- like (5)
Aromatic			
Acetophenone	6,10		
Acetophenone, 2-hydroxy	44		
Acetophenone, arylmethyl	28		
Acetophenone, 3-methoxy	11		
Methyl benzyl ketone	6		
Butyl benzyl ketone	11		
Methyl tolyl ketone	6,19		
Methyl naphthyl ketone	11		
Subtotal (%)	59 (8.5)	26 (10.3)	
ALCOHOLS			
Methanol	21,29,30,70	81,84,89,90	
Ethanol	4,5,7,8, 19-21,30,41, 45,70	81,85,87,89, 91-93	
Ethanol, 2-ethoxy	5		
Ethanol, 2-butoxy	4,5,13	90	
Propanol	7,8,13	91,93	
2-Propanol	19,21,22	90-92	
Propanol, 2-methyl	7,8	90,92	
2-Propanol, 2-methyl	7,8,31	90	
1-Butanol	2,4,5,7,8, 13,19-21,70	90-93	
2-Butanol	44,46		
Butanol, 2-methyl	6		
Butanol, 3-methyl	6,7,9,19,20	81,89,92	
2-Butanol, 2-methyl		85,92	
2-Butanol, 2,3-dimethyl	5		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
2-Buten-1-ol, 3-methyl	5		
3-Buten-2-ol, 3-methyl	5		
2,3-Butanediol	12,13		
Pentanol	4,5,7,8,10, 13,19-21,70	81,84,85,89-92	
2-Pentanol		81-89,92	
Pentanol, 3-methyl	5		
Pentanol, 4-methyl	5		
1-Penten-3-ol	5,7,8,18, 21,23	84,85,90,92	Grassy, ethereal (5)
Hexanol	4,5,10,13,19-22	81,85,89-92	
2-Hexanol		84,91-93	
2-Hexanol, 3-methyl	11		
2-Hexanol, 4-methyl	4,5		
2-Hexanol, 5-methyl	5		
Hexenol	6		
2-Hexen-1-ol	7,8		
3-Hexen-1-ol	6		
2-Hexen-1-ol, 3-methyl	6		
Heptanol	6,10,13,19, 20,22	81,89,93	
2-Heptanol	27	92	
3-Heptanol	13		
4-Heptanol	13		
1-Heptanol, 6-methyl	4,5		
2-Heptanol, 4-methyl	11		
2-Heptanol, 5-methyl	11		
Octanol	5,7,8,10, 13,19,20,70	84,93	
2-Octanol		92	
3-Octanol	5,13,15	84,92	
4-Octanol	5,13,15		
3-Octanol, 3-methyl	11		
1-Octen-3-ol	4,5,7,8, 10,21	83-85,92,93	Heavy, metallic, fungal (4), mushroom-like, slight metallic (5), mushroom, sickly, sweet (21)
2-Octen-1-ol	5,13,15	84	
2-Octen-3-ol	11		
2-Octen-4-ol	5		
Nonanol	10,15	84,93	
3-Nonanol	11		
4-Nonanol	5		
1-Nonen-3-ol	11		
Decanol	10,15		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Undecanol	15		
10-Undecen-1-ol	11,15		
Dodecanol	15,70		
Tridecanol	11		
Tetradecanol	11		
Pentadecanol	11		
Hexadecanol	11		
Octadecanol	11		
4-Terpineol	11		
Cyclopentanol	10,11		
Benzyl alcohol	4-6,13	93	
Benzyl alcohol, 2-methyl	11		
Phenethyl alcohol	16		
Subtotal (%)	60 (8.5)	24 (9.5)	
PHENOLS			
Phenol	4-6,13	87	
Phenol, 3-methyl		86	
Phenol, 4-methyl		86,87	
Phenol, 4-methyl-2,6-di- t-butyl	18	91	
Phenol, 4-methyl-3,5-di- t-butyl	10		
Phenol, ethyl		87	
Phenol, vinyl		93	
Phenol, 2-methoxy		85-87,93	
Phenol, 4-ethyl-2- methoxy		87	
Phenol, 2-methoxy-4-vinyl		85,93	
Subtotal (%)	3 (0.4)	9 (3.6)	
CARBOXYLIC ACIDS			
Aliphatic, acyclic			
Methanoic (formic)	41	87	
Ethanoic (acetic)	4,5,13, 41,70	80,87, 89,92	
Ethanoic, 2-phenyl		87	
Propanoic	7,41	80,87	
Propanoic, 2-methyl	29,30,41,30		
Propanoic, 3-phenyl		87	
Butanoic	2,7,13,42,70	87	
Butanoic, 2-methyl	13		
Butanoic, 3-methyl		80,87	
2-Butenoic		87	
2-Butenoic, 2-methyl		87	
Pentanoic	5	80,87	

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Pentanoic, 2-methyl	52		
Pentanoic, 4-methyl	52	80	
Hexanoic	5,7,8,70	80,84	
Heptanoic	5		
Octanoic	5	80	
Nonanoic	5	80	
Decanoic	32	80	
Dodecanoic	32		
Tetradecanoic	32		
Pentadecanoic	32		
Hexadecanoic	32		
Heptadecanoic	32		
9,12-Octadecadienoic	32		
Aromatic			
Benzoic		87	
Benzoic, 4-ethyl		87	
Benzoic, 2-hydroxy		79	
Benzoic, 4-hydroxy		79	
Benzoic, 2,5,-dihydroxy		79	
Benzoic, 4-hydroxy-3- methoxy		79	
Benzoic, 4-hydroxy-3,5- dimethoxy		79	
Cinnamic, 4-hydroxy		79	
Cinnamic, 4-hydroxy-3- methoxy		79	
Subtotal (%)	20 (2.9)	24 (9.5)	
ESTERS			
Methanoate (formate), methyl	32		
Methanoate, ethyl		93	
Methanoate, ethyl	4,5	91	
Methanoate, hexyl	5		
Methanoate, heptyl	5		
Methanoate, octyl	11		
Ethanoate (acetate), methyl		92	
Ethanoate, ethyl		87,91-93	
Ethanoate, butyl		92	
Ethanoate, pentyl	5	81,89,92	
Ethanoate, hexyl	5,11	84,92	
Ethanoate, heptyl	11	92	
Ethanoate, octyl	11		
Ethanoate, acetol	15,23		
Ethanoate, bornyl	5		
Ethanoate, citronellyl	11		
Ethanoate, terpinyl	11		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Propionate, butyl		91	
Butanoate, pentyl-3- methyl	11		
Butanoate, heptyl	11		
Pentanoate, ethyl	5,23		
Hexanoate, ethyl	5,11		
Hexanoate, pentyl		84	
Heptanoate, ethyl	5,11		
Octanoate, ethyl	5,11		
Nonanoate, ethyl	5,11		
Decanoate, ethyl	11		
Tetradecanoate, ethyl	11		
Pentadecanoate, ethyl	11		
Hexadecanoate, methyl	6,11		
Hexadecanoate, ethyl	11		
Heptadecanoate, ethyl	11		
Octadecanoate, ethyl	5,11		
Succinate, diethyl	11		
Phthalate, diethyl	5		
Phthalate, dibutyl	4,5		
Salicylate, methyl	11		
5,6-Dihydropyran-3,4- dimethyl-6-carboxylic acid methyl ester	48		
Subtotal (%)	33 (4.7)	8 (3.2)	
LACTONES			
γ -Butyrolactone	13	92	
γ -Crotonlactone		91	
γ -Butyrolactone, β -methyl		92	
γ -Butyrolactone, β -methylthia	50		Sulfur-like note of onions (50)
γ -Butyrolactone, 2-hydroxy- 3,3-dimethyl	50		
γ -Pentalactone	6-8,13	92	
δ -Pentalactone	13		
γ -Pentalactone, methyl	70		
2-Pentenoic acid, 4-hydroxylactone		87	
3-Pentenoic acid, 4-hydroxylactone		87	
Anhydromevalolactone	50,43		
γ -Hexalactone	4-6,13		
δ -Hexalactone	5,49		
2-Hexenoic acid, 4-hydroxylactone	5		
3-Hexenoic acid, 4-hydroxylactone	5		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
γ -Heptalactone	6,13	91	Sweet (66)
δ -Heptalactone	5,13		
γ -Octalactone	5,6,13		Oily (66)
δ -Octalactone	13		
γ -Nonalactone	5,13	84,93	Musk (66)
δ -Nonalactone	13		
2-Nonenoic acid, 4-hydroxylactone	5		Deep-fat fried (5)
3-Nonenoic acid, 4-hydroxylactone	5		Deep-fat fried (5)
γ -Decalactone	13,51		Oily, peachy, nut-like (66)
δ -Decalactone	6,13,51		Creamy, sweet, nut-like (66)
γ -Undecalactone	51	87	
δ -Undecalactone	51		
γ -Dodecalactone	6,51		
δ -Dodecalactone	6,51		
γ -Tridecalactone	51		
δ -Tridecalactone	51		
γ -Tetradecalactone	49,51		
δ -Tetradecalactone	49,51		
γ -Pentadecalactone	6		
δ -Pentadecalactone	49,51		
γ -Hexadecalactone	5		
δ -Hexadecalactone	5		
γ -Octadecalactone	49		
Subtotal (%)	35 (5.0)	9 (3.6)	
FURANS			
Furan	19,23,70	87,90,92	Beany, grassy (50), sickly, nasty-smelling (21)
Furan, 2-methyl	3,6,21,23,70	90	Pleasant, slightly sulfurous, meaty (3), sickly (21)
Furan, 3-methyl	21,23,70	90	
Furan, dimethyl	6,11		
Furan, 2,5-dimethyl	6,11,21,23	90	
Furan, trimethyl	6		
Furan, 2-ethyl	3,6,9,23,70	90	Acid, sour, whey butter-like (50)
Furan, 2-methyl-5-ethyl	6,21,23	90	
Furan, 2-propyl	3,4,6,11,21	90	
Furan, 2-methyl-5-propyl		90	
Furan, 2-propenal		90	

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Furan, 2-methyl- propenal	21		
Furan, 2-butyl	6,21,23	90	
Furan, 2-pentyl	3-9,13,21,23, 70,74	84,90,92	Licorice-like, beany- greenish (5), green, pungent, sweet (21)
Furan, 2-pentyl (cis and trans)		94	
Furan, 2-methyl-5- pentyl		90	
Furan, 3-(4-methyl- 3-pentenyl)		92	
Furan, 2-hexyl	13,21,23	90	
Furan, 2-hexenyl	21		
Furan, 2-heptyl	6,13,23		
Furan, 2-Octyl	13		
Furan, 2-hydroxymethyl	28,70		
Furan, 2-acetyl	5,6,47	87	
Furan, 2-acetyl-5- methyl	4-6	87	
Furan, 2-acetonyl		85	
Furan, 2-propionyl	4		
Furan, 2-acetyl-5- propionyl		87	
Furan, dihydro	6		
Furan, 2,3- dihydrobenzo		85	
Furan, 2- methyldihydrobenzo	6		
Furan, 2- methyltetrahydro		90	
Furan, 2-phenyl		91	
3-Furanone, dihydro- 5-methyl-4-hydroxy	52		
3-Furanone, dihydro- 2,5-dimethyl-4- hydroxy	52		Caramel-like, burnt pineapple (46,50), Strawberry-like (dilute) (50)
3-Furanone, tetrahydro- 2-methyl	6-8,70		
Furfural (2-furaldehyde)	4-6,10, 15,26	85,87,91-93	
2-Furfural, 5-methyl	5,6	85-87,93	Burnt, caramel-like, slightly meaty (50)
Furfural, 5-methyl-2- acetyl	4,5,70		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
2-Furfural, 5-thiomethyl	5,7,8		
2-Furylacetaldehyde	6		
3-(2-Furyl)- propionaldehyde	6		
4-(2-Furyl)- butan-2-one	6		
Furfuryl alcohol	4,5	85,93	
(2-Furyl)-ethanol	11		
3-(2-Furyl)-propanol	6		
2-Furan, carboxylic acid		87	
Furoate, methyl	70		
2-Furoate, ethyl	11		Burnt, buttery, vanilla-like (50)
2-Furoate, allyl	11		
2,2'-Difurfuryl ether	6		
2,3-Difurfuryl ether	6		
Furfuryl methyl ketone	15		Rum-like, radish (50)
Subtotal (%)	41 (5.9)	26 (10.3)	
PYRIDINES			
Pyridine	4,5,9,10,41		Vile (concentrated) (4), bitter, pleasant, roasted (dilute) (4)
Pyridine, methyl	3,10,28,70		Astringent, hazelnut- like (55)
Pyridine, dimethyl	3		
Pyridine, 3-ethyl-2,6- dimethyl	70		
Pyridine, 2-ethyl	44		Green (68)
Pyridine, 2-pentyl	44		
Pyridine, 2-acetoxy	50		
Pyridine, 2-carbonitrile	50		
Pyridine, 1,6-naphtha	43		
Nicotinate, methyl	50		
Nicotinonitrile	50		
Subtotal (%)	11 (1.6)	0 (0)	
PYRAZINES			
Pyrazine	3,5,65	85,86,88, 92,93	
Pyrazine, 2-methyl	3-5,10,16, 44,53,65,	85,86,88, 91-93	Potato-like (4), roasted, nutty (68)
Pyrazine, dimethyl	13		
Pyrazine, 2,3- dimethyl	16,10,44,65	85,86,88,93	Green, nutty (68)

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Pyrazine, 2,5-dimethyl	4,5,10,16,44,53,65,	85,86,88,91-93	Potato-like (4), roasted, earthy (5)
Pyrazine, 2,6-dimethyl	5,10,16,53,54,65,70	86,88,91-93	Roasted, earthy (5)
Pyrazine, trimethyl	10,16,44,53,65	85,86,88,91,93	Nutty, roasted (68)
Pyrazine, tetramethyl	16,44,53,65	86,88	
Pyrazine, 2-ethyl	3,16,44,65	92,93	Nutty, roasted (68)
Pyrazine, ethyl methyl	70		
Pyrazine, 3-ethyl-2-methyl	53		Nutty, roasted (68)
Pyrazine, 6-ethyl-2-methyl	16,24,65		
Pyrazine, 5-ethyl-2-methyl		91	
Pyrazine, 2-ethyl-3-methyl		85,88,93	
Pyrazine, 2-ethyl-5-methyl	16,44,53,65	85,88,93	
Pyrazine, ethyl dimethyl	70		
Pyrazine, 5-ethyl-2,3-dimethyl	53,65		
Pyrazine, 3-ethyl-2,5-dimethyl	15,16,44,47,53,65	85,86,88	
Pyrazine, 3-ethyl-2,6-dimethyl		86,88,93	
Pyrazine, 2-ethyl-3,5-dimethyl	15,53,65		Nutty, roasted (68)
Pyrazine, 3,5,6-trimethyl-2-ethyl	3,53	86,88	
Pyrazine, 2,6-diethyl	47,65	93	
Pyrazine, 2,3-diethyl-5-methyl	3,65		Nutty, roasted (68)
Pyrazine, 2,5-diethyl-3-methyl	3,53,65	93	
Pyrazine, 2,6-diethyl-3-methyl	44,65		
Pyrazine, 3,5-diethyl-2-methyl	53,65		
Pyrazine, 3,6-diethyl-2,5-dimethyl	65		
Pyrazine, triethyl	13,65		
Pyrazine, 2-vinyl	65		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Pyrazine, 6-vinyl- 2-methyl	65		
Pyrazine, methylpropyl	65		
Pyrazine, 2,6- dimethyl-3-propyl	3,53		
Pyrazine, 2,5- dimethyl-N-propyl		91	
Pyrazine, isopropenyl	65		
Pyrazine, propan-2-one	65		
Pyrazine, isobutyl- methyl	3		
Pyrazine, t-butyl	13		
Pyrazine, 2-acetyl	65		Popcorn (60,69)
Pyrazine, 2-acetyl-5- methyl	55,65		
Pyrazine, 2-acetyl-5- ethyl	65		
Pyrazine, 6,7-dihydro- 5(H)-cyclopenta	65,75		
Pyrazine, 6,7-dihydro- 5(H)-cyclopenta-2- methyl	65,75		
Pyrazine, 6,7-dihydro- 5(H)-cyclopenta-5- methyl	65,75		
Pyrazine, 6,7-dihydro- 5(H)-cyclopenta-2 (or 3)-5-methyl	65,75		
Pyrazine, 6,7-dihydro- 5(H)-cyclopenta-2, 3-dimethyl	75		
Pyrazine, 6,7-dihydro- 5(H)-cyclopenta-2- ethyl-3-methyl	75		
Pyrazine, 6,7-dihydro- 5(H)-cyclopenta-2, 3,5-trimethyl	75		
Pyrazine, pyrrolo	9,65		
Pyrazine, methylpyrrolo	76		
Pyrazine, 3-methyl- pyrrolo	76		
Pyrazine, 4-methyl- pyrrolo	76		
Pyrazine, 2,3-di- methylpyrrolo	76		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Pyrazine, 1,4- dimethylpyrrolo	76		
Pyrazine, 3,4-di- methylpyrrolo	76		
Subtotal (%)	50 (7.2)	17 (6.7)	
OTHER NITROGEN COMPOUNDS			
Ammonia	32,72,41	80	
Amine, methyl	32	80	
Amine, dimethyl		80,89	
Pyrrole, 2-formyl	4,5,57	85,93	
Pyrrole, 2-formyl- 1-methyl		85,86	
Pyrrole, 1-acetyl		93	
Pyrrole, 2-acetyl	4,5,13,15	85,93	Unpleasant, plastic, antiseptic (4), unpleasant, heated plastic (18), weak, brown, fruit-pit (5)
Pyrrole, N-methyl- 2-acetyl	15		
2-Pyrrolidone, 1-propyl		87	
Oxazole, 4,5-dimethyl	11		
Oxazole, 2,4,5- trimethyl	4,5		Nutty, sweet, green (9)
Oxazole, 2,4-dimethyl- 5-ethyl	57		
Oxazole, 2,5-dimethyl- 4-ethyl	57		
Oxazole, 2-isobutyl- 4,5-dimethyl	70		
3-Oxazoline, 2,4- dimethyl	57,70		Nutty, vegetable (9)
3-Oxazoline, 2,5- dimethyl	11		
3-Oxazoline, 2,4,5- trimethyl	4,7,47,70		Woody, musty green (9)
3-Oxazoline, 2,4- dimethyl-5-ethyl	57		Nutty, sweet, green, woody (9)
3-Oxazoline, 2,5- dimethyl-4-ethyl	57		Nutty, sweet, vegetable (9)
3-Oxazoline, 3,5- dimethyl-2,4-dione	43		
Thiazole	12		
Thiazole, 2-methyl	12		Green, vegetable (68)

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor description (References)
Thiazole, 4-methyl	12		
Thiazole, 2,4-dimethyl	12		Meat, cocoa-like (68)
Thiazole, 2,4,5- trimethyl	12		Cocoa, nutty (9,68)
Thiazole, 4-ethyl-2- methyl	12		
Thiazole, 5-ethyl-4- methyl	12		Nutty, green, earthy (68)
Thiazole, 5-ethyl-2,4- dimethyl	12,70		Nutty, roasted, meaty (9,68)
Thiazole, 2,4-dimethyl- 5-vinyl	12		Nut-like (50)
Thiazole, 4,5-dimethyl- 2-propyl	70		
Thiazole, 5-ethyl-4- methyl-2-isopropyl	70		
Thiazole, 4-methyl-5- (2-hydroxyethyl)	11,12		
Thiazole, 2-acetyl	4,5,12		Pleasant, popcorn-like, strong nutty, roasted (18), strong, nutty, cereal, pop- corn (50), pleasant, popcorn, strong, nutty, roasted (9), nutty, cereal, pop- corn (68)
Thiazole, benzo	4,5,10,12, 13,15,70	84	Slightly sweet, nutty, roasted-brown, slightly popcorn-like (18)
Thiazole, methyl- thiobenzo	43,50		Fatty, smoky (50)
3-Thiazoline, 2,4- dimethyl	53		Nutty, roasted, vegetable (9)
2-Thiazoline, 2- acetyl	58		Freshly baked bread, bready (56)
3-Thiazoline, 2- acetyl	12,77		
3-Thiazoline, 2,4,5- trimethyl	4,5,7,43,47		Meaty, nutty, onion (9)
Piperidine		85	
Pyrimidine, 2,4- dimethyl	43		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor description (References)
Pyrimidine, 4- acetyl-2-methyl	9,43		
Quinoxaline, 5,6,7,8- tetrahydro	65		
Quinoxaline, 5,6,7,8- tetrahydro-2-methyl	65		
Subtotal (%)	39 (5.6)	8 (3.2)	
SULFUR COMPOUNDS			
Hydrogen sulfide	9,21,29-32,41, 42,59,62	89,90,92	
Mercaptan, methyl	12,21,29-31, 41,42,59,65, 70,62	90	Sickly, sulfurous cooked vegetable (21)
Mercaptan, ethyl	21,29-31,41, 42,59,62	90	
Mercaptan, propyl	31,41	90	
Mercaptan, 2,2- dimethylpropyl	60		
Mercaptan, butyl	8,42		
Mercaptan, sec-butyl	61		
Mercaptan, isobutyl	12		
Mercaptan, t-butyl	59		
Mercaptan, butyl-2- methyl	12		
Mercaptan, 2-butyl-3- methyl	12		
Mercaptan, hexyl	61		
Mercaptan, Heptyl	61		
Mercaptan, octyl	59		
Mercaptan, nonyl	59		
Mercaptan, 1-methyl- thioethane	12,39,59		Meaty odor (18), fresh onion (39)
Mercaptan, benzyl	61		
Mercaptan, naphthyl	12		
Mercaptan, furfuryl	61		
β -Methyl mercapto- propionaldehyde (methional)	39		
Dimercaptan, 1,3- propane	61		
Dimercaptan, 1,4- butane	61		
Dimercaptan, 1,5- pentane	61		
Dimercaptan, 1,6- hexane	61		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Sulfide, dimethyl	6,8,9,13,21, 29-31,41,42, 70,62	90	Sickly, sulfurous (21)
Sulfide, ethyl methyl	12,21	90	
Sulfide, diethyl	12		
Sulfide, ethylene	21,23,59	90	Sickly, cooked cabbage, pungent (21)
Sulfide, propylene	21,23	90	
Sulfide, methyl propyl	7,8		
Sulfide, methyl isopropyl		90	
Sulfide, methyl allyl	7,8,18,28		
Sulfide, ethyl propyl	6		
Sulfide, diisopropyl	59		
Sulfide, propyl isopropyl	6,23		
Sulfide, diallyl	7,8		
Sulfide, methyl butyl	60		
Sulfide, ethyl butyl	60		
Sulfide, ethyl isobutyl	61		
Sulfide, dibutyl	61		
Sulfide, methyl pentyl	6	90	
Sulfide, dipentyl	61		
Sulfide, diisopentyl	61		
Sulfide, methyl octyl	59		
Sulfide, methyl nonyl	59		
Sulfide, methyl phenyl	60		
Sulfide, benzyl methyl	59		
Sulfide, vinyl phenyl	60		
Sulfide, carbonyl	21,63,70	90	
Sulfide, diacetyl	8		
Thiothane, 1,1- dimethyl	12		
Thioacetate, methyl	12		
Thioacetate, ethyl	59		
Thiopropionate, ethyl	6		
Thioanisole	61		
Disulfide, dimethyl	3,6,7,13, 19-21,31, 59,70	90,92	Very strong, sulfurous, garlic, onion (3), sulfurous, sickly, cooked cabbage (21)

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Disulfide, ethyl methyl	12,59,70		
Disulfide, methyl vinyl	12		
Disulfide, diethyl	6,12,59		
Disulfide, methyl propyl	59		
Disulfide, methyl isopropyl	59		
Disulfide, dipropyl	6,12		
Disulfide, diisopropyl	61		
Disulfide, dibutyl	61		
Disulfide, di-sec- butyl	17		
Disulfide, diisobutyl	61		
Disulfide, di-t-butyl	59		
Disulfide, dipentyl	61		
bis(Methylthio)- methane	59		
bis(Methylthio)- ethane	64		
Disulfide, 1,3- diethylene (1,3-dithiane)	60,61		
Disulfide, 1,4- diethylene (1,4-dithiane)	60,61		
Disulfide, carbon Trisulfide	21,23,59,70	90,91 90	
Trisulfide, dimethyl	21,59,61,70		Sulfurous, burnt, cooked cabbage (21)
Trisulfide, methyl ethyl	59		
Trisulfide, diethyl	59		
Tetrasulfide, dimethyl	11,59		
Sulfone, dimethyl	67		
1,3,5-Trithiane, 2,4,6-trimethyl (trithioacetaldehyde)	12		Heated meat (50)
1,3,5-Trithiane, 2,2,4,4,6,6- hexamethyl (trithioacetone)	12		
1,3-Dithiolane	60		
1,3-Dithiolane, 2-methyl	60		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
1,2,4-Trithiolane, 3,5-dimethyl	12,21,39, 47,65	90	Dry camphor (39)
1,3,4-Trithiolane, 2,5-dimethyl	7		
1,2,4-Trithiolane, 3-ethyl-5-methyl	12		
1,2,4-Trithiolane, 3-isopropyl-5- methyl	12		
1-(2-Thienyl)-1- propanone	12		
1-(2-Methyl-5- thienyl)-1- propanone	12		
Thiophene	12,21,59	90	Sickly, pungent (21)
Thiophene, 2-methyl	3,6,9,12, 21,59,70	90	Green, sweet (21)
Thiophene, 3-methyl	23	90	
Thiophene, 2,3- dimethyl	21		
Thiophene, 2,5- dimethyl	6,21,70		
Thiophene, 2-ethyl	6,12,30	90	
Thiophene, 2-propyl	6	90	
Thiophene, 2- propenyl	12		
Thiophene, 5-methyl- 2-propyl	12		
Thiophene, 2-butyl	6,12	90	
Thiophene, 2-dibutyl		91	
Thiophene, 2-t-butyl	60		
Thiophene, 3-t-butyl	60		
Thiophene, 2-pentyl	6,12,21	90,91	
Thiophene, 2-hexyl	6		
Thiophene, 2-heptyl	6		
Thiophene, 2-octyl	12		
Thiophene, 2- tetradecyl	12		
Thiophene, 3- tetradecyl	12		
Thiophene, 2- (hydroxymethyl)	12		
Thiophene, 2- butanoyl	11		
Thiophene, 2- heptanoyl	6,11		
Thiophene, 2- octanoyl	11		

Table 4 (cont'd.)

Chemical compound	Beef	Soy	Odor descriptions (References)
Thiophene, 2-carboxaldehyde	4,7,12 28,59		Spicy, meat (18), sharp, sweet, nutty, roasted grain-like (5)
Thiophene, 3-carboxaldehyde	12		
Thiophene, 2-carboxaldehyde-5-methyl	12		Cherry-like (50)
Thiophene, 3-carboxaldehyde-2,5-dimethyl	56		
Thiophene, 2-acetyl	6,12,59		
Thiophene, 3-acetyl	12		
Thiophene, 2-acetyl-5-methyl	12		Onion-like, malty, roasted (50)
Thiophene, tetrahydro-2-methyl	60		
Thiophene, tetrahydro-2,5-dimethyl	60		
Thiophen-3-one, tetrahydro	12		
Thiophen-3-one, tetrahydro-2-methyl	12		
Thiophenol	60		
Thiophenol, 2-methyl	60		
Thiophenol, 2,6-dimethyl	60		
Thiophenol, 2- t-butyl	60		
1,3,5-Dithiazine, 5,6-dihydro-2,4,6-trimethyl	12		
1,3,5-Dithiazine, perhydro-2,4,6-trimethyl (thialdine)	12,39		
Trithiepane		91	
Subtotal (%)	127 (18.2)	24 (9.5)	
HOLOGENATED COMPOUNDS			
Carbon, tetrachloro	70		
Methane, trichloro (chloroform)	4,5,18		
Ethane, trichloro	70	91	
Ethane, tetrachloro	3		
2-Propanol, 1-chloro	3		
Benzene, chloro	10,70		

Table 4 (cont'd.)

Chemical compound	Beef volatile	Soy volatile	Odor descriptions (References)
Benzene, 1,4-dichloro	4,5,7,8,10		
Benzene, tetrachloro		91	
Biphenyl, 2-chloro	11		
Subtotal (%)	8 (1.1)	2 (4.0)	
MISCELLANEOUS COMPOUNDS			
Air	70		
Carbon dioxide	70	92	
Water	70		
Ethyl isopropyl ether	5		
Dipentyl ether	7		
Diphenyl ether	11		
1,1-Dimethoxyethane	5		
1,1-Diethoxyethane	4,5	84	
1,1-Diethoxypropane		84	
1,1-Diethoxy-n-hexane	11	84	
1,1-Diethoxy-n-octane	11		
1,1-Diethoxynonane		84	
Methoxybenzene (anisole)	6		
1,3-Diethoxybenzene	5		
Methoxytoluene	6		
Butylated hydroxyanisole	6		
Butylated hydroxytoluene	6		
Dimethyl pyrone		87	
Pentyl pyrone	5,11		
3-Hydroxy-2-methyl-4-pyrone		87	
Cyanobenzene	11		
Benzyl cyanide	11		
Isomaltol		87	
Coumarin		87	
Methylcoumarin		87	
Hexanonitrile	5		
Hexamethyldisiloxane	70		
Trimethylethoxy-silane	70		
Trimethylsilanol	70		
Hexamethylcyclo-trisiloxane	70		
Octamethylcyclo-tetrasiloxane	70		
Subtotal (%)	24 (3.4)	10 (4.0)	
Total (%)	697 (100)	252 (100)	

^aReferences:

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|----------------------------|-------------------------------|
| 1. Merrit (1974) | 48. Lee et al. (1981) |
| 2. Sanderson et al. (1966) | 49. Watanabe and Sato (1968a) |

Table 4 (cont'd.)

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|-----------------------------------|------------------------------------|
| 3. MacLeod and Coppock (1976) | 50. Ohloff and Flament (1978b) |
| 4. Peterson et al. (1975) | 51. Watanabe and Sato (1968b) |
| 5. Peterson and Chang (1982) | 52. Tonsbeek et al. (1968) |
| 6. Min et al. (1979) | 53. Flament and Ohloff (1971) |
| 7. Hirai et al. (1973) | 54. Park et al. (1974) |
| 8. Herz (1968) | 55. Ho et al. (1983) |
| 9. Laurie (1982) | 56. Mussinan and Walradt (1974) |
| 10. Mottram et al. (1982) | 57. Mussinan et al. (1976) |
| 11. Hsu et al. (1982) | 58. Tonsbeek et al. (1971) |
| 12. Wilson et al. (1973) | 59. Golvnja and Rothe (1980) |
| 13. Liebich et al. (1972) | 60. Garbusov et al. (1976) |
| 14. Maillard (1912) | 61. Shankaranarayana et al. (1982) |
| 15. Watanabe and Sato (1972) | 62. Takken et al. (1976) |
| 16. Watanabe and Sato (1971) | 63. Grey and Shrimpton (1967) |
| 17. Holley (1978) | 64. Hartman et al. (1984) |
| 18. Chang and Peterson (1977) | 65. Mussinan et al. (1973) |
| 19. Wicks (1963) | 66. Arctander (1969) |
| 20. Wicks (1965) | 67. Shankaranarayana et al. (1975) |
| 21. Peterson and von Sydow (1973) | 68. Pittet and Hruza (1974) |
| 22. Wicks et al. (1967) | 69. Robert (1964) |
| 23. Peterson et al. (1973) | 70. Galt and MacLeod (1984) |
| 24. Greenberg (1981) | 71. Lillard and Ayres (1969) |
| 25. Wilson and Katz (1972) | 72. Hornstein et al. (1960) |
| 26. Uralets and Golovnja (1980) | 73. Qvist and von Sydow (1976) |
| 27. Piotrowski et al. (1970) | 74. Nonaka et al. (1967) |
| 28. Wong et al. (1975) | 75. Flament et al. (1976) |
| 29. Bender (1961) | 76. Flament et al. (1977) |
| 30. Bender and Ballance (1961) | 77. Evers (1976) |
| 31. Self et al. (1963) | 78. Fujimaki et al. (1965) |
| 32. Allen and Foegeding (1981) | 79. Arai et al. (1966a) |
| 33. Cho and Bratzler (1970) | 80. Arai et al. (1966b) |
| 34. Yamato et al. (1970) | 81. Arai et al. (1967) |
| 35. Giacino (1970) | 82. Sessa et al. (1969) |
| 36. Hoffman and Meijboom (1968) | 83. Badenhop et al. (1969) |
| 37. Nixon et al. (1979) | 84. Wilkens et al. (1970a) |
| 39. Brinkman et al. (1972) | 85. Wilkens et al. (1970b) |
| 40. Kramlich and Pearson (1960) | 86. Manley et al. (1970a) |
| 41. Yueh and Strong (1960) | 87. Manley et al. (1970b) |
| 42. Brennan and Bernhard (1964) | 88. Maga et al. (1973) |
| 43. Flament et al. (1978) | 89. Cowan et al. (1973) |
| 44. Watanabe and Sato (1971b) | 90. Qvist and von Sydow (1974) |
| 45. Bailey and Swain (1973) | 91. Palkert (1980) |
| 46. Hodge (1967) | 92. Rosario et al. (1984) |
| 47. Chang et al. (1968) | 93. Kato et al. (1981) |
| | 94. Arai et al. (1970) |

Sulfur-containing compounds (18.2%), hydrocarbons (17.5%), followed by aldehydes (9.5%), alcohols (8.6%) and ketones (8.5%) make up the largest proportion (62.5%) of the cooked beef volatiles.

Chemical Nature and Relative Contribution of Volatiles to Cooked Beef Aroma

Cooked beef volatiles with varying degrees of solubility in water, are present in low concentrations, and give rise to a variety of odor sensations (MacLeod and Seyyedain-Ardebili, 1981). In contrast to the non-volatiles, few are essential intermediates in the biochemistry of the animal (Schutte, 1976). With minor variations, the composition of all meat is similar and this is reflected in the volatile compounds isolated from different cooked meat samples (Dwivedi, 1975; Shahidi et al., 1986).

Thus far, no single compound uniquely responsible for cooked beef aroma has been identified, although some have been described as meat-like (Table 4, Wasserman, 1979). According to Wasserman (1979), direct evidence for the involvement of individual chemical compound in cooked beef aroma is difficult to glean from the literature for the following reasons:

- (1) No true character impact compounds exist;
- (2) Very few studies have been quantitative;
- (3) Threshold values for all compounds are not available; and
- (4) Additive, antagonistic, and synergistic effects occur.

Characteristically, cooked beef aroma is subdivided into boiled and roasted beef aroma. Boiled beef aroma is produced in the presence of water whereby the temperature during boiling does not exceed 100°C;

whereas, roasted beef aroma is liberated under relatively drier heating conditions whereby the temperature rises well above 100°C (Wasserman, 1979). The summarized comparison of boiled versus roasted beef volatiles by MacLeod and Coppock (1977) reveals that except for aliphatic amines and carboxylic acids, thiols, dithianes, dithiolanes, trithiolanes and hydantoins, all other chemical classes have been more frequently identified in roasted than in boiled beef aroma.

Min et al. (1979) studied the volatile compounds in the neutral fraction of roast beef. Due to the powerful odor characteristics and relatively large numbers of lactones, substituted aromatics, furans, and sulfur compounds, these classes of compounds were considered to be important contributors to roast beef flavor.

Chang and Peterson (1977) listed carbonyl compounds, aliphatic and aromatic hydrocarbons, saturated alcohols, esters and ethers as classes which, in their opinion, may not be primary contributors to beef flavor. They also listed classes of compounds that they believed to be important. These include lactones, furanoid or hydrofuranoid compounds, acyclic sulfur-containing compounds, and heterocyclic compounds containing sulfur, nitrogen, and oxygen.

Schutte (1974) suggested that carbonyls, heterocyclics, and, sulfur- and nitrogen-containing compounds, as well as some phenols, are the most important contributors to beef flavor. Bodrero et al. (1981) concluded that sulfur compounds and nitrogen and oxygen heterocyclics are the most important groups contributing to beef aroma.

A number of compounds identified in beef flavor volatiles have been described when isolated from meat systems. However, some have apparently

been described independently since the food system was not specified (Table 4). Many of the odor descriptions have been assigned by the investigators in a purely subjective fashion without resorting to acceptable methods of sensory evaluation. Nevertheless, Table 4 permits some interesting observations. Various terminologies were used by different researchers to describe a particular compound as in the case for hexanal, benzaldehyde, 3-methylbutanal, and 1-octen-3-ol. While the descriptions given for 1-octen-3-ol provide similar impressions, compounds such as 2-methylfuran and 2-acetylpyrrole have been given conflicting descriptions. 1-Octen-3-ol, for example, has been described as mushroom, sickly and sweet (Persson and von Sydow, 1973), mushroom, slightly metallic note (Peterson and Chang, 1982), and heavy metallic and fungal (Peterson et al., 1975). 2-Methylfuran has been described as sickly (Persson and von Sydow, 1973), and pleasant, slightly sulfurous, and meaty (MacLeod and Coppock, 1976). Both description pertain to the compound as evaluated in beef. As pointed out by Shahidi et al. (1986), relatively few of the compounds identified in beef volatiles have so far been described organoleptically. Not more than a dozen compounds have been organoleptically described by two or more research workers. No alcohols, acids, or esters have been evaluated.

In general, pyrazines frequently have roasted/burned/grilled, nutty, green or earthy aroma (Pittet and Hruza, 1974; Ohloff and Flament, 1978a). Several members of the oxazoles, oxazolines, thiazoles and thiazolines have been described as nutty. Other odor descriptions frequently associated with the oxazoles and oxazolines are sweet, green, woody, musty, and vegetable-like (Mussinan et al., 1976). Some thiazoles

and thiazolines (2,4-dimethylthiazole, 2,4-dimethyl-5-ethylthiazole, trimethylthiazoline), however, have meaty odors (Pittet and Hruza, 1974; Mussinan et al., 1976). Many Strecker aldehydes contribute to "browned", roasted, and toasted aromas (Self et al., 1963; Hodge et al., 1972). Thiophenes are also believed to contribute roasted notes in meat (Maga, 1975). Diacetyl and acetoin are considered to provide a buttery note to cooked meat (Hirai et al., 1973; Peterson and Chang, 1975).

Persson and von Sydow (1973) demonstrated that certain carbonyl and sulfur compounds are responsible for the high heat (retort) off-flavor of canned beef. Chang and Peterson (1977) suggested that 2-formylpyrrole, 2-acetylpyrrole and benzothiazole may contribute to the retort flavor of canned beef stew. MacLeod and Coppock (1977) provided evidence that carbonyl compounds (particularly 2-methylbutanal), sulfides and also pyrroles and pyridines are probably important in roasted aromas of heated beef and tentatively suggested that benzenoids and furans may contribute to the desirable qualities associated with well-cooked beef.

There are a number of sulfur compounds (Table 5) that have been synthesized and are described as having meat odor characteristics. None of these has been found in meat volatiles (May, 1974; D'Souza, 1984). It is therefore evident that the cooked meat aroma profile is due to the sum of all sensory effects produces simultaneously at the olfactory epithelium by a large number of volatiles of different structures present in a particular quantitative proportion (MacLeod and Coppock, 1977; Ohloff and Flament, 1978b; Rhodes, 1979).

Table 5. Compounds possessing meaty notes.

Chemical compounds	Aroma notes (References) ^a
Furan	
4-Mercapto-2-methyl-	Green, meaty, herbaceous (1,2)
4,5-Dihydrofuran	
3-Mercapto-2-methyl-	Roasted meat (1,2)
Tetrahydrofuran	
4-Mercapto-3-oxo-	Green, meaty, maggi-like (1,2)
4-Mercapto-5-methyl-3-oxo-	Meaty, maggi-like (1,2)
Furanone	
4-Mercapto-5-methyl-3(2H)-	Sweet, meat-like (2)
Mercaptan	
Pyrazinyl methyl	Roasted meat-like (1)
Thiol	
2-Ethylbenzene-	Burnt, meatlike (1)
2-Methyl-3-furan-	Roasted meat (1)
Pyrazine methane-	Roasted meat (1)
Thiophene	
3-Mercapto-2-methyl-	Roasted meat (1,2)
2,3-Dihydrothiophene	
3-Mercapto-2-methyl-	Sweet, roasted meat (1,2)
3-Mercapto-4-hydroxy-2-methyl-	Meaty, savory (2)
4,5-Dihydrothiophene	
3-Mercapto-	Meaty (2)
3-Mercapto-2-methyl	Meaty (2)
4-Mercapto-2-methyl-	Roasted meat (2)
Tetrahydrothiophene	
3-Mercapto-2-methyl-	Meaty (2)
4-Mercapto-2-methyl-	Meat-like (2)

^aReferences:

1. Chang and Peterson (1977).
2. van den Ouweland and Peer (1975).

Comparison of Beef and Soy Volatiles

Unlike cooked beef aroma, hydrocarbons (13.5%), aldehydes (12.3%), ketones and furans (10.3% each) are more frequently identified in SPP than the sulfur-containing compounds (9.5%) (Table 4). In comparison, relatively little research effort has been expended in the characterization of volatile components in heated/raw SPPs. Some 252 compounds have been identified in the volatile fractions of SPP. In general, heating causes an increase in the concentrations of soy volatiles.

Kato et al. (1981) examined the changes in the volatile components of soybeans during roasting (200°C for 10-30 min). They found that the major volatile components of raw soybeans, such as n-hexanol, 1-octen-3-ol and n-hexanal, decreased during the course of roasting, but the rate of decrease was not rapid. During roasting, alkylated pyrazines, oxygenated furans and pyrroles, and phenols were formed or increased markedly. Sensory evaluation showed that a flavor change to desirable from "beany" or "objectionable" occurred between 10-20 min of roasting. These results suggested that the roasted flavor (possible contributors may be 2-ethyl-5- (and 3-) methyl-pyrazine) may have masked the "beany" flavor in soybean. Hrdlicka and Cuba (1971) studied the changes in sulfur-containing compounds when heating soy protein with glucose. They found an increase of the total amount of such compounds with increasing temperature and/or heating time.

More recently, Rosario et al. (1984) in their comparison of head-space volatiles from winged beans and soybeans revealed that raw soybean volatiles contained a significant amount of methyl substituted 1-butanols, pentanol, hexanol, 2-/3-octanol, and 1-octen-3-ol, and few

furans, pyrazines, sulfur compounds and terpenoids. On heating, the concentration of nearly all compounds decreased except for pentanal, hexanal, 2-heptanone, 1-penten-3-ol, 1-octen-3-ol, 2-pentylfuran, methylpyrazine, 2,5- and 2,6-dimethylpyrazine. These results are in disagreement with those of Hrdlicka and Cuba (1971), Qvist and von Sydow (1974) and Kato et al. (1981).

Qvist and von Sydow (1974) offered the only report comparing the similarities and dissimilarities of the volatiles isolated from heated beef and heated soy isolate (Promine D). The authors reported that although aldehydes are important in both samples, the concentrations of butanal, pentanal, and hexanal are much higher in heated soy isolate. The important branched-chain aldehyde, 2-methylpropanal is about four times more abundant in heated soy isolate than in heated beef. More furans were detected in the heated Promine D sample and the concentrations of those present in both samples were generally higher in the heated soy protein sample. On the other hand, hydrogen sulfide, methanethiol, ethanethiol, dimethylsulfide, and ethylene sulfide are present in larger concentrations in heated beef; whereas, methyldisulfide and thiophene are generally somewhat higher in concentration in the soy sample. In general, the concentrations of almost all volatiles (except alcohols) increased on heating, independent of protein source. A number of new compounds (particularly sulfur compounds) are detected in heated samples.

Based on odor threshold data and experience from samples of heat sterilized beef, Qvist and von Sydow (1974) concluded that the odor of all heated samples depends on the presence of low molecular weight

branched-chain aldehydes and sulfur compounds. Several straight-chain aldehydes and several furan derivatives are particularly important to flavor in the heated soy isolate.

Flavoring Textured Soy Protein Products

Meat Flavor System

An array of meat flavors (beef, chicken, bacon, ham, and pork) based on hydrolyzed proteins and including the appropriate precursors required for heat-generated flavors are available in liquid, paste, or spray dried states (Gutcho, 1977). In general, the precursors for these flavors consist of an amino and/or sulfur source on the one hand, and reducing sugars or carbonyl compounds on the other (Manson and Katz, 1976; Schutte, 1976). According to MacLeod and Seyyedain-Ardebili (1981) and Gutcho (1977), these commonly include:

- (1) Amino acids/peptides/nucleotides
glycine, B-alanine, aspartic and glutamic acid, lysine, histidine, proline, glutathione, and 5'-nucleotides;
- (2) Protein hydrolyzates
hydrolyzed vegetable protein, defatted cod fish flesh, casein, whey, ground nut, egg, yeast, blood and liver hydrolyzates;
- (3) Sulfur-containing compounds or hydrogen sulfide releasing agents
cysteine, thiamine, hydrogen sulfide, methionine, taurine, egg protein, vegetable extract, organic thiols and sulfides, inorganic sulfides, thiocarbonates, thioamides, 2-mercapto-alkanoic acids and their amides, mercaptoalkylamines, mercapto-alcohols, and S-acetylmercaptosuccinic acid;
- (4) Sugars and carbonyl compounds
arabinose, glucose, fructose, lactose, ribose, xylose, ribose-5-phosphate, hydrolyzed polysaccharides, yeast autolyzate/hydrolyzate, aliphatic aldehydes, ketones, nucleotide carbohydrate, ascorbic/isoascorbic acid, furanones or their precursors, and carboxylic acids;
- (5) Fats
beef fat, edible fat, coconut oil, triglyceride, fatty material, and fatty acids;

- (6) Solvents, and,
water, glycerol, propan-1,2-diol, ethanol, and ethandiol;
- (7) Flavor adjuvants
stabilizers, thickeners, surface active agents, conditioners,
flavorants, and flavor intensifiers.

The commonly used sulfur-containing compounds have been cysteine, thiamine, and hydrogen sulfide. Cysteine is the paramount source of sulfur-containing volatiles and is active either in the free form or within the tripeptide glutathione or as part of proteinaceous materials such as hydrolyzed vegetable protein (MacLeod and Seyyedain-Ardebili, 1981). Of all the amino acids occurring naturally in meat, cysteine and cystine yield the meatiest odors when subjected to thermal processing (Wilson, 1975).

Wilson (1975) also considered the relevance of methionine and taurine in processed meat flavors. The use of methionine is limited to flavors in which the "potato skin" odor of methional (Strecker aldehyde) and the "green vegetable" odor of methanethiol and dimethyldisulfide are either suppressed, tolerable, or desired (Wilson, 1975). Methionine is the preferred amino acid for pork flavor (Gutcho, 1977). Taurine (2-aminoethanesulfonic acid) present in natural meat extract at ~1.2-1.5% by weight on a dry basis (Gutcho, 1973) appears in several patents but its role is uncertain (Wilson, 1975).

Carbonyl compounds supply a roasted burned note which is both highly desirable and also difficult to obtain in their absence (Wilson, 1975). Pentoses are more reactive than hexoses (May, 1974; Gutcho, 1977); sugar phosphates are more reactive than sugars (Manson and Katz, 1976). Strecker degradation perpetuates the supply of carbonyl compounds in

the form of Strecker aldehydes.

In 1980, Hsieh et al. using surface response methodology, developed a synthetic model meat flavor system consisting of an autoclaved mixture of three simple sugars (glucose, xylose, and ribose), ten amino acids (glycine, alanine, monosodium glutamate, cysteine hydrochloride, methionine, taurine, leucine, isoleucine, serine, and arginine), inosine-5'-nucleotide, guanosine-5'-nucleotide (optional), glyco-protein, salt, and fat (optional). The meat flavor produced is claimed to be equal to or superior to commercial meat flavor extracts and nearly equal to authentic beef extracts. A closely parallel system developed by Schrodter and Wolm (1980) consisted of glucose and nine amino acids (aspartic and glutamic acid, histidine, alanine, glycine, serine, proline, arginine, and cysteine-hydrochloride). The optimized model was characterized by very high amounts of aspartic and glutamic acid, arginine and proline.

Of increasing importance in formulating meat flavorings are meat flavor-contributing chemicals (mercaptofurans and mercaptothiophenes) which have not yet been identified in natural meat aroma (van den Ouweland and Peer, 1978). Because of the complexity of meat flavor and incomplete knowledge, a genuine fascimile has not yet been produced.

Methods of Flavoring

Thermally-induced meat flavors may be added to TSP before or after texturization. Numerous methods have been suggested and utilized for the flavoring of TSP. These include: pre-extrusion flavor addition, flavor development from precursors during extrusion, and post-extrusion

flavor addition. Combinations of two or more of these methods are also used (Fischetti, 1975; Palkert, 1980; Kinsella, 1983).

Post-extrusion Flavor Addition

Currently, flavor addition most commonly occurs post-extrusion (Blanchfield and Ovenden, 1974; Pagington, 1975; Williams et al., 1977a). This involves: (1) hydrating the TSP in a flavor medium followed by drying, or (2) spraying an oil and flavor mixture onto the dried TSP (Pagington, 1975).

Post-extrusion flavor addition suffers from the disadvantage of involving an additional processing step and thus would be considerably more expensive than pre-extrusion addition of flavor compounds or flavor precursors. Also, post-extrusion added flavorings are very prone to loss during storage (Blanchfield and Ovenden, 1974). Additionally, the hydration method is prone to flavor loss through leaching, while the surface flavor addition method results in uneven distribution of the flavors (Fischetti, 1975).

Pre-extrusion Flavor Addition

On the other hand, pre-extrusion flavor addition is the simplest and cheapest method of flavor addition (Blanchfield and Ovenden, 1974; Fischetti, 1975; Pagington, 1975). This method yields a homogeneously flavored product which probably suffers little flavor loss during storage (Pagington, 1975). However, at present pre-extrusion flavoring yields an unsatisfactory flavored product and considerable flavor loss apparently occurs during extrusion (Pagington, 1975; Williams et al., 1977a).

Palkert (1980) studied the effect of extrusion processing upon flavor retention in pre-extrusion flavored TSP using a Tenax trapping system. The synthetic meat flavors consisted of C₃-C₄ sulfides, C₂-C₄ disulfides, heterocyclics (2,4-dimethylthiazole, 2,5-dimethylthiophene, furfural and pyrrole), and undecanal. The author reported that the die temperature of the extruder from 205-230°C had little effect upon flavor retention. In contrast, decreasing the third barrel temperature from 205°C to 180°C reduced flavor retention by more than half. Palkert (1980) attributed the reduction in flavor recovery to the highest density of the low temperature extruded sample which inhibited flavor migration during sampling.

Interacting the synthetic meat flavors with soy flour in the presence of water prior to extrusion, slightly increased the flavor retention. Drying TSP under conditions which reduced its moisture content from 10% to 3.5% resulted in little loss of the flavor compounds, with the exception of furfural. Furfural, however, is known to polymerize rapidly even at room temperature (Noller, 1966). Its loss during drying was probably due to polymerization rather than volatilization.

In general about 90% of the pre-extrusion added flavor compounds could not be recovered following extrusion. The recovery of the compounds ranged from 4-22%, with the nitrogen-containing heterocyclics: pyrrole (20%) and 2,4-dimethylthiazole (22%), being recovered to a much greater extent than the rest. However, there was no obvious relationship between molecular structure and their recovery following extrusion.

According to Palkert (1980), processes causing the loss of pre-extrusion added flavor compounds during processing include (Palkert,

1980);

- (a) Thermal degradation, oxidation, and polymerization of the added flavor compounds during extrusion;
- (b) Reaction of the added flavor compounds with soy flour components during extrusion; and,
- (c) Volatilization of the flavor compounds during extrusion or post-extrusion during drying of the TSP.

Except for the effect of post-extrusion drying, the quantitative effects of these processes are difficult to determine (Palkert, 1980).

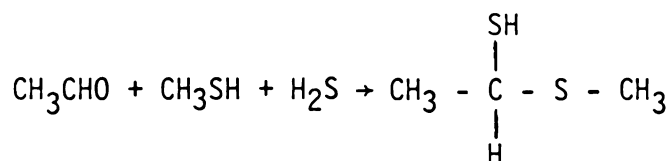
Pre-extrusion Addition of Flavor Precursors

The use of flavor precursors which react with one another or with soy flour components during extrusion forming desirable flavor compounds has been suggested by many workers (Coleman, 1975; Hashida, 1974; Heath, 1972; Pagington, 1975; van den Ouweland and Schutte, 1978; Schutte and van den Ouweland, 1979; Kinsella, 1983). However, many difficulties arise in this method from the fact that the optimum conditions for TSP productions are narrow and do not correspond to those for flavor development (Blanchfield and Ovenden, 1974). Additionally, Maillard reactions used for the production of meat flavors are open ended and undesirable flavors can also develop during storage (Blanchfield and Ovenden, 1974; Heath, 1972).

The pre-extrusion addition of flavor precursors has the advantage of not involving an addition processing step as is the case of post-extrusion flavor addition. It also has the unique potential of yielding flavors characteristic of the degree of doneness of the meat to which the flavored TSP has been added (Heath, 1972).

van den Ouweland and Schutte (1978) reported that the pre-extrusion addition of a well balanced mixture of carbonyls (glycoaldehyde, gloxal,

pyruvaldehyde, dihydroxyacetone, glyceraldehyde, acetoin, diacetyl and hydroxydiacetyl) or an Amadori compound and hydrolyzed vegetable protein/yeast autolysates generated a meaty background in TSP. Additionally, the meaty background may be intensified with the use of two meat flavor-generating reactions. The first one is an interesting example of the way in which amino acids can act as flavor precursors for the formation of 1-methylthioethanethiol. The formation of this compound has been described by Schutte and Koenders (1972) with the net result being as follows:



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CHAPTER I
COMPARATIVE AROMA ASSESSMENT OF SELECTED MEAT/BEEF FLAVORS

ABSTRACT

The meatiness and general aroma qualities of two synthetic meat flavors (HH and SW) thermally generated from mixtures of meat flavor precursors were sensorially compared to those of the commercial (BV, MM, H0, and GG) and natural (BE) beef flavors. A sample from each group (HH, H0, and BE) was selected for further descriptive aroma evaluation against a conceptualized "Ideal" meat flavor. The synthetic flavors were significantly more meaty than the commercial samples while not being significantly different in meatiness from the natural sample. The dominant aroma qualities of HH were "Meaty", "Toasted/Burnt", and "Cooked Vegetables", of H0 were "Spicy/Fragrant" and "Cooked Vegetables", and of BE were "Meaty" and "Flat/Dull".

INTRODUCTION

A synthetic meat flavor consisting of an autoclaved mixture of meat flavor precursors (amino acids, simple reducing sugars, 5'-nucleotides, and glycoprotein) and salt with fat as an optional component was developed by Hsieh et al. (1980). The thermally-generated meat flavor mixture was found to be equal or superior to several of the commercially available synthetic meat flavor mixtures and nearly equal to natural beef extract. Concurrently, a system involving a mixture of amino acids and glucose was independently developed in East Germany by Schrodter and Wolm (1980). However, descriptive sensory evaluations were not conducted on either models.

Despite the importance of correlating chemical data with sensory scores for meat aroma, only four detailed descriptive sensory reports on meat aroma are available. The first was a study of the sensory properties of canned beef aroma using 28 odor qualities (Persson et al., 1973), while a second involved a comparison of the odor qualities of beef cooked conventionally and by microwave radiation (MacLeod and Coppock, 1978). More recently, Galt and MacLeod (1983) applied factor analysis to previously published data (MacLeod and Coppock, 1978) and concluded that nine major factors describe the sensory properties of raw/cooked (boiled and roasted) beef aroma. With regard to simulated meat flavors, MacLeod and Seyyedain-Ardebili (1981) published the only

report comparing the sensory properties of the aroma of natural (boiled and roasted) and some commercially available simulated beef flavors. However, the compositions of these simulated flavors were not disclosed.

Because of our interest in meat flavor development via pre-extrusion addition of flavor precursors, the model conceived by Hsieh et al. (1980) and a model based on the composition proposed by Schrodter and Wolm (1980) were first evaluated sensorially for their meatiness and aroma qualities, and compared with those of commercial and natural beef flavors. On the basis of this study, three samples each of synthetic, commercial, and natural origins were selected for further descriptive aroma evaluations. The purpose of this study was to relate the development of meat flavor to formulation variables in a systematic manner. The flavor precursor mix of the selected model was used in subsequent extrusion studies.

EXPERIMENTAL

Selection of Meat/Beef Flavors

Two synthetic, four commercial and one natural meat/beef flavor mixtures were selected for this study and their compositions are presented in Table 1. Synthetic meat flavors were thermally generated from a mixture of flavor precursors and could be consistently and easily reproduced in the laboratory. Of the commercial samples, only those described as beefy flavored, offered variety with respect to price and composition, and that were available in local supermarkets/specialty shops, were selected for the study. Based on earlier conclusive evidence that precursors of the characteristic aroma of meat are low molecular weight, water-soluble compounds (Batzer et al., 1960; 1962; Wasserman and Gray, 1965; Zaika et al., 1968), a heated cold-water extract of ground beef chuck was used as the natural beef (or reference) flavor sample.

Preparation of Meat/Beef Flavors

Synthetic Meat Flavors

The synthetic meat flavor mixture developed by Hsieh et al. (1980) was prepared as described. A second system of the composition proposed by Schrodter and Wolm (1980) was also prepared. The chemical composition of these two systems is presented in Table 2.

Table 1. Chemical compositions of flavor precursors of synthetic meat flavors.

Flavor precursors ^a	Synthetic meat flavors ^b			
	HH		SW	
Simple D sugars				
Glucose	60 ^d	(6.4) ^c	220.7 ^d	(23.6) ^c
Ribose	40	(4.3)		
Xylose	60	(6.4)		
Subtotal	160	(17.1)	220.7	(23.6)
L-amino acids				
Glycine	8	(0.8)	18.7	(2.0)
Alanine	23	(2.5)	18.7	(2.0)
Leucine	10	(1.0)		
Isoleucine	9	(1.0)		
Serine	21	(2.2)	18.7	(2.0)
Cysteine Hydrochloride	20	(2.1)	63.6	(6.8)
Methionine	11	(1.2)		
Taurine	22	(2.4)		
Aspartic acid			112.2	(12.0)
Glutamic acid			239.4	(25.6)
Glutamic acid (monosodium salt)	20	(2.1)		
Arginine	6	(0.6)	112.2	(12.0)
Histidine			18.7	(2.0)
Proline			112.2	(12.0)
Subtotal	150	(15.9)	714.4	(76.4)
5'-Nucleotides				
Inosine monophosphate (IMP)	25	(2.7)		
Glycoprotein				
Gelatin*	500	(53.5)		
Salt				
Sodium chloride (Table salt)	100	(10.7)		
Total	935	(99.9)	935.1	(100.0)

^aAll chemicals were of 95-99%+ purity and obtained from Sigma^R Chemical Company (St. Louis, MO) except where specified.

^bSee Table 2.

^cPercent dry weight.

^dWeight in mg per 50 mL of deionized water.

*Knox unflavored gelatin (Lipton Co., Englewood Cliffs, NJ).

Table 2. Characteristic features and formulations of synthetic, commercial, and natural meat/beef flavors.

Meat/Beef Flavor	Symbol used	Aroma character	Physical appearance	Formulations/Use-level (%) ^a /Price (\$/100 g) ^b
Synthetic meat flavors Model developed by Hsieh et al. (1980a)	HH	"Meaty"	Clear, brown liquid	Thermally generated from a mixture of amino acids (glycine, alanine, leucine, isoleucine, serine, cysteine, simple reducing sugars, 5'-nucleotide (IMP [*]), glycoprotein (gelatin), and salt/1.8c/25.25c
Model based on the composition proposed by Schrodter and Wolm (1980)	SW	"Meaty"	Clear, pale yellow liquid	Thermally generated from a mixture of amino acids and glucose/1.8c/13.49c.
Commercial beef flavors Beef-flavored drink	BV	"Beef"	Opaque, dark brown viscous liquid	Basic formulation ^d plus beef stock and extract, hydrolysed beef protein, powdered lean beef, HVP [*] , yeast extract, starch, lactic acid and spices/~5.0/3.00
Beef-flavored soup base	MM	"Beef"	Light brown sauce cube	Basic formulation plus dehydrated beef stock, beef fat, HVP, MSG [*] , dry vegetables (onion, parsley and carrot), hydrogenated cottonseed oil, yeast extract, spices, BHA [*] +propyl gallate and tumeric/~1.8/1.80
Beef-flavored soup base	H0	"Beef"	Light brown sauce cube	Basic formulation plus beef extract, beef fat, natural flavoring, sugar, malto-dextrin, onion, and spices/~1.8/0.64
Beef-flavored soup base	GG	"Beef"	Dark brown viscous paste	Basic formulation plus roasted beef, beef fat, HVP, MSG, flavoring, and soybean lecithin/~5.0/2.04

Table 2 (cont'd.)

Natural beef flavor	BE	"Beef"	Clear meat broth	Thermally generated from cold-water extract of lean ground beef chuck/~5.8 ^c /24.16 ^c
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^aGram (g) of meat/beef flavors per 100 g of water x 100%.
^bEstimated from current local retail and/or Sigma's (Sigma^R Chemical Company, St. Louis, MO) catalogued prices.

^cBased on flavor precursors.

^dBasic formulation includes salt, caramel, and disodium inosinate and guanylate.

*Abbreviations:

IMP	Inosine monophosphate	HVP	Hydrolyzed vegetable protein	MSG	Monosodium glutamate
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To develop the flavor in each of the synthetic systems, the components were weighed into a 125 mL flask and solubilized in 25 mL of deionized water. The mixture was then autoclaved at 17 psi for 90 min at 121°C (Castle Thermatic 60, Wilmot Castle Co., Rochester, NY). The flavor mixture was diluted with an equal volume of hot deionized water before presenting to the panel.

Commercial Beef Flavors

Four commercial beef flavors purchased from local supermarkets/specialty shops were prepared according to the manufacturers' specifications and standardized as follows: 10 g (± 0.1 g) sample of the liquid/paste or a sauce cube (3.75 ± 0.1 g) was added to 200 mL (1 cup) of hot boiling water.

Natural Beef Flavor

Fresh ground beef chuck (80% lean) was obtained from Food Stores (Michigan State University, East Lansing, MI) and homogenized with 4 times its weight of cold deionized water for 2 min in a Waring blender according to the procedure of Zaika et al. (1968). The homogenate was allowed to stand for 2 hr at 4°C and filtered through cheese cloth. The solids in the filtrate were further separated by centrifugation (International Centrifuge, Model K, size 2, top speed for 10 min; International Equipment Co., Needham Heights, MA).

The supernatant, after discarding the top fat layer, was divided into 150 mL portions. Each portion was delivered into a 300 mL round-bottomed flask and subsequently frozen in a dry ice-acetone bath on a Rotovapor^R (model 310928, Buchi, Switzerland). The frozen portions

were lyophilized overnight at room temperature (21°C). Approximately 37.1±1.3 g of freeze-dried extract was obtained from 1 kg of fresh ground beef chuck.

The moisture content of the beef was found to be 66.8±0.3% (A.O.A.C. method 24.003, 1975). Based on this analysis, 1.45 g of the freeze-dried sample were redissolved in 25 mL of deionized water. For meat flavor development, the solution was autoclaved. Clear beef extract, served both as natural beef flavor and reference sample, was obtained by filtering the autoclaved sample through glass wool.

Sufficient samples from each group were prepared a week in advance and stored under nitrogen at -20°C.

Presentation of Meat/Beef Flavors

Seven mL of each of the prepared meat/beef flavors were pipetted into 20 mL wide-necked Kimble Opticlear^R vials and capped with hollow polyethylene caps (Thomas Scientific Co., Swedesboro, NJ). Each sample was randomly coded with a three-digit number, heated on high for 10 sec in a microwave oven (model 02216, Tappan Microwave Oven, Tappan Co., Mansfield, OH) and served immediately to the panelists in their individual booths. Three samples were served in a controlled order at each session. A reference sample of natural beef extract was provided throughout the first half of the study. The panelists were instructed to uncap the vials and to evaluate the aroma by sniffing in the order presented without retracking. To eliminate any possible physical effects among samples, red-colored light was used during aroma assessment.

Experimental Designs and Sensory Methodology

General Aroma Assessment

The samples were initially presented in a balanced incomplete block design of seven treatments (treatments=blocks=7), number of replications=number of treatments per block=3), number of occurrence per pair of treatments=1, and efficiency of design=0.78; Cochran and Cox, 1957). All seven possible tertiary combinations of meat/beef flavors were evaluated by each panelist over a total of seven sessions, with two sessions per day, for 3 1/2 consecutive days. At each session, the panelists were requested to: (a) evaluate each sample for "meaty" aroma on a 1 (does not contribute or resemble meat aroma) to 9 (exceptionally good full meaty aroma) point scale as utilized by Hsieh et al. (1980), and (b) describe the perceived aroma qualities associated with each sample. Based on the results obtained, three samples each of synthetic, commercial, and natural origins were selected for further comparative study involving descriptive aroma evaluation.

Descriptive Aroma Evaluation

A completely randomized block design was used in the second half of this study. Only one session was conducted. The panelists were requested to score the three selected samples and a conceptualized "Ideal" meat flavor for intensity of each of the six major aroma descriptors: "Meaty", "Cooked vegetables", "Toasted/Burnt", "Oily/Fatty", "Spicy/Fragrant", and "Flat/Dull" on a 1-10 point scale where 1 represented none or absent and 10 represented very pronounced intensity. Ten-point intensity scales have previously been used by Persson et al.

(1973) and MacLeod and co-workers (1978; 1980).

Sensory Panel

Participating in this study were six trained panelists (2 females and 4 males, aged 20-40) recruited among the staff and graduate students at this research facility. They were previously screened from a pool of twenty-one panelists for their consistency in intensity scaling and ability to discriminate between aromas. All panelists have received formal training in sensory evaluation and were familiar with evaluating meat products.

Statistical Analyses

To ascertain whether significant differences exist and to afford multiple comparisons among samples, collected sensory data were statistically analyzed with Analysis of Variance followed by Duncan's Multiple Range Test (Duncan, 1955) and/or Dunnett's t-test (Dunnett, 1964). The "Ideal" meat flavor was treated as the control in Dunnett's t-test for 1 control and 3 treatments. The applied statistical procedures and inferences were in accordance to those of Gacula and Singh (1984).

RESULTS AND DISCUSSION

General Aroma Assessment

Preliminary evaluations of meaty aromas (Table 3) using 1 (does not contribute or resemble meat aroma) to 9 (exceptionally good full meaty aroma) revealed that the synthetic meat (HH and SW) and natural beef flavors (BE) were rated significantly higher than the four commercial beef flavors (BV, MM, HO and GG), while no significant difference was found between the natural and synthetic samples, or within sample groups at ($p < 0.01$), as previously reported by Hsieh et al. (1980).

The two synthetic meat flavor mixtures (HH and SW) were scored 5.8 and 5.6, respectively, indicating that they faintly (to slightly) resembled meat aroma. The commercial beef flavors (BV, MM, HO, and GG) had mean panel scores of 3.7, 3.4, 3.8, and 3.7, respectively, implying that they probably resembled meat aroma. The natural beef flavor (BE) had a slight meaty aroma and received a mean panel score of 6.1. The meatiness of the natural beef flavor (BE) could probably be increased by using a more concentrated extract. This may also have been true for the other flavors.

Descriptive terms used by the panelists to evaluate the aroma qualities of the samples are summarized in Table 3. Many of the terms were previously used by Persson et al. (1973), and by MacLeod and Coppock (1978) to describe the cooked beef aroma. The synthetic meat

Table 3. Meaty aroma ratings and general comments on aroma qualities of synthetic, commercial, and natural meat/beef flavors.

Meat/Beef flavor ^a	Meaty aroma ratings ^b	General comments on aroma qualities
Synthetic meat flavor ^d		
HH	5.8±1.7	Burnt (14) ^c , sulfurous (10), onion-like (5), roasted meat (3), and vegetables (2)
SW	5.6±1.8	Strongly sulfurous (18), burnt (4), garlic-like (4), roasted meat (3), vegetables (2), onion-like (2), chemical-like (1)
Commercial beef flavor ^e		
BV	3.7±0.8	Cooked vegetables (10), onion-like (7), garlic-like (6), soy sauce like (4), spicy (3), sweet (3), bouillion-/oxo-/MSG-like (1), and hydrolyzed vegetables (1)
MM	3.4±0.7	Strong vegetables (6), onion-like, burnt (6), bouillion-like (2), cooked potato-like (2), brothy (1), spicy (1), and soy sauce-like (1)
HO	3.8±0.8	Onion-like (14), cooked vegetables (10), garlic-like (5), bouillion-like (2), soy sauce-like (2), salty (2), sweet (2), meaty (1), and burnt (1)
GG	3.7±1.1	Onion-like (14), vegetables (7), garlic-like (4), bouillion-like (4), sweet (4), spicy (3), brothy (2), salty (2), soy-like (1), and caramel (1)
Natural beef flavor ^d		
BE	6.1±1.2	Sweet (8), boiled meat/diluted beef broth (5)

^aSee Table 2, and Experimental section for details.

^bMeans±standard deviations of a 6-member panel. A 1 (does not contribute or resemble meat aroma) to 9 (exceptionally good full

Table 3 (cont'd.)

meaty aroma) point scale was used.

^cTotal frequency of use.

^dAre significantly higher than ^e at $p < 0.01$ as established using the Analysis of Variance and Duncan's Multiple Range Test.

flavors were frequently described as sulfurous, burnt, and roasted meat, while cooked vegetables, garlic-like, and onion-like characterized the aromas of the commercial beef flavors. As observed by MacLeod and Seyyedain-Ardebili (1981), burnt or roasted aroma qualities in the synthetic flavors tended to obliterate rather than augment the meaty aroma quality present.

Sulfurous aroma, due to the addition of sulfur-containing amino acid(s) in the systems (Gutcho, 1977; MacLeod and Seyyedain-Ardibili, 1981; Hsieh et al., 1980), was more pronounced in SW than in HH. The major sulfur-donor(s) in SW and HH were cysteine hydrochloride and cysteine hydrochloride and methionine, respectively. Suppression of the sulfurous aroma could be brought about by (a) the addition of gelatin and fat, and optimizing the ratio of cysteine:alanine as reported by Hsieh et al. (1980), (b) the addition of disodium inosinate (Kuninaki, 1966), and (c) adjusting the pH to 3.0 with sulfuric or hydrochloric acid to dispel excess hydrogen sulfide (Weiner, 1972). Interestingly, the aromas of the synthetic meat flavors were occasionally described as onion-like or garlic-like. Some of the non-enzymatic browning reaction products, viz., hydrocarbons, lactones, mercaptans, thiazolines, thiophenes, and disulfides, reportedly contribute to onion-like and/or garlic-like aroma qualities (Shahidi et al., 1986). These compounds may be present in the aroma volatiles of the synthetic flavors and contribute an onion-like or garlic-like note to their aroma.

The aroma of the natural beef flavor was frequently described as sweet, boiled meat, and brothy. Batzer et al. (1960) similarly described the dialyzable water-extract of raw beef muscle as having a

beef broth aroma when boiled with water.

The highest rated samples (HH of the synthetic meat flavors and H0 of the commercial beef flavors) were selected for subsequent extrusion studies. Comparative descriptive aroma evaluations were subsequently conducted on these flavor mixtures as well as the natural beef flavor (BE).

Descriptive Aroma Evaluation

The intensity scores of the six major descriptors for the selected and "Ideal" meat/beef flavors were statistically analyzed and are presented in Table 4. Selection of the descriptors was based on comments resulting from general aroma assessments and from the work by Galt and MacLeod (1983). The results were in agreement with the preliminary findings of the previous section.

Again, the synthetic meat flavor (HH) and the natural beef flavor (BE) were scored significantly ($p < 0.01$) higher in "Meaty" aroma than the commercial beef flavor (H0), while no significant ($p < 0.01$) difference in meatiness was found between the synthetic (HH) and natural (BE) samples. The results of the descriptive aroma evaluations further indicated that the synthetic meat flavor (HH) was significantly ($p < 0.01$) more pronounced in the "Toasted/Burnt" aroma qualities than the commercial (H0) and natural (BE) samples. On the other hand, the commercial beef flavor (H0) was significantly ($p < 0.01$) more "Spicy/Fragrant" than the other two samples (HH and BE). Interestingly, both the synthetic (HH) and commercial (H0) samples were scored higher in "Cooked Vegetables" than the natural (BE) sample at $p < 0.01$, while the

Table 4. Intensity scores of six major aroma descriptors for an "Ideal" and three selected meat/beef flavors.

Major aroma descriptor aroma qualities	"Ideal" meat flavor	Selected meat/beef flavors ^a		
		Natural (BE)	Synthetic (HH)	Commercial (HO)
"Meaty" broth-like meaty/boiled meaty/roasted	7.8±1.2 ^b	6.2±1.2	6.0±1.2	3.3±0.5*
		<u>BE HH</u> > HO ^c (p<0.01) ^d		
"Cooked vegetables" cooked cabbage vegetables, overcooked	4.3±1.0	2.7±1.2*	5.0±1.5	6.2±1.3*
		<u>HO HH</u> > BE (p<0.01)		
"Toasted/Burnt" toasted burnt	3.0±0.6	1.8±0.8	6.2±1.6**	3.5±1.4
		HH > <u>HO BE</u> (p<0.01)		
"Oily/Fatty" oily fatty	3.7±1.2	2.3±1.2*	2.0±0.9*	2.5±1.0
		<u>HO BE HH</u> (p<0.05)		
"Spicy/Fragrant" spicy fragrant	4.7±1.5	3.7±1.6	3.8±1.7	6.5±1.2**
		HO > <u>HH BE</u> (p<0.01)		
"Flat/Dull" flat dull	1.0±0.0	4.0±1.6**	1.7±0.8	2.0±1.07
		BE > <u>HO HH</u> (p<0.05)		

^a See Table 2 and Experimental section for details.

^b Intensity scores were rated on a 1 (none) 10 (pronounced) point intensity scale. Values reported were the means±standard deviations of a 6-member panel.

^c Samples are listed in decreasing order of intensity where underscored samples are not significantly different as established using the Analysis of Variance and Duncan's Multiple Range Test.

^d Level of significance.

*and ** refers respectively to significantly lower and higher than "Ideal" at p<0.05 as established using the Analysis of Variance and Dunnett's t-test.

latter was significantly ($p < 0.05$) higher in "Flat/Dull".

In general, the dominant aroma properties (average intensity scores) associated with (a) the synthetic meat flavor (HH) were "Meaty" (6.0), "Toasted/Burnt" (6.2), and "Cooked Vegetables" (5.0), (b) the commercial beef flavor (H0) were "Spicy/Fragrant" (6.5), and "Cooked Vegetables" (6.2), and (c) the natural beef flavor (BE) were "Meaty" (6.2) and "Flat/Dull" (4.0). All three samples (HH, H0, and BE) were described as having very slight "Oily/Fatty" aroma notes.

Similar conclusions were drawn when comparing the selected meat/beef flavors against the "Ideal" meat flavor. At $p < 0.05$, the synthetic meat flavor (HH) was significantly higher in "Toasted/Burnt" and lower in "Oily/Fatty" than ideally desirable, while the commercial beef flavor (H0) was significantly lower in "Meaty" and higher in "Spicy/Fragrant" and "Cooked Vegetables" than the "Ideal" model. In contrast, the natural beef flavor (BE) was significantly ($p < 0.05$) lower in "Cooked Vegetables" and "Oily/Fatty" and more pronounced in "Flat/Dull" than the "Ideal" meat flavor. "Flat/Dull" may be negatively correlated with "Meaty", "Toasted/Burnt", "Spicy/Fragrant", and/or "Cooked Vegetable". The mean intensity scores of the six major aroma descriptors for the "Ideal" meat flavor were as follows: "Meaty" - 7.8, "Cooked Vegetables" - 4.3, "Toasted/Burnt" - 3.0, "Oily/Fatty" - 3.7, "Spicy/Fragrant" - 4.7, and "Flat/Dull" - 1.0. These scores may be viewed as the optimum or ideal levels of intensities.

Again, some of the non-enzymatic reaction products, Strecker aldehydes, pyrazines, thiazoles, thiazoline, thiophenes, sulfides, and furans, have been reported to contribute to burnt and roasted aroma

qualities (Shahidi et al., 1986), and may be responsible for the more intense level of "Toasted/Burnt" aroma property in the synthetic flavor. However, aromatizing agents such as straight or branched alkyl substituted α - β -unsaturated aldehydes can be used to provide, improve or modify savory, burnt, or meaty flavors (Pickenhagen and Velluz, 1982). Their application in the synthetic flavor should be investigated.

A potato-/cabbage-like aroma has been observed in heated glucose-methionine mixtures (Arroyo and Lillard, 1970; Lindsay and Lau, 1972). The latter authors suggested that browning reaction products such as mercaptans and sulfides were probably responsible for the cabbage-like odor, while methional played a major role in imparting the boiled potato-like aroma. Therefore, methionine may be directly responsible for the "Cooked Vegetables" aroma property associated with the synthetic flavor. The significance of the volatile components in contributing to these aroma qualities will be discussed more fully in Chapter III.

HVP, dry vegetables, and spices in the formulations of commercial beef flavors contributed directly to "Cooked Vegetables" and "Spicy/Fragrant" aroma properties characterizing these samples.

CONCLUSIONS

The meaty aromas of the two synthetic meat flavor mixtures were not rated as being significantly different from that of the natural beef flavor, but all were rated significantly higher than those of the commercial beef flavor samples. Burnt and sulfurous, and cooked vegetables, garlic-like, and onion-like generally comprised the nonmeaty aroma qualities frequently associated with the synthetic meat flavors and commercial beef flavors, respectively. The natural beef flavor was described as being sweet, boiled meat, and brothy. Descriptive aroma evaluations further revealed that the synthetic meat flavor was characterized by having more "Toasted/Burnt" notes than the "ideal", natural and commercial meat/beef flavors, while the latter tended to have pronounced "Spicy/Fragrant" and "Cooked Vegetables" aroma characteristics. In comparison, the natural beef aroma was characterized as being more "Flat/Dull".

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CHAPTER II
MEAT FLAVOR GENERATION IN EXTRUDED SOY PROTEIN PRODUCTS.
I. SENSORY EVALUATION

ABSTRACT

The investigation into the effects of pre-extrusion addition of meat flavor precursors on the sensory properties of a soy extrudate (15HH) revealed that there was a moderate, but significant improvement in "Meaty" flavor when compared to an unflavored extrudate (UFC). No significant difference in meatiness was observed between 15HH and a commercial beef flavored extrudate (15H0). Neither the flavor precursor system nor the commercial beef flavor was entirely successful in masking the "Green" and "Beany" off-flavors of soy protein products. Except for saltiness where 15H0 was rated significantly higher, no differences in "Roasted", "Sweet" or "Bitter" notes were found among 15HH, 15H0, and UFC, nor when they were compared to a conceptualized "Ideal" meat flavored extrudate (IMF). All three extrudates were scored significantly lower in "Meaty" flavor but higher in "Green" and "Beany" notes than ideally desirable. Subtle differences in moisture and fat contents, pH values, and browning indices $_{420\text{nm}}$ were observed among 15HH, 15H0, and UFC.

INTRODUCTION

Controlling off-flavor development while successfully simulating desirable meat flavor in extruded soy protein products is a major factor preventing the more widespread use of extruded soy protein products as meat extenders or analogs (Gruelle, 1974; van den Ouweland and Schutte, 1978; Kinsella and Damodaran, 1980; Palkert, 1980; Kinsella, 1983; Kinsella et al., 1985). Flavor addition most commonly occurs after extrusion, either by hydrating the extrudate in a flavor medium followed by drying, or by spraying an oil and flavor mixture onto the dried extrudate (Blanchfield and Ovenden, 1974; Pagington, 1975; Williams et al., 1977; Kinsella et al., 1985). These methods, however, suffer from the disadvantage of involving an additional processing step. In addition, added flavors are not evenly distributed throughout the product (Fischetti, 1975), and can be lost during storage or through leaching while cooking in an aqueous medium (Blanchfield and Ovenden, 1974).

Pre-extrusion addition or internal application of flavors to a soy mix is more practical, but extensive losses occur during processing due to steam volatilization of the flavor compounds at the exit port of the extruder and binding by proteins (Pagington, 1975; Williams et al., 1977; Palkert and Fagerson, 1980). The extent of loss varies with the compound (Palkert and Fagerson, 1980). Thus, flavor development from precursors during extrusion has been suggested as a solution by several

authors (Heath, 1972; Hashida, 1974; Coleman, 1975; Pagington, 1975). This latter technique has the unique potential of producing flavors characteristic of the degree of doneness of the meat to which the flavored TSP has been added (Heath, 1972). Several researchers have stated that the optimum conditions for the production of soy extrudate are often narrow (20-30 sec) (Williams et al., 1977), and may not correspond well to those for flavor development (Blanchfield and Ovenden, 1974). Furthermore, undesirable flavors may develop during storage (Blanchfield and Ovenden, 1974; Heath, 1972). However, such information is frequently proprietary and unavailable to the general scientific community.

To date, results of sensory or instrumental analyses of soy extrudate pre-extrusionally added with meat flavor precursors have not been published. With the more recent developments in meat flavor research as discussed in Chapter I, pre-extrusion addition of the meat flavor precursors developed by Hsieh et al. (1980) offered a challenging and viable alternative. This paper, therefore, constitutes the first of a three-part study on meat flavor development from added precursors during extrusion.

The objective of this study was to examine the effects of pre-extrusion addition of meat flavor precursors on the sensory properties of a soy extrudate. These properties are discussed in relation to those of the extrudate pre-extrusionally flavored with a commercial beef flavor, an unflavored product, and a conceptualized "Ideal" meat flavored extrudate. A previous study (Chapter I) formed the basis for the selection of the flavor systems examined.

EXPERIMENTAL

Material

Defatted Soy Flour

Soyafluff^R 200W defatted soy flour (mesh size 100, protein dispersion index-moderate, 50-54% protein, 6-9% moisture, 1-1.5% fat, 36-28.5% carbohydrate, 5-7% ash; Central Soya Co., Fort Wayne, IN) was used in this study.

Flavor Systems

Meat flavor precursors (Hsieh et al., 1980) containing 17.1% reducing sugars, 16.0% amino acids, 2.7% nucleotide, 53.5% gelatin, and 10.7% salt was formulated in the laboratory. Commercial beef flavor (H0) containing beef extract, beef fat, natural flavoring, salt, sugar, caramel, disodium guanylate/inosinate, malto-dextrin, spice, and onion, was obtained from a local supermarket. Detail descriptions of these flavor systems have been reported earlier (Chapter I).

Model System Study

Thermal development of meat aroma in a soy protein matrix on adding varying levels of the meat flavor precursor system was examined. Experimental results were used as a guide for establishing the level of addition of the precursor system in defatted soy flour for subsequent extrusion study. The results of this part of the study, which were

preliminary in nature will not be discussed under "RESULTS AND DISCUSSION".

Preparation

Reaction mixtures for the model system study were prepared by careful delivery into 100 mL crimped-sealed serum-type reaction vial (Supelco Inc., Bellefonte, PA) with the components listed in Table 1 (in the order from left to right).

Table 1. Chemical composition of model systems.

Vial no.	Water (g)	Flavor precursors (g)	Defatted soy flour (g)	Total weight (g)
1	1.50	0.00 (5%) ^a	5.00	6.50
2	1.45	0.24 (5%)	4.81	6.50
3	1.40	0.46 (10%)	4.64	6.50
4	1.35	0.67 (15%)	4.48	6.50
5	1.30	0.87 (20%)	4.33	6.50
6	1.26	1.05 (25%)	4.19	6.50

^aPercent weight, weight of defatted soy flour.

Based on previous extrusion studies by Aguilera (1976), Maurice et al. (1976) and Palkert (1980), water was added at a level of 30% (wet basis) of the total weight of defatted soy flour. No correction was made for the presence of moisture (~6%) in the flour. Upon delivery of the flavor precursors, the mixture was sonicated (Ultrasonic Vibrator, Fisher Scientific Co., Fair Lawn, NJ) for 5 min to solubilize the chemical components. Due to the relatively small amount of water present, a considerable amount of the flavor precursors, particularly the gelatin, remained undissolved. Gradual addition of defatted soy flour was accomplished while stirring intermittently on a vortex stirrer

(Virtis 45 Homogenizer, The Virtis Co., Gardiner, NY). The reaction mixtures were conditioned overnight at 4°C. Subsequently, the serum reaction vials were heated individually in a glycol bath (Hi-TempTM Model 160, Fisher Scientific Co., Fair Lawn, NJ) at 220°C for 8 min. Duplicate sets of vials were prepared. After heating, the outsides of vials were washed with acetone and the vials stored at -20°C until ready for the ranking test. The crimp-sealed caps were replaced with Mininert^R valves (Supelco Inc., Bellefonte, PA) for ease of handling. The valves were set in a "closed" position at all times.

Ranking Test

The test conditions, the six-member panel, and the general sample handling and coding procedures used in the model study and in subsequent evaluation of extrudates were described earlier (Chapter I). Two sessions, a week apart, were conducted. During each session, the panelists were presented with six coded samples in a random order. Immediately before serving, the samples were heated on high for 20 sec in a Tappan microwave oven (Model 02216, Tappan Co., Manfield, OH). The panelists were requested to uncap, sniff, and rank the samples for meat aroma intensity (1-least intense to 6-most intense). Duplicate assessments by the six panelists were treated as representative of twelve panelists for the purpose of data analysis.

The rank totals for the samples containing 0, 5, 10, 15, 20 and 25% of the flavor precursors were 22, 25, 31, 59, 56, and 59, respectively. Rank totals required for significance for 12 panelists and six treatments at the 5% level are <32 and >52 (Kramer, 1963). Therefore,

the flavor precursors were added at a level of 15% of the weight of the flour in the extrusion study. Similarly, the commercial beef flavor (H0) was added at a 15% level without further testing.

Extrusion Study

Preblending Flavor Systems with Defatted Soy Flour

Because of the process design and the limited solubility of flavor precursors in water as mentioned earlier, the flavor systems were preblended with defatted soy flour before extrusion. Two flavored and one unflavored preblends of 8 kg each were formulated. The flavored preblends were prepared by initially mixing 1.2 kg of each of the flavor systems with 2 kg of the flour in a Hobart Mixer (Model K-200) set at speed one for 5 min. Thereafter, the remaining 4.8 kg of flour was added in three stages alternated with a 3-min mixing period. When the flour was completely added, mixing was continued for another 5 min to ensure uniform distribution of the flavor system in the soy matrix. An unflavored preblend was similarly prepared with 1.2 kg of defatted soy flour added in place of the flavor system. The preblends were prepared in the order of: unflavored, flavored with meat flavor precursors, followed by flavored with commercial beef flavor. All three preblends were placed in polyethylene bags and stored overnight at 4°C before being extruded.

Extrusion Process

The extrusion runs were carried out at the Gerber Products Company (Fremont, MI) with the assistance of their Food Product Development Team. The pilot plant extruder used was a Creusot-Loire twin screw

extruder (Model BC-45, Creusot-Loire, France) having the following specifications: barrel length 50 centimeter (cm), barrel diameter 5.5 cm, die diameter 0.4 cm, one zone electric heater, electrically heated die assembly, variable speed motor assembled drive unit capable of screw speeds from 110 to 150 revolutions per min. The screw profile was made up of 5 screw element sections as listed below from beginning to product discharge:

<u>Screw pitch (cm)</u>	<u>Screw Element Length (cm)</u>
5.0	20
3.5	10
2.5	5
1.5	10
1.5 (cut flight element)	5
	<u>50</u>

The material to be extruded was fed into the extruder using a gravity feeder. Water for moistening the feed materials (the flavored and unflavored preblends) was fed through a line feeder to the mixing chamber of the mixing chamber of the extruder.

Trial extrusion runs (feed moisture 22-28%, screw speed 110-150 rpm, barrel temperature 140-170°C) with the flavored and unflavored preblends revealed that the optimum condition for the production of extruded soy protein products did not coincide with the conditions necessary for optimum flavor development. The flavored preblends containing either the meat flavor precursors or the commercial beef flavor when extruded under the conditions used for the unflavored preblend produced an excessively burnt, charred and friable product.

Rather than resorting to a compromise set of extrusion condition, the flavored and unflavored preblends were extruded using the following

set of conditions:

	<u>Flavored</u>	<u>Unflavored</u>
Feed moisture (%) (wet basis)	28	28
Screw speed (rpm)	130	150
Barrel temperature (°C)	155	160

The materials were extruded in the order described previously for the preblending of the flour flavor mixtures. The initial product (~2 kg) of each extrusion run was discarded with the remainder (~6 kg) being collected, and dried at 55°C for 10-15 min. The three extrudates prepared were: UFC - the unflavored product, and 15HH and 15H0 - the products pre-extrusionally added with the precursor system and the commercial beef flavor, respectively.

After drying, the extrudates were placed in polyethylene bags and stored at 4°C for subsequent testings. The elapsed time was approximately three weeks. A representative 1.5 kg sample was randomly drawn from each extrudate. Subsequent test samples were obtained from the 1.5 kg sample.

Chemical/Physical Analyses

In preparation for the following analyses, 45 g of each extrudate were finely ground in 15 g portions (~1.5 min) using a Waring blender. The ground samples were used for moisture, fat, pH, and browning index determinations. Each test was carried out in triplicate.

Moisture and fat determinations were carried out according to A.O.A.C. (1975) procedures, 24.003 and 24.005, respectively. The browning index was determined using a clear brown extract obtained by adding 20 mL of deionized water to a 5 g sample in a test tube. The

content was stirred continuously for 1 min using a vortex stirrer and filtered through Whatman #2 filter paper followed by a membrane filter (0.45 μ M Metrice1^R membrane filter) to remove any minute particles which may interfere with the absorbance reading. Absorbance of the extract was read at 420 nm using a Spectronic^R 2000 (Bausch and Lomb, Rochester, NY). Browning index was expressed as absorbance 420 nm $\times$ 100. pH was determined using a standardized digital ionalyzer (Model 601A, Orion Research Inc., Cambridge, MA).

Sensory Evaluation

The three extrudates (UFC, 15HH, and 15H0) were profiled in terms of aroma ("Meaty", "Roasted", "Green", and "Beany") and flavor-by-mouth ("Meaty", "Roasted", "Green", "Beany", "Sweet", "Salty", and "Bitter") on a 1 (none) to 10 (very pronounced) point intensity scale. The choice of the descriptors was limited to those which were reported to have significant influence on the sensory properties of soy extrudates intended for use as meat extenders or analogs (van den Ouweland and Schutte, 1978; Rackis, 1979; Palkert, 1980; Kinsella, 1983).

For aroma evaluation, 10 g of each extrudate were hydrated with 20 mL of water for 10 min in a coded, covered plastic container. Subsequently, they were heated on high for 10 sec in the microwave oven and served immediately to the panelists. For evaluation of flavor-by-mouth, the extrudates were served as meat snacks without rehydration.

A completely randomized block design was used in sample presentation. Additionally, each panelist was requested to provide a sensory profile of a conceptualized "Ideal" meat flavored soy extrudate (IMF).

Water was provided for rinsing between samples to reduce carryover flavor.

Statistical procedures and inferences as described in Chapter I were used for data analyses and interpretation.

RESULTS AND DISCUSSION

Chemical/Physical Analysis

The chemical (% moisture and % fat) and physical (pH and browning index) data of the extrudates (UFC, 15HH, and 15H0) were statistically analyzed and compared (Table 2).

Soy extrudate (15HH), flavored with meat flavor precursors was found to be significantly higher in browning index (BI), and significantly lower in pH and moisture content as compared to 15H0 or UFC at $p < 0.01$. In contrast, pre-extrusion addition of the commercial beef flavor did not significantly ($p < 0.01$) affect the moisture nor pH of the extrudate (15H0) as compared to the unflavored product (UFC). However, the fat content was found to be significantly ($p < 0.01$) higher in 15H0 than in either 15HH or UFC. The unflavored soy extrudate (UFC), on the other hand, was significantly ($p < 0.01$) lower in fat content and browning index than the flavored extrudates.

Browning Index (BI)

The Maillard reaction between amino acids and reducing sugars appeared to be chiefly responsible for the increased browning in 15HH (BI-142) as compared to 15H0 (BI-108) and UFC (BI-73). Amino acids and reducing sugars were added initially at 2.4% and 2.7% (flour weight basis), respectively, in 15HH. Caramel, a commercial colorant for

Table 2. Comparisons of some chemical/physical data of an unflavored (UFC) and flavored (15HH and 15H0)^a soy extrudates.

Chemical/physical property	Soy extrudate			Comparison ^c
	UFC	15HH	15H0	
Moisture (% dry basis)	6.93 ±0.04 ^b	5.42 ±0.13	6.75 ±0.05	<u>UFC</u> <u>15H0</u> > 15HH
Fat (% dry basis)	0.42 ±0.01	0.46 ±0.02	0.54 ±0.03	15H0 > 15HH > UFC
Browning index _{420nm}	72.8 ±3.0	142.5 ±6.4	108.8 ±5.3	15HH > 15H0 > UFC
pH	6.50 ±0.13	5.90 ±0.15	6.29 ±0.10	<u>UFC</u> <u>15H0</u> > 15HH

^a15HH and 15H0 were prepared with the pre-extrusion addition of the meat flavor precursor system (Hsieh et al., 1980) and the commercial beef flavor (H0), respectively. See Experimental section C.

^bReported values were the means±standard deviations of triplicate analyses.

^cSamples were listed in decreasing order where underscored samples were not significantly ($p < 0.01$) different as established using the Analysis of Variance and Duncan's Multiple Range Test.

textured soy protein products, was primarily responsible for the higher BI in 15H0 as compared to UFC. The colors of these products as observed visually were: UFC-yellow tan, 15H0-light brown, and 15HH-brown.

pH

Due to the short residence time (~9 sec) in the extruder, the residual unreacted amino acids were probably responsible for the lower pH value in 15HH (pH 5.9) as compared to 15H0 (pH 6.3) and UFC (pH 6.5). The pH value of UFC was in close agreement with those reported for textured sunflower/soy flour (pH 6.5; Vasquez et al., 1979) and meat analogs (pH 6.5; Hegarty and Ahn, 1976).

Moisture

Shifting of the pH value to the isoelectric point (pH 4.5) of the soy protein as in the case of 15HH probably reduced the water binding capacity of the protein by affecting the magnitude of the net charge on the protein (Kuntz, 1971). This together with the length of drying (10-15 min at 55°C) which was not rigidly monitored, were the most probable factors contributing to the significantly lower moisture content in 15HH (5.4%) as compared to those of UFC (6.9%) and 15H0 (6.8%).

Fat

Beef fat, present in the commercial formulation of beef flavor (H0) was reflected in the higher fat content (0.54%) associated with the commercial beef flavored extrudate as compared to 15HH (0.46%) and UFC (0.42%). The difference in fat content among the latter two was

probably due to the presence of a higher amount of ether extractables (such as Maillard reaction products) other than fat in 15HH.

The moisture and fat contents of UFC were within the maximum limits of reported values on textured soy flour, these being, 10% (max) for moisture and 1% (max) for fat (Company literature: Central Soya Co., Fort Wayne, IN).

Sensory Evaluation

Soy extrudates (15HH, 15H0, and UFC) and a conceptualized "Ideal" meat flavored extrudate (IMF) were evaluated for four aroma ("Meaty", "Roasted", "Beany", and "Green") and seven flavor-by-mouth ("Meaty", "Roasted", "Beany", "Green", "Sweet", "Salty", and "Bitter") attributes on a 1 (none) to 10 (pronounced) point intensity scale. The sensory data were statistically analyzed and compared (Table 3). The aroma and flavor-by-mouth difference scores between (a) soy extrudate(s) and IMF, and (b) flavored extrudate(s) and unflavored extrudate are graphically presented in Figure 1A-D.

"Green" and "Beany"

Pre-extrusion addition of either the meat flavor precursors or the commercial beef flavor was not entirely successful in masking the "Green" and "Beany" off-flavor notes associated with soy protein products. The extrudates were all perceived as having a slight "Green" flavor with a moderately intense "Beany" note. No significant ($p < 0.05$) differences in the "Green" and "Beany" sensory scores were found among the soy extrudates. However, all three extrudates (15HH, 15H0, UFC) were scored significantly ($p < 0.05$) higher in both of these attributes

Table 3. Comparisons of the sensory intensity scores of an "Ideal" meat flavored (IMF), an unflavored (UFC), and flavored (15HH and 15HO)^a soy extrudates.

Sensory property	Unflavored and flavored soy extrudate				
	IMF	UFC	15HH	15HO	Comparison ^c
AROMA					
Meaty	8.0 ±0.9 ^b	2.0 ±1.1*	3.3 ±1.4*	3.3 ±1.5*	<u>15HH 15HO</u> > UFC ^d
Roasted	6.2 ±1.8	6.7 ±1.8	5.2 ±1.8	4.3 ±1.5	<u>UFC 15HH 15HO</u> ^d
Green	1.0 ±0.0	3.0 ±2.8**	3.0 ±1.7**	3.5 ±1.4**	<u>15HO 15HH UFC</u> ^d
Beany	1.7 ±0.8	6.0 ±1.9**	5.2 ±1.9**	4.5 ±1.6**	<u>UFC 15HH 15HO</u> ^d
FLAVOR-BY-MOUTH					
Meaty	8.2 ±0.8	1.5 ±0.6*	3.2 ±1.0	3.7 ±1.4*	<u>15HO 15HH</u> > UFC ^e
Roasted	6.3 ±0.6	5.0 ±1.9	4.7 ±1.6	4.3 ±1.5	<u>UFC 15HH 15HO</u> ^d
Green	1.2 ±0.4	3.3 ±1.6**	3.3 ±1.8**	4.0 ±1.1**	<u>15HO UFC 15HH</u> ^e
Beany	2.0 ±1.1	5.3 ±1.9**	5.2 ±1.8**	5.3 ±1.9**	<u>UFC 15HO 15HH</u> ^e
Sweet	2.8 ±1.7	1.3 ±0.5	2.3 ±1.2	2.5 ±1.4	<u>15HO 15HH UFC</u> ^d
Salty	4.8 ±1.6	1.8 ±1.2*	2.5 ±1.1*	6.7 ±1.5**	15HO > <u>15HH UFC</u> ^e
Bitter	1.3 ±0.5	2.8 ±1.0	2.7 ±1.5	1.5 ±0.6	<u>UFC 15HH 15HO</u> ^d

^a15HH and 15HO were prepared with the pre-extrusion addition of the meat flavor precursor system (Hsieh et al., 1980) and the commercial beef flavor (HO), respectively. See Experimental section C.

^bSensory intensity scores were rated on a 1 (none) to 10 (very pronounced) point intensity scale. Values reported were the means±standard deviations of a 6-member panel.

Table 3 (cont'd.)

^cSamples were listed in decreasing order of intensity where underscored samples were not significantly different at ^d $p < 0.05$ or ^e $p < 0.01$ as established using the Analysis of Variance and Duncan's Multiple Range Test.

* and ** denotes respectively to significantly ($p < 0.05$) lower and higher than IMF as established using the Analysis of Variance and Dunnett's t-test.

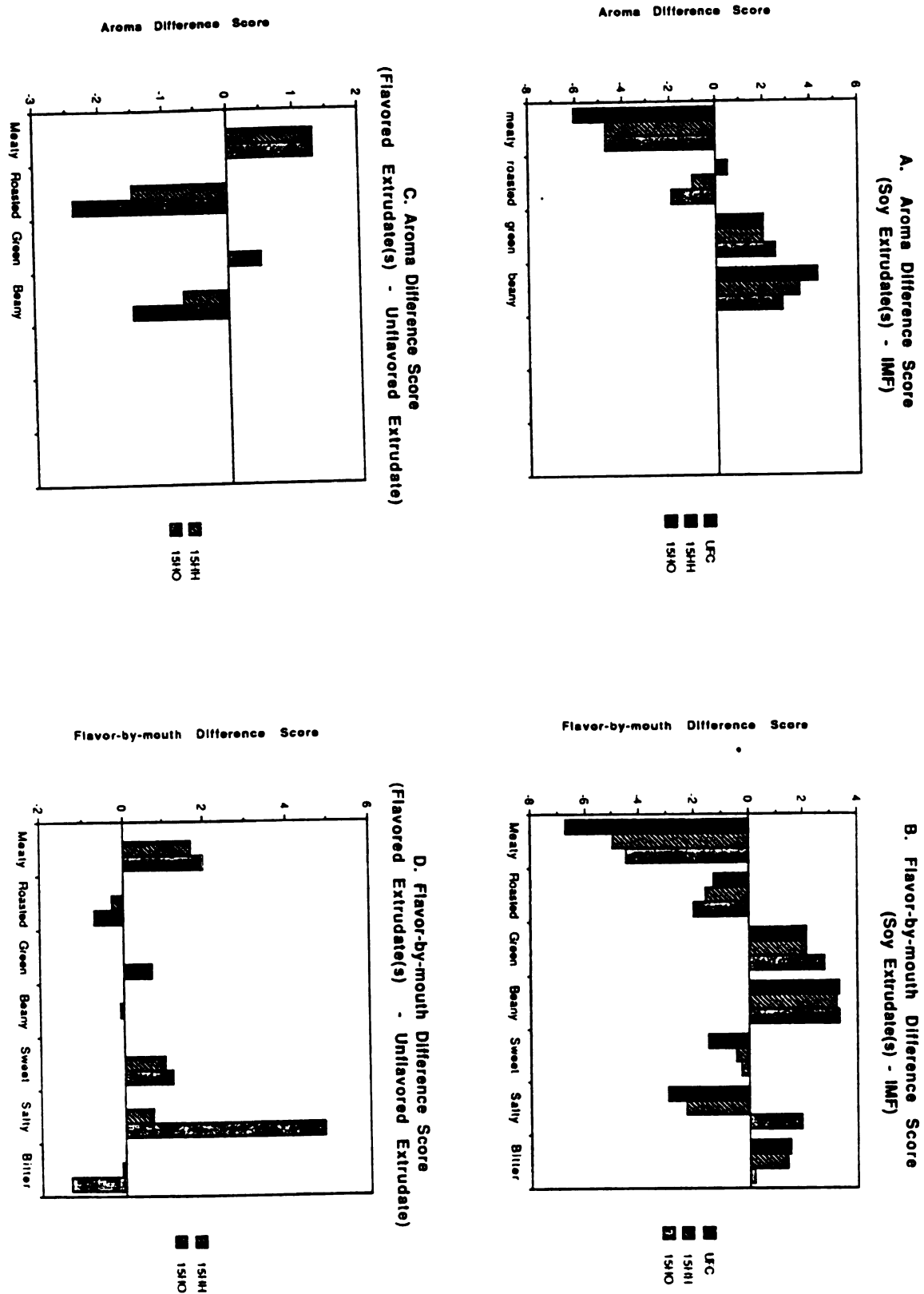


Figure 1. Aroma and flavor-by-mouth difference scores between soy extrudate(s) and IMF (A and B), and flavored extrudate(s) and unflavored extrudate (C and D).

when compared to the conceptualized "Ideal" model (IMF).

A slightly higher tolerance for the "Beany" rather than the "Green" off-flavor was found among the panelists. This was being reflected in the higher intensity scores for the "Beany" attribute in IMF.

As reported by Rackis et al. (1979), n-hexanal, cis-3-hexenal, and ethyl vinyl ketone are the major contributors to the "Green/Grassy" off-flavor notes in soy protein products, whereas n-pentylfuran and cis- or trans-2-(1-pentenyl)furan are primarily responsible for the "Beany" note. In addition, the "Green" and "Beany" off-flavors may be accentuated by the presences of C₅-C₇ alcohols (Rackis et al., 1979). The flavor threshold values in oil are in the range of 0.11-0.35 ppm (Grosch and Laskawy, 1975; Chang et al., 1966) and 2-10 ppm (Chang et al., 1966; Arai et al., 1970; Ho et al., 1978) for the compounds responsible for the "Green/Grassy" and "Beany" off-flavors, respectively.

"Meaty" and "Roasted"

The soy extrudate, 15HH prepared with the pre-extrusion addition of the flavor precursors, was scored significantly ($p < 0.05$) higher in meatiness than the unflavored extrudate (UFC). However, no significant ($p < 0.05$) difference in meatiness was found between 15HH and 15H0. The flavored soy extrudates (15HH and 15H0) were described as having a slight "Meaty" flavor. The short residence time (~ 9 sec) in the extruder may have prevented the "Meaty" flavor from being fully developed in 15HH. All three extrudates were scored significantly ($p < 0.05$) lower in "Meaty" flavor than ideally desirable.

In comparing the "Roasted" aroma and flavor-by-mouth intensity scores of the three extrudates (15HH, 15H0, and UFC), generally higher

intensity scores were obtained for the aroma than for the flavor-by-mouth evaluation. This may imply that the roasted quality of the extrudates was more of a aromatic property rather than a taste property. Similar observations were made by Palkert (1980) who reported that "Beany", "Cereal", "Roasted" were the important aroma notes in textured soy protein product, whereas "Cereal", "Beany", and "Sweet" were the prominent flavor notes. Nevertheless, in terms of the "Roasted" property, no significant difference ($p < 0.05$) was found among the three extrudates and they were not significantly different from the "Ideal" model at $p < 0.05$.

The contribution of volatile Maillard reaction products to the "Meaty" and "Roasted" flavor notes of the extrudates will be discussed in Chapter III. The sensory properties of the volatile Maillard reaction products have been reviewed by Vernin (1982) and Fors (1983). Wilson (1975) reported that carbonyl compounds (such as sugars, sugar phosphates, and Strecker aldehydes) are responsible for supplying a roasted, burnt note in synthetic meat flavors. Some thiol-substituted furan and thiophene derivatives were reported to provide a "Meaty" note (Gruelle, 1974; van den Ouweland and Peer, 1975).

"Sweet", "Salty", and "Bitter"

On evaluating the three basic tastes, no ($p < 0.05$) significant difference was found among the three extrudates (UFC, 15HH, 15H0) nor when they were compared with the "Ideal" extrudate (IMF) for the "Sweet" and "Bitter" notes. In general, the flavored extrudates had more pronounced "Sweet" notes than the unflavored product (UFC). Bitterness

was more perceptible in 15HH and UFC than in 15H0.

The commercial beef flavored soy extrudate (15H0), however, was found to be significantly ($p < 0.01$) higher in saltiness than either 15HH or UFC. The soy extrudate, 15H0, was also rated significantly ($p < 0.01$) higher in saltiness than the "Ideal" extrudate (IMF), whereas 15HH and UFC were rated significantly ($p < 0.05$) lower. Rakosky (1974) reported that salt has a masking effect on the off-flavors of soy protein products. This effect was observed in 15H0.

Sessa et al. (1976, 1977) concluded that oxidation products of phosphatidylcholines are largely responsible for the inherent bitter taste of soy protein products (Rackis, 1979). Phenolic acids (Arai et al., 1966), ethyl- α -D-galactopyranoside and L-tryptophan (Honig et al., 1971), and daidzein, glycitein 7-d-0-glucoside, and genestein (Huang et al., 1981) may also contribute to or accentuate the bitter taste.

The differences in the intensity scores for the "Sweet" and "Salty" notes were directly attributed to the compositional differences of the starting materials. 15HH was formulated with $\sim 2.7\%$ of reducing sugars and $\sim 1.6\%$ of salt. 15H0, on the other hand, was formulated with $\sim 2.0\%$ of sugar and $\sim 3.0\%$ of salt. Using Stevens' Law, the desired level of salt addition was estimated to be $\sim 2.3\%$. The percentages were expressed as weight/weight of soy flour.

GENERAL COMMENTS

In retrospect, the meat flavor precursors added at a level of 15% to the defatted soy flour as pre-determined using a heated model system, may be an overestimation. More discriminatory testings should be carried out to monitor meat flavor development under varying combinations of precursors formulations and extrusion conditions. Surface response methodology may prove to be an invaluable tool (Box and Wilson, 1951). Pre-extrusion addition of Maillard reaction intermediates derived from the meat flavor precursors may offer a solution to the short residence time encountered in the extruder for flavor development.

In general, both the flavored extrudates (15HH and 15H0) were perceived as having a slight "Meaty" flavor which was found lacking in the unflavored extrudate (UFC). All three extrudates (UFC, 15HH, and 15H0) were rated as having a moderately intense "Roasted" and "Beany", and a slight "Green" flavor. Bitterness was not a problem associated with these extrudates. The "Salty" note was moderately intense in 15H0 but was not noticeable in 15HH and UFC. In comparison, the "Ideal" meat flavored soy extrudate (IMF) was characterized as having a pronounced "Meaty", moderately intense "Roasted", a slight to moderate "Salty", and an imperceptible "Green", "Beany" and "Bitter" flavor.

In view of the above findings, pre-extrusion addition of the precursor system was moderately successful in imparting a "Meaty"

flavor to the soy extrudate under the extrusion condition employed. These data indicate that the pre-extrusion addition of meat flavor precursors to extruded soy protein products is a technically viable concept that could be utilized to produce meat-like flavors in soy protein products but probably will require carefully-balanced formulations and extrusion conditions.

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CHAPTER III

MEAT FLAVOR GENERATION IN EXTRUDED SOY PROTEIN PRODUCTS. II. CAPILLARY GAS CHROMATOGRAPHY/MASS SPECTROMETRIC ANALYSIS OF VOLATILE COMPONENTS

ABSTRACT

The formation of desirable volatile components as influenced by the pre-extrusion addition of meat flavor precursors in a soy extrudate (15HH) was investigated. Volatile identification by gas chromatography-mass spectrometry and computerized spectra matching of catalogued flavor compounds revealed the formation of substantially higher levels of 2- and 3-methylbutanal, 2-pentanone, and dimethyltrisulfide and of 27 new components including pyrazines, thiols, furans and furanones in 15HH as compared to an unflavored soy extrudate (UFC). Only four volatile components were found to be common to both 15HH and the synthetic meat flavor (HH), a thermally generated flavor mixture from the precursors used in 15HH. The volatile isolates of 15HH consisted mainly of aldehydes (30.7%), ketones (20.8%), thiols (15.8%) and pyrazines (7.2%). UFC consisted predominantly of pyrazines (16%), while 15HH was composed of aldehydes (21.8%), alcohols (12.9%), and acids (9.8%). A total of 59, 55, and 29 volatile components were identified in 15HH, UFC, and HH, respectively. Twenty-four of the unflavored soy volatiles were identified for the first time in textured soy proteins. The relative

significance of the identified components to the aroma qualities of 15HH, UFC, and HH are discussed along with their probable precursors.

INTRODUCTION

Approximately 750 compounds have been identified in the volatile fractions extracted from cooked beef (MacLeod and Seyyedain-Ardibili, 1981; Shahidi et al., 1986; MacLeod and Ames, 1986, 1987; Vercellotti et al., 1987; St. Angelo et al., 1987). Although their relative significance is unclear, oxygen-, nitrogen-, and/or sulfur-containing compounds, mostly cyclic Maillard reaction products, have been repeatedly suggested as being the principal contributor to meat flavor. In contrast, the flavor volatiles of soy protein products (SPPs) have not been investigated as extensively.

Thus far, some 250 compounds have been identified in the volatile fractions of SPPs. Numerous researchers have examined the flavor volatiles of raw soybean (Arai et al., 1966b; Arai et al., 1967; Badenhop and Wilkens, 1969; Mattick and Hand, 1969; Honig and Rackis, 1975), soybean milk (Wilkens and Lin, 1970a), soy flour (Fujimaki et al., 1965; Arai et al., 1966a; Sessa et al., 1969; Hsieh et al., 1981), and soy protein concentrate (Arai et al., 1970). However, there have been only a few studies directed toward the identification of the flavor volatiles of heated SPPs. These studies have been limited to deep-fat fried soybeans (Wilkens and Lin, 1970), roasted soybeans (Miyata et al., 1977; Kato et al., 1981), and heated soybeans (190°C/20 min) (Rosario et al., 1984). There has been only one report pertaining to

the flavor analysis of textured soy protein (Palkert, 1980).

Qvist and von Sydow (1974) in their analysis of the volatile components of unconventional proteins, offered the only comparison of flavor volatiles of heated soy protein isolate and heated beef. Reportedly, the concentrations of C₄-C₆ aldehydes and 2-methylpropanal were much higher in heated soy isolate. Furans were more frequently detected and at higher concentrations in the heated soy product. On the other hand, sulfides (hydrogen-, dimethyl-, and ethylene-), and thiols (methane- and ethane-) were present in larger concentrations in heated beef, while methyldisulfide and thiophene were present in higher concentrations in the heated soy isolate. In general, the concentrations of almost all volatiles (except alcohols) increased on heating, independent of protein source.

The primary objective of this study was to investigate the formation of desirable volatile components as influenced by the pre-extrusion addition of flavor precursors in a soy extrudate (15HH). The specific objectives were (a) to provide some chemical information on the native volatiles of an unflavored soy extrudate (UFC) and the synthetic meat flavor (HH), a thermally generated flavor mixture from the precursors used in 15HH, and (b) to discuss the relative significance of the identified volatiles to the aroma qualities of 15HH, 15H0, and HH. The preparations and sensory properties of the soy extrudates (Chapter II) and the synthetic meat flavor (HH) have been reported earlier.

EXPERIMENTAL

Sample Sources and Descriptions

The formulations, extrusion conditions, and sensory properties of the flavored (15HH) and unflavored (UFC) soy extrudates have been described in Chapter II. The flavored soy extrudate (15HH) was formulated with the meat flavor precursor system previously described by Hsieh et al. (1980a) after adding it to the defatted soy flour at a level of 15% (w/w).

The synthetic meat flavor (HH), an autoclaved mixture of the precursor system (Hsieh et al., 1980a) consisting of amino acids, reducing sugars, 5'-nucleotide, and glycoprotein, has been described and sensorially evaluated in Chapter I.

Isolation and Concentration of Volatile Components

Volatile Isolates of Soy Extrudates (HH and UFC)

The soy extrudates to be analyzed were ground in 50 g portions for 5 sec in a Waring blender with a rheostat setting at 45. A 150 g aliquot each of the ground samples were mixed with 1.5 L of deionized water in a 2.5 L round bottom flask. Antifoam A concentrate (0.30 g) (Sigma Chemical Co., St. Louis, MO) was added to prevent foaming. The soy extrudates were extracted with 30 mL of Nanograde^R diethyl ether (Mallinkrodt, Inc., Paris, KY) for 4 hr in a modified Likens and

Nickerson (1964) apparatus (Kontes Glass, Vineland, NJ) as described by MacLeod and Cave (1975). The ether extract was dried over anhydrous sodium sulfate and concentrated to 0.2 mL in a stream of nitrogen at a flow rate of 60 mL/min.

Volatile Isolate of Synthetic Meat Flavor (HH)

A 25 mL aliquot of the autoclaved mixture was diluted with an equal volume of deionized water. The water components were extracted in diether ethyl and concentrated as described above. The use of an antifoaming agent was not necessary in this instance.

Blank Volatile Isolates

Two blank volatile isolates each for the soy extrudates (15HH and UFC) and the synthetic meat flavor (HH) were obtained using deionized water in place of the samples during solvent extraction.

Capillary Gas Chromatography-Mass Spectrometry (GC-MS)

Volatile components were separated and identified using a Finnigan 4021 GC-MS system. A high performance 50 m x 0.32 mm i.d. fused silica OV-101 (0.52 μ m film thickness) capillary column was used for separation. The column temperature was held at 40⁰C for 1 min, and then increased by 5⁰C/min to a holding temperature of 210⁰C for 6.4 min. Helium was used as the carrier gas with a head pressure of 0.8 kgf/cm². The injection temperature was 250⁰C and a 3 μ L aliquot of each of the isolates was injected using a split ratio of 30:1.

The mass spectrometer was operated under the EI mode using the following conditions: ionization voltage, 73.3 eV; electronic multiplier

voltage, 1432 V; source and line temperature, 250°C; scanning range, 34-400 mass units, at 0.9 sec/cycle (repetitive throughout run).

The identification of the volatile components was based on computer matching (>80%) of full or partial mass spectra of compounds catalogued in a specialized user's flavor library using the library program of the INCOS data system. Identifications were also made or confirmed by comparing experimental mass spectra with those of authentic compounds (see Appendix A) or published spectra (Stenhagen et al., 1974; Jennings and Shibamoto, 1980; Vernin, 1982). Mass spectral identifications were considered tentative when they were based solely on computer matching (70-75%) of catalogued compounds. Kovats retention indices (Jennings and Shibamoto, 1980) of many volatile components on OV-101 were included.

The ion counts of identified volatile components were expressed as percentage of the total ion counts or relative percent abundance (RPA). The contributions of solvent and contaminant ions were not included in the total ion counts.

RESULTS AND DISCUSSION

The volatile components identified by capillary GC-MS are listed in Table 1. Kovats retention indices (Jennings and Shibamoto, 1980) of some of these components on OV-101 are included in the table, and they confirmed the general elution order. To assist in the following discussion, published information on the odor descriptions characterizing some of these compounds and/or their occurrences in beef/soy products are provided. The blank isolates showed that silicon-containing compounds, such as octamethylcyclotetrasiloxane, 2-(trimethylsilyl)benzoic acid, and other trimethylsilyl derivatives, were contaminant compounds. Their origins, e.g. heated glass, silylating agent, septum or column bleed, have been discussed previously (Jeon et al., 1976; Galt and MacLeod, 1984; Jeon et al., 1976). In the soy extrudate extracts, the antifoaming agent was the major source for these silicon derivatives (Jeon et al., 1976; Palkert, 1980). Reconstructed ion chromatograms displaying the elution patterns of the volatile components are presented in Figure 1a-c.

Table 2 is a summarized comparison of the results extracted from Table 1. The number of unidentified compounds (and their relative percent abundances) associated with the samples were as follows: 13 (3.1%) for the flavored soy extrudate (15HH), 26 (53.8%) for the unflavored soy extrudate (UFC), and 18 (39.7%) for the synthetic meat

Table 1. Volatile components identified in synthetic meat flavor (HH), flavored soy extrudate (15HH), and unflavored soy extrudate.

Volatile component	Synthetic meat flavor (HH)	Flavored soy extrudate (15HH)	Unflavored soy extrudate (UFC)	Odor descriptions (Reference) ^a	Previously identified ^a	
					Beef	Soy
<u>ACIDS/ESTERS</u>						
Acetic acid	1.31 ^b (5) ^c	0.51 ^b (11) ^c	1.66 ^b (7) ^c	10,11	22,28,30,33	
Propanedioic acid?	6.67(9)					
Carbamic acid, ethyl ester?	1.86(27)					
3-Pentenoic acid,4-methyl-?		0.24(43)				
<u>ALCOHOLS</u>						
Ethanol, 2-propoxy-	0.07(15)					
Ethanol, 2-mercapto-:		0.15(20)	0.32(10)			
1-Propanol, 2-ethoxy-:						
2-Propanol, 1-(1-methyl-ethoxy)-	0.09(23)					
1-Butanol, 3-methyl-	0.23(20)			10,11	23,30,33,35	
2-Butanol,3-methyl- (671) ^d ?	4.78(12)	0.12(12)		10,11	23,30,24	
2,3-Butanediol:			0.45(28)	10,11		
1-Pentanol(756)		0.14(23)	0.81(16)	10,11,12,13	23,25,26,30,31,34,35	
4-Penten-2-ol(673)?		0.13(32)		Grassy, ethereal (5)	10,11	25,26,31,33
1-Hexanol(858)		0.78(34)	2.16(30)	Fragrant (17)	10,11	23,26,30,31,32,35
2-Hexanol(786)			0.54(22)			25,32,33,34

Table 1 (cont'd.)

3-Hexanol						35
1-Hexyn-3-ol?						
<u>ALDEHYDES</u>						
Butanal, 2-methyl-	7.69(11)	0.35(28)	1.20(21)		10,11,13	31,32
		14.92(9)	0.32(3)	Burnt, sickly (1) Cat's urine (8)		
Butanal, 3-methyl-		14.61(8)	0.57(2)	Burnt, roasted (4) Meaty, sulfurous (3)	10,11	31,33
				Burnt, green, sickly (1) Chemical solvent, estery (8)	10,11 10,11,13	
Butanal, 2-ethyl- Propanal, 3-(methyl- thio)-; Pentanal	0.07(19)	0.56(35)				
			0.52(6)	Burnt, green (1)	10,11,12, 13	25,31,34, 35
Pentanal, 2,4- dimethyl-? Hexanal(780)	21.73(1)	0.30(24)	0.93(17)	Strong rancid, unpleasant (3) Green, pungent, sickly (1)	10,11,12, 13	21,24,25, 26,30, 31,32, 33,34, 35

Table 1 (cont'd.)

[illegible]

Table 1 (cont'd.)

Heptane, 2,6-dimethyl-:- Octane(800)	0.04(28)	0.05(53)	0.50(52) 0.13(49)	Meaty (3)	10,11,12, 33 13
1-Nonene, 4,6,8- trimethyl-:- Undecane(1100):		1.06(58)	0.13(53) 1.99(54)		10,11,12, 13 10,11,12, 13
Cyclopentane, 2-methyl-:- Cyclohexane, 2-(4- methylpentyl)-:- Cyclohexane, hexyl-:- Cyclohexane, octyl-:- 1,3,5-Cyclohepta- triene:		0.76(7)	0.08(1)		
Benzene	0.41(6)	0.05(52)	0.13(48)		
Benzene, methyl-		0.14(59)	0.21(51) 0.35(55) 0.13(13)		
					10,11,12, 25,32,33 13
		0.37(19)		Strong fruity, becoming dank, bitter (3) Unpleasant, estery (8)	10,11,12, 32,33,34 13
<u>KETONES</u> 2-Butanone, 4-hydroxy- 3,3-dimethyl-? 2-Butanone, 3-hydroxy-(697) 2-Pentanone(672)	2.37(2)	20.31(4)	0.36(9) 0.27(5)	Buttery (4) Buttery, sweet, sickly, meaty (3) Burnt, green (1)	10,11,12 10,11,12

Table 1 (cont'd.)

3-Pentanone, 2-methyl - 2-Hexanone(772)	0.08(21) 0.10(22)	0.21(18)	10,11,12 10,11,12	31 21,30,31, 32
3-Hexanone		0.22(15)	Slightly caramel (12)	12 31
2-Heptanone(872)		1.36(29)	Green, pungent, sickly (1)	10,11,12 25,26,30, 32,33,34, 35
a Methyl ketone (MW=128) 2-Octanone(928)		0.10(34) 0.08(43)	Green, mushroom (1) Caramel (12)	10,11,12 25,26,31, 32,34,35
2,3-Octanedione Cyclopentanone OXYGEN-CONTAINING HETEROCYCLICS	0.59(14)	0.27(44)		10,11 12 25
Oxirane:		1.55(1)		
Oxirane, 2,3-dimethyl-	0.27(13)	0.54(27)		
1,3-Dioxolane, 2-methyl-:		1.51(19)		
Furan, 2,5-dimethyl-(697)	0.08(10)	0.06(8)		10,11 31
Furan, 2-pentyl-(983)		0.84(35)	Licorice- like, beany- greenish (5) Green, pungent, sweet (1) Urine, rubbery, lamb (8) Beany (9)	10,11 10,11,12 25,31,33

Table 1 (cont'd.)

Furan, 2-(methanethio)-: Furan, 2-n-propyl-(782)	0.01(16) 0.05(18)	0.18(54)	10,11 10,11,12 28	Floral, fragrant, honeysuckle (8)
2-Furfural(815)	1.17(21)	0.61(31)	2.76(27)	Oily, fatty, 10,11,12, 32,33,34 rancid (8) 13
2(3H)-Furanone, 3-ethyl- 2(3H)-Furanone, dihydro-3- hydroxy-:	0.26(17)	0.08(26)		
3(2H)-Furanone, dihydro-2- methyl-:		0.19(25)		Caramel, 10,11,12, green (12) 13
2-Furoate, ethyl-(1029)	0.04(25)			Burnt, 10,11 buttery, vanilla- like (18)
2H-Pyran, 3,4-dihydro- NITROGEN-CONTAINING HETEROCYCLICS	0.02(26)			
1H-Imidazole, 4,5-dihydro- Pyridine:	0.40(24)	0.03(16)		Vile 10,11,12, (concen- trated), 13 Bitter, pleasant, roasted (diluted) (4)
Pyridine, 2-methyl-:		0.02(24)		Astringent, 10,11,12, hazelnut- like (19) 13 Sweet, sickly, green (19)

Table 1 (cont'd.)

1H-Pyrrole: Pyrazine(739)	0.29(13)	1.00(20) 2.68(11)	12,13 10,11,12, 13	26,27,19, 33,34
Pyrazine, methyl-(805)	1.37(29)	4.01(25)	Potato- like (4) Roasted, nutty (6)	26,27,29, 32,33, 34
Pyrazine, 2,5-dimethyl-(893)	3.89(36)	6.14(31)	Potato- like (4) Roasted, earthy (5) Musty, meaty-roast, green (14) Peanut butter, solvent, estery (8)	26,27,29, 32,33, 34
Pyrazine, trimethyl-(985)	0.64(41)	1.21(37)	Nutty, roasted (14) Sweet, caramel (15) Roasted nuts, solvent- like (8)	10,11,12, 13 26,27,29, 32,34
a Pyrazine (MW=122) Pyrazine, 2-ethyl-5- or 6-methyl-	0.06(49) 0.12(40)	0.33(36)	Sickly, fruity, toffee (15)	10,11,12 26,27,29

Table 1 (cont'd.)

Trisulfide, dimethyl-:	4.12(38)	1.20(33)	Burnt, buttery (8)	10,11,12, 13
a Tetrasulfide (MW=158)	2.01(48)	0.46(45)		10,11
1-Butanethiol:	0.06(17)			
Cyclobutanethiol?	0.02(8)			
1-Propene, 3-(methylthiol)-?	15.88(5)			
Thiophene(650)		0.26(4)	Sickly, pungent (1)	10,11,13 31
Thiophene, 2- or 3-methyl-		0.04(14)	Green, sweet (1)	10,11,13 31
1,2,4-Trithiolane, 3,5-dimethyl-		0.07(40)	Dry camphor (20)	10,11 31
a 1,2,4-Trithiolane (MW=153)		0.11(41)		
NITROGEN- AND SULFUR-CONTAINING HETEROCYCLICS				
Isothiazole or Thiazole:				
Thiazole, 4- or 5-methyl-(800)	0.16(14)	0.33(23)	Very sickly (15)	10,11,12, 13
MISCELLANEOUS				
1,2-Propandiamine?				
Hydroxylamine, 2-(2-methyl-propyl)-:	8,79(3)			
Methane, trichloro-:				
Hydroperoxide, 1-methylhexyl-	0.25(47)	0.09(46)		10,11
CONTAMINANTS	2.74(6)	0.43(39)		
Cyclotetrasiloxane,	--(C1)	--(C1)		16
octamethyl-				
Benzoic acid, 2-(trimethyl-silyl)-	--(C2)	--(C2)		
a Silicon derivative	--(C3)	--(C3)		

Table 1 (cont'd.)

^aReferences:

- | | | |
|---|-------------------------------|--------------------------------|
| 1. Peterson and von Sydow (1973) | 12. MacLeod and Ames (1987) | 24. Sessa et al. (1969) |
| 2. Garbusov et al. (1976) | 13. MacLeod and Ames (1987) | 25. Wilkens et al. (1970a) |
| 3. MacLeod and Coppock (1976) | 14. Cho and Bratzler (1970) | 26. Wilkens et al. (1970b) |
| 4. Peterson et al. (1975) | 15. Tonsbeek et al. (1971) | 27. Manley et al. (1970a) |
| 5. Peterson and Chang (1982) | 16. Galt and MacLeod (1984) | 28. Manley et al. (1970b) |
| 6. Pittet and Hruza (1974) | 17. Watanabe and Sato (1972) | 29. Maga et al. (1973) |
| 7. Roberts (1964) | 18. Ohloff and Flament (1978) | 30. Cowan et al. (1973) |
| 8. Ames and MacLeod (1985) | 19. Ho et al. (1983) | 31. Qvist and von Sydow (1974) |
| 9. Rackis et al. (1979) | 20. Brinkman et al. (1972) | 32. Palkert (1980) |
| 10. MacLeod and Seyyedain-Ardebili (1981) | 21. Fujimaki et al. (1965) | 33. Rosario et al. (1984) |
| 11. Shahidi et al. (1986) | 22. Arai et al. (1966) | 34. Kato et al. (1981) |
| | 23. Arai et al. (1967) | 35. Hsieh et al. (1981) |

^bRelative percent abundance.^cPeaks numbering on the respective chromatograms in Figure 1.^dKovats Index (Jennings and Shibamoto, 1980):Have not been previously reported in soy protein products.
?tentatively identified

Reconstructed ion current

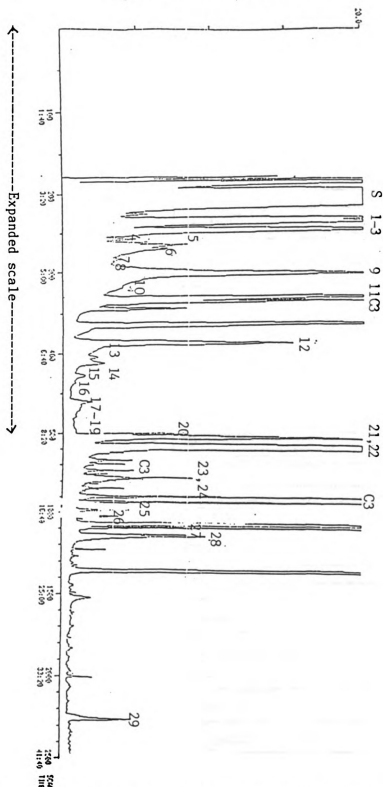


Figure 1. Reconstructed ion chromatograms of the volatile isolates of (a) synthetic meat flavor (HH), (b) flavored soy extrudate (15HH), and (c) unflavored soy extrudate (UFC). See peak identification in Table 1. S: solvent.

b. Flavored soy extrudate (0.5M)

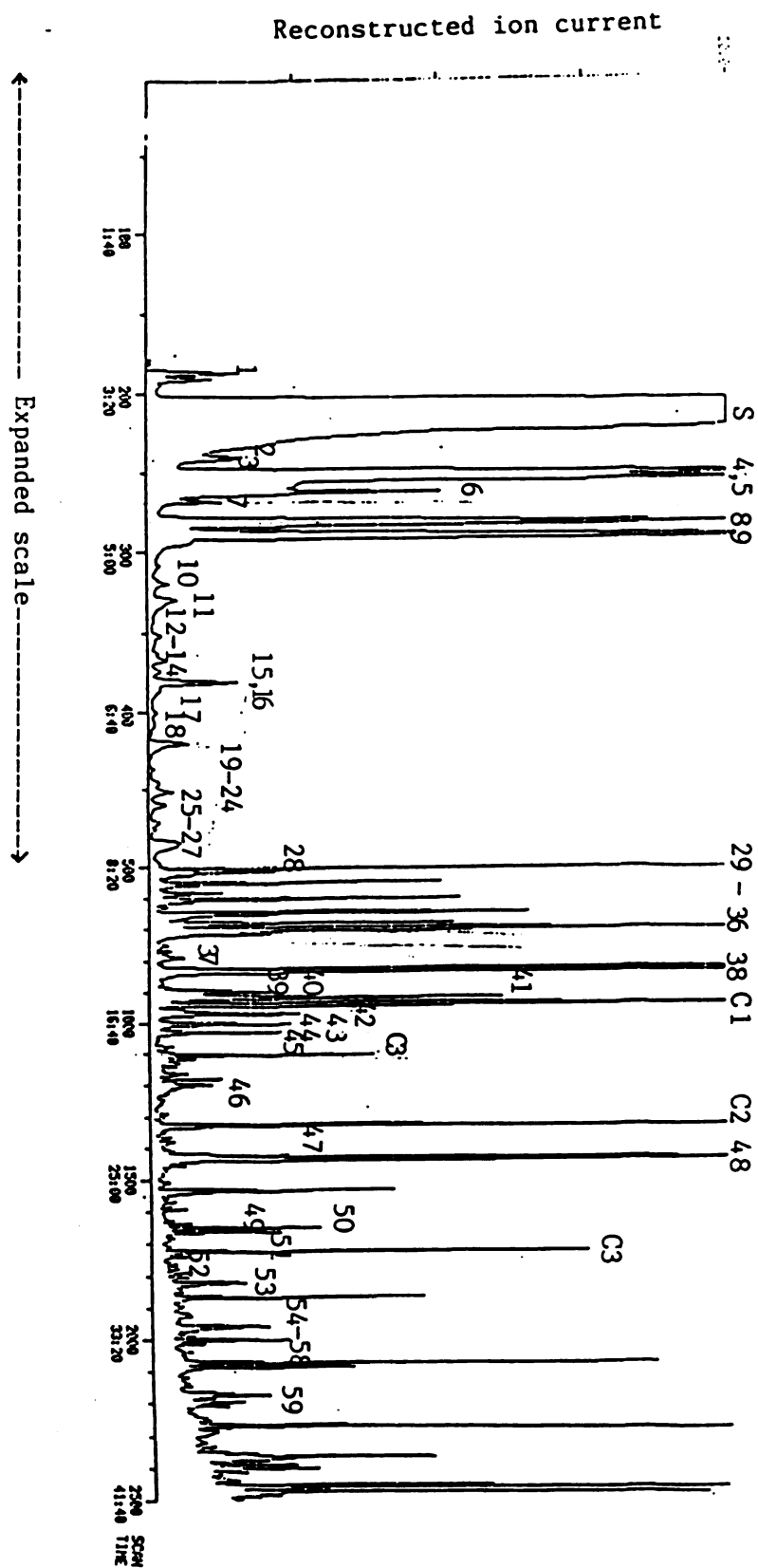


Figure 1 (cont'd.)

c. Unflavored soy extrudate (UFC)

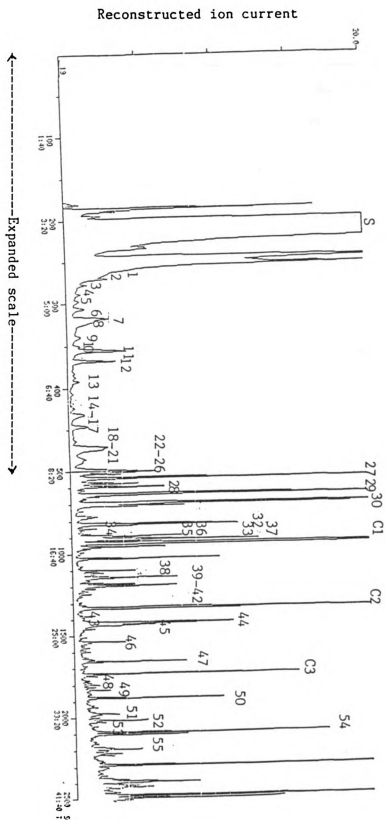


Figure 1 (cont'd.)

Table 2. A summarized comparison of relative percent abundances of the major classes of volatile components identified in synthetic meat flavor (HH), flavored soy extrudate (15HH), and unflavored soy extrudate (UFC).

Major class of volatile components	Synthetic meat flavor (HH)		Flavored soy extrudate (15HH)		Unflavored soy extrudate (UFC)
ACIDS/ESTER	9.84 ^a (3) ^b		0.75(2)		1.66(1)
		0.08 ^c		0.45 ^d	
ALCOHOLS	12.86(5)		1.67(6)		5.48(6)
		0.01		0.30	
ALDEHYDES	21.80(2)		30.69(6)		3.41(5)
		1.42		9.00	
HYDROCARBONS	1.69(6)		5.73(15)		6.65(13)
		3.39		0.88	
KETONES	2.96(2)		20.76(4)		2.60(7)
		7.01		7.98	
<u>OXYGEN-CONTAINING HETEROCYCLICS</u>					
Furans and Derivatives	1.61(6)		1.27(5)		3.66(3)
		0.79		0.35	
Miscellaneous	0.29(2)		2.09(2)		1.51(1)
		7.21		1.38	
Total	1.90(8)		3.36(7)		5.17(4)
		1.77		0.65	
<u>NITROGEN-CONTAINING HETEROCYCLICS</u>					
Pyrazines	--		7.15(10)		14.98(7)
		Undefined		0.48	
Miscellaneous	0.40(1)		0.03(1)		1.02(2)
		0.08		0.03	
Total	0.40(1)		7.18(11)		16.00(9)
		17.95		0.45	
<u>SULFUR-CONTAINING COMPOUNDS</u>					
Sulfides	--		7.72(3)		3.93(3)
		Undefined		1.96	
Thiols	0.02(1)		15.94(2)		--
		797		Undefined	

Table 2 (cont'd.)

Thiophenes and Trithiolane	--		--		0.48(4)
		Undefined		Undefined	
Total	0.02(1)	1183	23.66(5)	5.37	4.41(7)
<u>NITROGEN- AND SULFUR- CONTAINING HETEROCYCLICS</u>					
Thiazole	--	Undefined	0.16(1)	Undefined	0.33(1)
<u>MISCELLANEOUS</u>	8.79(1)	0.34	2.99(2)	5.75	0.52(2)
Total ions counts	10 722 914		6 280 661		4 829 793
Total number of scans	47		72		81
Compounds identified	60.26 ^a (29) ^b		96.95(59)		46.23(55)
Compounds unidentified	39.74 ^a (18) ^b		3.05(13)		53.77(26)

^aRelative percent abundance (RPA).^bTotal number of compounds identified.^cRPA ratio of 15HH/HH.^dRPA ratio of 15HH/UFC.

flavor. The mass spectral fragmentation patterns of these unidentified compounds did not result in any probable matches with the catalogued or authentic flavor compounds, nor did they conform to any characteristic fragmentation modes which render them easily recognizable. Thus far, 59 volatile components have been identified in the flavored soy extrudate (15HH) as compared to 55 in the unflavored product (UFC) and 29 in the synthetic meat flavor (HH). The majority of these compounds (Table 1) have been reported in heated beef aromas (MacLeod and Seyyedain-Ardibili, 1981; Shahidi et al., 1986; MacLeod and Ames, 1986, 1987; Vercellotti et al., 1987; St. Angelo et al., 1987). Their precursors and possible formation pathways have been reviewed (MacLeod and Seyyedain-Ardebili, 1981; Vernin, 1982). Because of the importance of heterocyclics, thiols, and sulfides in meat aroma (MacLeod and Seyyedain-Ardebili, 1981), the following discussion will focus on these groups of compounds.

The aroma qualities of the volatile isolates were characteristic of those previously reported for soy extrudates (Chapter II) and synthetic meat flavor (Chapter I). Isolates of the soy extrudates (15HH and UFC) were described as slightly meaty (15HH only), slightly green, and moderately pronounced in the toasted and beany aroma qualities. The synthetic meat flavor (HH) isolate was characterized as meaty, cooked vegetables-like, sulfurous, and toasted/burnt.

Synthetic Meat Flavor (HH) vs Flavored Soy Extrudate (15HH)

In a previous study, Hsieh et al. (1980b) tentatively identified 13 compounds from the volatile fraction of the synthetic meat flavor

(HH). However, under similar GC operating conditions, the elution order of four of the identified compounds namely, furan, 2,2,5,5-tetramethyltetrahydrofuran, 2-methylthiophene, and 2-methylfurfural, was found to be vastly different from that reported by Hsieh et al. (1980b). It was considered necessary, therefore, to re-identify the volatile components of the mixture. Surprisingly, none of the 28 identified volatiles were reported by Hsieh et al. (1980b).

The volatile fraction of the synthetic meat flavor (HH) consisted primarily of aldehydes (21.8%), alcohols (12.9%), and acids (9.8%). The major volatile components identified in the synthetic meat flavor (HH) were 2,4-dimethylpentanal (21.8%) (tentatively identified), 1-hexyn-3-ol (7.7%), and propanedioic acid (6.7%). None of these have been identified in meat volatiles and their contribution to cooked meat aroma is of doubtful significance (MacLeod and Seyyedain-Ardebili, 1981; Shahidi et al., 1986).

Oxygen-containing heterocyclics (1.9%), particularly furans and furanones, were the dominant heterocyclics found in the synthetic meat flavor (HH). Identified components included 2,5-dimethylfuran, 2-n-propylfuran*, 2-(methanethio)furan, 2-ethylfuroate, and 3-ethyl-2(3H)-furanone*, and two minor components, 3,4-dihydro-2H-pyran* and 2,3-dimethyloxirane*. The components with the asterisks have not been reported in cooked beef volatiles. These compounds may arise from sugar degradation, sugar-amine interactions, or thermal degradation of 5'-nucleotides (MacLeod and Seyyedain-Ardebili, 1981). Furans and furanones are mainly associated as having caramel-like, sweet, fruity, nutty, meaty, and burnt odor notes (Vernin, 1982). Therefore, they were

likely contributors to the toasted/burnt odor in the synthetic meat flavor (HH).

Recently, MacLeod and Ames (1986) associated the meaty aroma of cooked beef to 2-methyl-3-(methylthio)furan and 3-methylcyclopentanone. The thiofuran can be formed from (a) the reaction of methanethiol and 2-methyl-3-thiofuran, which itself has a meaty odor (van der Linde et al., 1979), or (b) from the reaction of 4-hydroxy-5-methyl-3(2H)-furanone and hydrogen sulfide (van den Ouweland and Peer, 1975). The cyclopentanone, on the other hand, has been isolated from a model system of heated cyclotene/hydrogen sulfide/ammonia (Nishimura et al., 1980). Therefore, the presence of cyclopentanone together with 2-(methanethio)furan may be responsible for the meatiness in synthetic meat flavor (HH). With the exception of 2-(methanethio)furan, 4,5-dihydro-1H-imidazole and cyclobutanethiol, no other nitrogen-/sulfur-heterocyclics, thiols, and sulfides were identified in the synthetic meat flavor (HH). The absence of pyrazines was surprising, since these are common Maillard reaction products contributing to the roasted/toasted/burnt odors in heated foods (MacLeod and Seyyedain-Ardebili, 1981; Vernin, 1982). More unexpectedly was the lack of sulfur-containing compounds (such as thiols, sulfides and sulfur heterocyclics) which are widely recognized as important contributors to meat aroma (MacLeod and Seyyedain-Ardebili, 1981; Bailey, 1983; Shahidi et al., 1986). Sulfides and thiophenes, in particular, also contribute to the sulfurous and cooked vegetables-like odor (Shahidi et al., 1986). In the absence or lack of such nitrogen-/sulfur-containing compounds, the meaty, sulfurous, cooked vegetables-like,

and toasted/burnt aroma qualities of the synthetic flavor mixture (HH) can not be fully explained. It is highly probable that these components might be present at extremely low concentrations and thus could not be detected under the existing analytical conditions. 4,5-dihydro-1H-imidazole and cyclobutanethiol have not been identified in cooked beef volatiles. However, imidazoles have been reported in a heated glucose/ammonia model system (Shibamoto and Russell, 1977).

In contrast, the flavored soy volatiles were characterized by high levels of aldehydes (30.7%), ketones (20.8%), thiols (15.9%), and pyrazines (7.2%). Only four of the identified components were common to both samples. These included acetic acid, 3-methyl-2-butanol, octane, 2-furfural, and 2-(methanethio)furan. The first three components have been identified in beef and soy volatiles, while the last component has been reported only in beef volatiles. Its significance in cooked meat aroma was discussed above. The relative distribution of the volatile components identified in the flavored soy extrudate (15HH) will be discussed in detail in the following section.

Flavored Soy Extrudate (15HH) vs Unflavored Soy Extrudate (UFC)

Twenty-four of the volatile components isolated from the unflavored soy extrudate (UFC) appear to have been identified for the first time in textured soy protein (Palkert, 1980) or SPPs, in general (Table 1). These compounds include 2-methylpyridine, 1H-pyrrole, 2-ethyl-5- or 6-methylpyrazine, 3-ethyl-2,5-dimethylpyrazine, dimethyltrisulfide (a trisulfide in textured soy protein was reported by Palkert, 1980), 4- or 5-methylthiazole, and 2-methyl-1,3-dioxolane, together with 2

alcohols, 1 amine, 11 hydrocarbons, 1 hydroperoxide, and 2 ketones. Among the volatile components identified in the soy extrudates (15HH and UFC), 32 volatile components were common to both. During extrusion, 27 new or different volatile components were generated in 15HH in the presence of the meat flavor precursor system. These 27 components consisted of 1 acid, 3 alcohols, 2 aldehydes, 7 hydrocarbons, 4 oxygen-containing heterocyclics, 2 ketones, 1 pyridine, 3 pyrazines, 2 thiols, 1 thiazole, and 1 chlorinated compound. The new volatile components isolated from the extrudates (15HH and UFC) were identified with a semicolon in Table 1.

When compared to the unflavored product (UFC), the volatile isolate of the flavored soy extrudate (15HH) was substantially higher in aldehydes (30.7% vs 3.4%), ketones (20.8% vs 2.6%), and sulfur-containing compounds (23.7% vs 4.4%) (Table 2). Specifically, there were 26- to 75-fold increases in the levels of 2-methylbutanal, 3-methylbutanal, and 2-pentanone with a less pronounced increase (3-fold) in dimethyltrisulfide. Additionally, several new sulfur-containing components were identified in the flavored soy extrudate (15HH). These included: 2-mercaptoethanol, 3-(methylthio)propanal (or methional), 1-butanethiol, 3-(methylthio)prop-1-ene, 2-(methanethio)-furan, and thiazole. Interestingly, no thiols were found in the unflavored soy extrudate (UFC). However, thiophenes (thiophene and 2-methylthiophene), 4- or 5-methylthiazole, and trithiolane (3,5-dimethyl-1,3,4-trithiolane and possibly its isomer) were found exclusively in the unflavored product (UFC). Similar observations have been made by Qvist and von Sydow (1974) in their comparison of

beef/soy volatiles. 2-Methylbutanal, 3-methylbutanal, and methional are Strecker aldehydes of isoleucine, leucine, and methionine, respectively. The sulfur-containing volatile components may arise from thermal degradation of sulfur amino acids (Merritt and Robertson, 1967; Kato et al., 1973; Shu et al., 1985a), the Maillard or Strecker degradation reactions of cysteine/cystine with glucose (Kato et al., 1973a; Scanlan et al., 1973), ribose (Mulders, 1973), and pyruvaldehyde (Kato et al., 1973b), by the reactions of furanones with cystine (Shu et al., 1985) and hydrogen sulfide (van den Ouweland and Peer, 1975), and in glucose/hydrogen sulfide/ammonia model systems (Shibamoto and Russell, 1977; Sakaguchi and Shibamoto, 1978). Because of their prominence in meat aroma, the sulfur-containing compounds, particularly 2-(methanethio)furan, are probably the major meaty aroma contributors in the flavored soy extrudate (15HH).

Although an increased number of furans and furanones (5) was generated in the flavored soy extrudate (15HH), they composed only one percent of the total abundances compared to 4% from the three identified in the unflavored soy extrudate (UFC). Besides the 2-(methanethio)furan mentioned above, 3-hydroxy-dihydro-2(3H)-furanone and 2-methyl-dihydro-3(2H)-furanone were among the new oxygen-containing heterocyclics identified in the flavored product (15HH). On the other hand, 2,5-dimethylfuran was found only in the unflavored soy extrudate (UFC). In addition to the formation pathways discussed in the previous section, certain furans (such as 2-pentylfuran) are formed as a result of lipid oxidation (Chang et al., 1966). Their odor impressions as a class have also been discussed in the previous section. The presence of furanones

in flavored soy extrudate is of particular interest, since they may react with hydrogen sulfide to form potent meat aroma-contributing compounds (van den Ouweland and Peer, 1975).

Another interesting feature was the formation of pyrazines in the flavored versus unflavored soy extrudates (15HH and UFC). Similarly, although 10 pyrazines were isolated from the flavored soy extrudate (15HH), they comprised only 7% of the total abundances compared to 15% from the 7 pyrazines identified in the unflavored product (UFC). The three new pyrazines associated with the flavored soy extrudate (15HH) were: 2-ethenyl-6-methylpyrazine, 2-butyl-3,5-dimethylpyrazine, and a pyrazine with a molecular weight of 122. Pyridine was also identified in the flavored product (15HH), whereas 2-methylpyridine and 1H-pyrrole were identified in the unflavored product (UFC). Pyrazines can arise from the condensation reactions of sugar/amino acids (Dawes and Edwards, 1966), cyclization of hydroxy amino acids such as serine and threonine (Wang and Odell, 1973), and from glucose/hydrogen sulfide/ammonia interactions (Shibamoto and Russell, 1977; Sakaguchi and Shibamoto, 1978). Pyrazines and Strecker aldehydes (such as 2-methylbutanal from isoleucine and 3-methylbutanal from leucine) contribute significantly to the roasted/toasted/burnt, and/or nutty aroma qualities of heated foods (Table 1). Other less significant contributors include furans and furanones, thiazoles, and sulfides (Shahidi et al., 1986). Interestingly, in spite of the differences in the relative distributions of these compounds, both the flavored and unflavored soy extrudates (15HH and UFC) were perceived as moderately roasted. The presence of pyrazines (Maga, 1982), pyridines (Maga, 1981a), and pyrroles (Maga,

1981a) in foods are well documented. The latter two are considered minor contributors to cooked meat aroma (MacLeod and Seyyedain-Ardebili, 1981).

In general, the RPA levels of 1-pentanol, 1-hexanol, 3-hexanol, and hexanal in flavored soy extrudate (15HH) were 40 to 80% lower than those reported for the unflavored product (UFC). As for 2-pentylfuran, the value was 33% lower. Again, in spite of these differences, both flavored and unflavored soy extrudates (15HH and UFC) were equally perceived as being slightly green with a moderately pronounced beany aroma character. The identified compounds are widely established as the lipoxygenase-catalyzed oxidation products of polyunsaturated acids, and as the major contributors to the green/grassy and beany notes in soy protein products (Rackis et al., 1979).

GENERAL COMMENTS

With the possible exception of Strecker aldehydes and other Maillard reaction-derived ketones, alcohols, aldehydes, ketones, and hydrocarbons are generally not considered as significant contributors to cooked meat aroma (MacLeod and Seyyedain-Ardebili, 1981). They are products derived mainly from sugar degradation and/or lipid oxidation (MacLeod and Seyyedain-Ardebili, 1981). However, synergistic and/or synosmic effects have been demonstrated among compounds isolated from cooked meat volatiles (Bodredo et al., 1981; Fooladi et al., 1986). Therefore, their relative contribution to cooked meat aroma can not be ruled out completely.

The meatiness associated with flavored soy extrudate (15HH) and synthetic meat flavor (HH) can not be easily explained from the compounds listed in Table 1. Several of these, such as the heterocyclics, thiols, and sulfides, are likely important contributors, and additional components present remain to be identified. To enhance the development of meat aroma in flavored soy extrudate (15HH), it is recommended that the flavor precursors system be reformulated with increased levels of sulfur amino acids (cysteine in particular) while reducing the levels of nonsulfur amino acids, such as leucine, isoleucine, and serine.

The results of this study strongly suggest that with carefully balanced formulations and processing conditions, the pre-extrusion addition of meat flavor precursors could be utilized to produce desirable meat aroma contributors in extruded soy protein products.

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CHAPTER IV

MEAT FLAVOR GENERATION IN EXTRUDED SOY PROTEIN PRODUCTS. III. APPLICATION OF FLAVORED AND UNFLAVORED SOY EXTRUDATES IN GROUND BEEF LOAVES

ABSTRACT

The quality characteristics (moisture and fat contents, cooking and sensory characteristics, and oxidative stability) of ground beef loaves substituted with increasing levels (30, 45 to 60%) of a flavored soy extrudate prepared with the pre-extrusion addition of meat flavor precursors, were evaluated. Overall, beef loaves substituted with increasing levels of the flavored extrudate were rated more acceptable than those with the unflavored soy extrudate, but less acceptable than the all-beef product (control). In comparison to the unflavored soy-substituted products, substitution with the flavored soy extrudate had a significantly positive effect on the aroma and color, but a limited effect on the flavor of ground beef loaves. The juiciness and mouthfeel of ground beef loaves were adversely affected by increasing soy-substitution. In contrast to the control, all soy-substituted products had higher cooking yields and moisture, lower fat, and enhanced oxidative stability ($\sim 4^{\circ}\text{C}$ for 6 days) as measured using the 2-thiobarbituric acid test.

INTRODUCTION

Soy protein products (SPPs), particularly textured soy protein products (TSPs), are increasingly being used as meat extenders in the school lunch program, institutional food services, and the retail market (Lauck, 1975; Kotula and Berry, 1986). The greatest incentive for extending ground beef with TSPs is the potential savings in product costs (Kotula and Berry, 1986). Other advantages include lower fat content, increased moisture retention, improved tenderness, reduced shrinkage during cooking, and inhibition of rancidity (Schweiger, 1974; Lngsdorf, 1981; Berry et al., 1985; Kotula and Berry, 1986). In spite of these advantages, the undesirable beany/grassy flavors typically associated with SPPs remain the primary constraint against their expanded use as meat extenders or analogs (Kotula and Berry, 1986).

Many studies have compared the sensory and cooking characteristics, and the oxidative stability of all beef and beef-TSP extended patties (Bowers and Engler, 1975; Drake et al., 1975; Smith et al., 1976; Seideman et al., 1977; Gardze et al., 1979; Ray et al., 1981; Nofal, 1981; Berry et al., 1985) or beef-TSP extended meat loaves (Williams and Zabik, 1975). Results of studies on beef-TSP patties have indicated that if the addition of TSP exceeds 20%, the beef flavor generated cannot mask the undesirable flavors of TSPs.

Therefore, this study was designed to investigate the effects of increasing substitution (30 to 60%) of a flavored soy extrudate (15HH) prepared as described in Chapter II, on the quality characteristics, particularly the sensory properties, of ground beef loaves as compared to an all-beef product (control) and those containing unflavored soy extrudate (UFC). The flavored soy extrudate (15HH) was prepared with the pre-extrusion addition of the meat flavor precursor system developed by Hsieh et al. (1980).

EXPERIMENTAL

Preparation of Ground Beef Loaves

Food Materials

Ground beef chuck (80% lean), bread crumbs (Toscana Baking Co., Oakland, CA), dried onions (The R.T. French Co., Rochester, NY), salt (Morton Thiokol, Inc., Chicago, IL), and Hunt's barbecue sauce and catsup (Beatrice Companies, Inc., Fullerton, CA) were obtained from the local supermarket. Flavored (15HH) and unflavored (UFC) soy extrudates were prepared as previously described in Chapter II.

Preparation

The all-beef product (control) and soy substituted beef loaves at 30, 45, and 60% were formulated as outlined in Table 1. The basic beef loaf recipe was adapted from Williams and Zabik (1975). Three 500 g loaves were prepared for all formulations.

Before mixing with ground beef, the soy extrudates were hydrated with two parts by weight of cold tap water for 15 min at room temperature. The beef/soy mixtures were mixed for 1 min in a Kitchen Aid Mixer (Model K-5A). The remaining ingredients were then added and mixed into the beef loaf mixtures for 30 sec. To insure uniformity, the beef loaf mixtures were passed through the mixer using a 4.7 cm plate.

likely contributors to the toasted/burnt odor in the synthetic meat flavor (HH).

Recently, MacLeod and Ames (1986) associated the meaty aroma of cooked beef to 2-methyl-3-(methylthio)furan and 3-methylcyclopentanone. The thiofuran can be formed from (a) the reaction of methanethiol and 2-methyl-3-thiofuran, which itself has a meaty odor (van der Linde et al., 1979), or (b) from the reaction of 4-hydroxy-5-methyl-3(2H)-furanone and hydrogen sulfide (van den Ouweland and Peer, 1975). The cyclopentanone, on the other hand, has been isolated from a model system of heated cyclotene/hydrogen sulfide/ammonia (Nishimura et al., 1980). Therefore, the presence of cyclopentanone together with 2-(methanethio)furan may be responsible for the meatiness in synthetic meat flavor (HH). With the exception of 2-(methanethio)furan, 4,5-dihydro-1H-imidazole and cyclobutanethiol, no other nitrogen-/sulfur-heterocyclics, thiols, and sulfides were identified in the synthetic meat flavor (HH). The absence of pyrazines was surprising, since these are common Maillard reaction products contributing to the roasted/toasted/burnt odors in heated foods (MacLeod and Seyyedain-Ardebili, 1981; Vernin, 1982). More unexpectedly was the lack of sulfur-containing compounds (such as thiols, sulfides and sulfur heterocyclics) which are widely recognized as important contributors to meat aroma (MacLeod and Seyyedain-Ardebili, 1981; Bailey, 1983; Shahidi et al., 1986). Sulfides and thiophenes, in particular, also contribute to the sulfurous and cooked vegetables-like odor (Shahidi et al., 1986). In the absence or lack of such nitrogen-/sulfur-containing compounds, the meaty, sulfurous, cooked vegetables-like,

and toasted/burnt aroma qualities of the synthetic flavor mixture (HH) can not be fully explained. It is highly probable that these components might be present at extremely low concentrations and thus could not be detected under the existing analytical conditions. 4,5-dihydro-1H-imidazole and cyclobutanethiol have not been identified in cooked beef volatiles. However, imidazoles have been reported in a heated glucose/ammonia model system (Shibamoto and Russell, 1977).

In contrast, the flavored soy volatiles were characterized by high levels of aldehydes (30.7%), ketones (20.8%), thiols (15.9%), and pyrazines (7.2%). Only four of the identified components were common to both samples. These included acetic acid, 3-methyl-2-butanol, octane, 2-furfural, and 2-(methanethio)furan. The first three components have been identified in beef and soy volatiles, while the last component has been reported only in beef volatiles. Its significance in cooked meat aroma was discussed above. The relative distribution of the volatile components identified in the flavored soy extrudate (15HH) will be discussed in detail in the following section.

Flavored Soy Extrudate (15HH) vs Unflavored Soy Extrudate (UFC)

Twenty-four of the volatile components isolated from the unflavored soy extrudate (UFC) appear to have been identified for the first time in textured soy protein (Palkert, 1980) or SPPs, in general (Table 1). These compounds include 2-methylpyridine, 1H-pyrrole, 2-ethyl-5- or 6-methylpyrazine, 3-ethyl-2,5-dimethylpyrazine, dimethyltrisulfide (a trisulfide in textured soy protein was reported by Palkert, 1980), 4- or 5-methylthiazole, and 2-methyl-1,3-dioxolane, together with 2

alcohols, 1 amine, 11 hydrocarbons, 1 hydroperoxide, and 2 ketones. Among the volatile components identified in the soy extrudates (15HH and UFC), 32 volatile components were common to both. During extrusion, 27 new or different volatile components were generated in 15HH in the presence of the meat flavor precursor system. These 27 components consisted of 1 acid, 3 alcohols, 2 aldehydes, 7 hydrocarbons, 4 oxygen-containing heterocyclics, 2 ketones, 1 pyridine, 3 pyrazines, 2 thiols, 1 thiazole, and 1 chlorinated compound. The new volatile components isolated from the extrudates (15HH and UFC) were identified with a semicolon in Table 1.

When compared to the unflavored product (UFC), the volatile isolate of the flavored soy extrudate (15HH) was substantially higher in aldehydes (30.7% vs 3.4%), ketones (20.8% vs 2.6%), and sulfur-containing compounds (23.7% vs 4.4%) (Table 2). Specifically, there were 26- to 75-fold increases in the levels of 2-methylbutanal, 3-methylbutanal, and 2-pentanone with a less pronounced increase (3-fold) in dimethyltrisulfide. Additionally, several new sulfur-containing components were identified in the flavored soy extrudate (15HH). These included: 2-mercaptoethanol, 3-(methylthio)propanal (or methional), 1-butanethiol, 3-(methylthio)prop-1-ene, 2-(methanethio)-furan, and thiazole. Interestingly, no thiols were found in the unflavored soy extrudate (UFC). However, thiophenes (thiophene and 2-methylthiophene), 4- or 5-methylthiazole, and trithiolane (3,5-dimethyl-1,3,4-trithiolane and possibly its isomer) were found exclusively in the unflavored product (UFC). Similar observations have been made by Qvist and von Sydow (1974) in their comparison of

beef/soy volatiles. 2-Methylbutanal, 3-methylbutanal, and methional are Strecker aldehydes of isoleucine, leucine, and methionine, respectively. The sulfur-containing volatile components may arise from thermal degradation of sulfur amino acids (Merritt and Robertson, 1967; Kato et al., 1973; Shu et al., 1985a), the Maillard or Strecker degradation reactions of cysteine/cystine with glucose (Kato et al., 1973a; Scanlan et al., 1973), ribose (Mulders, 1973), and pyruvaldehyde (Kato et al., 1973b), by the reactions of furanones with cystine (Shu et al., 1985) and hydrogen sulfide (van den Ouweland and Peer, 1975), and in glucose/hydrogen sulfide/ammonia model systems (Shibamoto and Russell, 1977; Sakaguchi and Shibamoto, 1978). Because of their prominence in meat aroma, the sulfur-containing compounds, particularly 2-(methanethio)furan, are probably the major meaty aroma contributors in the flavored soy extrudate (15HH).

Although an increased number of furans and furanones (5) was generated in the flavored soy extrudate (15HH), they composed only one percent of the total abundances compared to 4% from the three identified in the unflavored soy extrudate (UFC). Besides the 2-(methanethio)furan mentioned above, 3-hydroxy-dihydro-2(3H)-furanone and 2-methyl-dihydro-3(2H)-furanone were among the new oxygen-containing heterocyclics identified in the flavored product (15HH). On the other hand, 2,5-dimethylfuran was found only in the unflavored soy extrudate (UFC). In addition to the formation pathways discussed in the previous section, certain furans (such as 2-pentylfuran) are formed as a result of lipid oxidation (Chang et al., 1966). Their odor impressions as a class have also been discussed in the previous section. The presence of furanones

in flavored soy extrudate is of particular interest, since they may react with hydrogen sulfide to form potent meat aroma-contributing compounds (van den Ouweland and Peer, 1975).

Another interesting feature was the formation of pyrazines in the flavored versus unflavored soy extrudates (15HH and UFC). Similarly, although 10 pyrazines were isolated from the flavored soy extrudate (15HH), they comprised only 7% of the total abundances compared to 15% from the 7 pyrazines identified in the unflavored product (UFC). The three new pyrazines associated with the flavored soy extrudate (15HH) were: 2-ethenyl-6-methylpyrazine, 2-butyl-3,5-dimethylpyrazine, and a pyrazine with a molecular weight of 122. Pyridine was also identified in the flavored product (15HH), whereas 2-methylpyridine and 1H-pyrrole were identified in the unflavored product (UFC). Pyrazines can arise from the condensation reactions of sugar/amino acids (Dawes and Edwards, 1966), cyclization of hydroxy amino acids such as serine and threonine (Wang and Odell, 1973), and from glucose/hydrogen sulfide/ammonia interactions (Shibamoto and Russell, 1977; Sakaguchi and Shibamoto, 1978). Pyrazines and Strecker aldehydes (such as 2-methylbutanal from isoleucine and 3-methylbutanal from leucine) contribute significantly to the roasted/toasted/burnt, and/or nutty aroma qualities of heated foods (Table 1). Other less significant contributors include furans and furanones, thiazoles, and sulfides (Shahidi et al., 1986). Interestingly, in spite of the differences in the relative distributions of these compounds, both the flavored and unflavored soy extrudates (15HH and UFC) were perceived as moderately roasted. The presence of pyrazines (Maga, 1982), pyridines (Maga, 1981a), and pyrroles (Maga,

1981a) in foods are well documented. The latter two are considered minor contributors to cooked meat aroma (MacLeod and Seyyedain-Ardebili, 1981).

In general, the RPA levels of 1-pentanol, 1-hexanol, 3-hexanol, and hexanal in flavored soy extrudate (15HH) were 40 to 80% lower than those reported for the unflavored product (UFC). As for 2-pentylfuran, the value was 33% lower. Again, in spite of these differences, both flavored and unflavored soy extrudates (15HH and UFC) were equally perceived as being slightly green with a moderately pronounced beany aroma character. The identified compounds are widely established as the lipoxygenase-catalyzed oxidation products of polyunsaturated acids, and as the major contributors to the green/grassy and beany notes in soy protein products (Rackis et al., 1979).

GENERAL COMMENTS

With the possible exception of Strecker aldehydes and other Maillard reaction-derived ketones, alcohols, aldehydes, ketones, and hydrocarbons are generally not considered as significant contributors to cooked meat aroma (MacLeod and Seyyedain-Ardebili, 1981). They are products derived mainly from sugar degradation and/or lipid oxidation (MacLeod and Seyyedain-Ardebili, 1981). However, synergistic and/or synosmic effects have been demonstrated among compounds isolated from cooked meat volatiles (Bodredo et al., 1981; Fooladi et al., 1986). Therefore, their relative contribution to cooked meat aroma can not be ruled out completely.

The meatiness associated with flavored soy extrudate (15HH) and synthetic meat flavor (HH) can not be easily explained from the compounds listed in Table 1. Several of these, such as the heterocyclics, thiols, and sulfides, are likely important contributors, and additional components present remain to be identified. To enhance the development of meat aroma in flavored soy extrudate (15HH), it is recommended that the flavor precursors system be reformulated with increased levels of sulfur amino acids (cysteine in particular) while reducing the levels of nonsulfur amino acids, such as leucine, isoleucine, and serine.

The results of this study strongly suggest that with carefully balanced formulations and processing conditions, the pre-extrusion addition of meat flavor precursors could be utilized to produce desirable meat aroma contributors in extruded soy protein products.

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CHAPTER IV

MEAT FLAVOR GENERATION IN EXTRUDED SOY PROTEIN PRODUCTS. III. APPLICATION OF FLAVORED AND UNFLAVORED SOY EXTRUDATES IN GROUND BEEF LOAVES

ABSTRACT

The quality characteristics (moisture and fat contents, cooking and sensory characteristics, and oxidative stability) of ground beef loaves substituted with increasing levels (30, 45 to 60%) of a flavored soy extrudate prepared with the pre-extrusion addition of meat flavor precursors, were evaluated. Overall, beef loaves substituted with increasing levels of the flavored extrudate were rated more acceptable than those with the unflavored soy extrudate, but less acceptable than the all-beef product (control). In comparison to the unflavored soy-substituted products, substitution with the flavored soy extrudate had a significantly positive effect on the aroma and color, but a limited effect on the flavor of ground beef loaves. The juiciness and mouthfeel of ground beef loaves were adversely affected by increasing soy-substitution. In contrast to the control, all soy-substituted products had higher cooking yields and moisture, lower fat, and enhanced oxidative stability ($\sim 4^{\circ}\text{C}$ for 6 days) as measured using the 2-thiobarbituric acid test.

INTRODUCTION

Soy protein products (SPPs), particularly textured soy protein products (TSPs), are increasingly being used as meat extenders in the school lunch program, institutional food services, and the retail market (Lauck, 1975; Kotula and Berry, 1986). The greatest incentive for extending ground beef with TSPs is the potential savings in product costs (Kotula and Berry, 1986). Other advantages include lower fat content, increased moisture retention, improved tenderness, reduced shrinkage during cooking, and inhibition of rancidity (Schweiger, 1974; Lngsdorf, 1981; Berry et al., 1985; Kotula and Berry, 1986). In spite of these advantages, the undesirable beany/grassy flavors typically associated with SPPs remain the primary constraint against their expanded use as meat extenders or analogs (Kotula and Berry, 1986).

Many studies have compared the sensory and cooking characteristics, and the oxidative stability of all beef and beef-TSP extended patties (Bowers and Engler, 1975; Drake et al., 1975; Smith et al., 1976; Seideman et al., 1977; Gardze et al., 1979; Ray et al., 1981; Nofal, 1981; Berry et al., 1985) or beef-TSP extended meat loaves (Williams and Zabik, 1975). Results of studies on beef-TSP patties have indicated that if the addition of TSP exceeds 20%, the beef flavor generated cannot mask the undesirable flavors of TSPs.

Therefore, this study was designed to investigate the effects of increasing substitution (30 to 60%) of a flavored soy extrudate (15HH) prepared as described in Chapter II, on the quality characteristics, particularly the sensory properties, of ground beef loaves as compared to an all-beef product (control) and those containing unflavored soy extrudate (UFC). The flavored soy extrudate (15HH) was prepared with the pre-extrusion addition of the meat flavor precursor system developed by Hsieh et al. (1980).

EXPERIMENTAL

Preparation of Ground Beef Loaves

Food Materials

Ground beef chuck (80% lean), bread crumbs (Toscana Baking Co., Oakland, CA), dried onions (The R.T. French Co., Rochester, NY), salt (Morton Thiokol, Inc., Chicago, IL), and Hunt's barbecue sauce and catsup (Beatrice Companies, Inc., Fullerton, CA) were obtained from the local supermarket. Flavored (15HH) and unflavored (UFC) soy extrudates were prepared as previously described in Chapter II.

Preparation

The all-beef product (control) and soy substituted beef loaves at 30, 45, and 60% were formulated as outlined in Table 1. The basic beef loaf recipe was adapted from Williams and Zabik (1975). Three 500 g loaves were prepared for all formulations.

Before mixing with ground beef, the soy extrudates were hydrated with two parts by weight of cold tap water for 15 min at room temperature. The beef/soy mixtures were mixed for 1 min in a Kitchen Aid Mixer (Model K-5A). The remaining ingredients were then added and mixed into the beef loaf mixtures for 30 sec. To insure uniformity, the beef loaf mixtures were passed through the mixer using a 4.7 cm plate.

Table 1. Ingredients of ground beef loaves substituted with/without flavored and unflavored soy extrudates.

Ingredient (g)	Ground beef loaves			
	Percent level of soy substitution			
	0 (All-beef)	30	45	60
Ground beef ^a	384(76.7) ^b	269(53.7)	211(42.2)	153(30.7)
Hydrated soy extrudate ^c				
Soy extrudate	0	38(7.7)	58(11.5)	77(15.3)
Water	0	76(15.3)	116(23.0)	154(30.7)
Bread crumbs	47(9.3)	47	47	47
Dried onions	8(1.7)	8	8	8
Salt	2(0.5)	2	2	2
Barbecue sauce	17(3.4)	17	17	17
Catsup	42(8.4)	42	42	42
Total (g)	500	500	500	500

^aGround beef (80% lean).^bPercent ingredient on weight/weight basis.^cFlavored (15HH) and unflavored (UFC) soy extrudates (prepared as described in Chapter II) were each hydrated with two parts by weight of cold tap water for 15 min at room temperature.

Approximately 500 g of the meat loaf mixture were placed in a mini E-Z^R loaf pan lined with Reynolon^R food service film. A 454 g can was placed horizontally over the mixture for 5 min in order to obtain loaves of the same degree of compactness. Each loaf was rewrapped in the food service film and aluminum foil, and stored at -20°C for a week or less. Before baking, the loaves were removed from the freezer and thawed overnight at ~4°C.

Beef loaves of the same level of soy substitution were baked at any one "baking" day. The loaves in the mini E-Z^R loaf pans were randomly placed on the baking racks directly over drip pans in a General Electric, 30-inch Compact oven (Model CN16). The oven temperature was set at 177°C. The loaves were baked for 30 to 35 min to an internal temperature of 75 to 78°C. Upon removal from the ovens the loaves were allowed to stand for 5 min after which total, volatile, and drip losses were determined according to the method outlined by Funk et al. (1966).

The middle third of each loaf was used for sensory evaluation. The end slices were removed and discarded. Two consecutive 0.5 inch slices were taken from each end portion for the 2-thiobarbituric acid (TBA) tests. These slices were then wrapped in aluminum foil and stored at ~4°C for 0, 2, 4, and 6 days. Assignment of slices was randomized. The remaining loaf was ground, mixed thoroughly and used for moisture and fat analyses.

Proximate Analyses

Triplicate analyses for moisture and fat in the raw and cooked ground beef loaves were determined using AOAC procedures 24.003 and 24.005, respectively (AOAC, 1975).

Sensory Evaluation

The test conditions, the six-member panel, and the general sample handling and coding procedure used were described earlier (Chapter I). Three sessions were conducted every other day. A completely randomized block design was used in sample preparation.

During each session, the panelists were presented with three coded samples. Immediately before serving, the samples were heated on high for 20 sec in a Tappan microwave oven (Model 02216, Tappan Co., Manfield, OH). The panelists were requested to evaluate each sample for aroma and flavor (1-lacking or masked to 10-very full), juiciness (1-very dry to 10-very juicy), mouthfeel and color (1-very undesirable to 10-very desirable) and overall acceptability (1-very poor to 10-very good), using the 10-point scales described in parentheses. Water and unsalted crackers were used between samples to reduce carryover flavor.

Oxidative Stability

The 2-thiobarbituric acid test (TBA) was used to monitor the development of oxidative rancidity of the ground beef loaves during short-term storage (0-6 days) at refrigerated temperature ($\sim 4^{\circ}\text{C}$). The TBA test procedure of Tarladgis and Watts (1960) and its modification by Whipple (1974) was used to determine the TBA numbers. The TBA numbers were reported as mg malonaldehyde/1000 g of sample based on the distillation constant ($K=14.09$) as determined by Witte et al. (1970).

Statistical Analyses

Statistical procedures and inferences as described in Chapter I were used for data analyses and interpretation.

RESULTS AND DISCUSSION

Proximate Analyses

The moisture and fat contents of raw and cooked ground beef loaves were statistically analyzed and are presented in Table 2. Significant differences ($p < 0.05$) in moisture and fat contents were found between (a) the raw and cooked beef loaves, and (b) the all-beef (control) and soy-substituted beef loaves (beef + 15HH and beef + UFC). However, no significant difference ($p < 0.05$) in either the moisture or the fat content was found between beef + 15HH and beef + UFC.

In general, soy-substituted beef loaves had higher moisture and lower fat contents than the all-beef product (control). The increased moisture was probably due to the addition of water to hydrate the soy extrudates, and the decrease in fat content was a result of the substitution with the low fat soy products. Similar observations have been reported for ground beef patties (Bowers and Engler, 1975; Seideman et al., 1977; Drake et al., 1975; Ray et al., 1981) and ground beef loaves (Williams and Zabik, 1975) substituted with soy protein products.

The moisture contents of the cooked, soy-substituted beef loaves did not appear to be affected by the level of soy-substitution, but the fat retention of these products apparently increased with increasing soy-substitution. However, Drake et al. (1975) and Seideman et al. (1977), on examining the interactive effect of fat and textured soy protein (TSP) in beef patties, concluded that soy proteins do not

Table 2. Effects of increasing substitution with flavored (15HH) and unflavored (UFC) soy extrudates on the moisture and fat contents of raw and cooked ground beef loaves.

Percent level of soy-substitution	Ground beef loaf	Moisture (%) ^a		Fat (%) ^a	
		Raw	Cooked	Differential ^b	Cooked
30	All-beef (control)	56.7 ±0.2 ^c	54.7 ±0.7 ^c	3.5	26.4 ±0.3 ^c
	Beef + 15HH	57.7 ±0.2 ^d	56.4 ±0.2 ^d	2.3	22.7 ±0.1 ^d
	Beef + UFC	57.8 ±0.3 ^d	56.0 ±0.5 ^d	3.1	22.8 ±0.5 ^d
45	All-beef (control)	56.3 ±0.4 ^c	54.3 ±0.4 ^c	3.6	25.6 ±0.4 ^c
	Beef + 15HH	58.7 ±0.9 ^d	56.3 ±0.3 ^d	4.1	18.3 ±0.3 ^d
	Beef + UFC	58.5 ±0.4 ^d	56.0 ±0.5 ^d	4.3	18.1 ±0.3 ^d
60	All-beef (control)	56.8 ±0.2 ^c	55.0 ±0.8 ^c	3.2	24.4 ±0.3 ^c
	Beef + 15HH	59.5 ±0.4 ^d	56.3 ±0.3 ^d	4.9	14.7 ±0.1 ^d
	Beef + UFC	59.4 ±0.2 ^d	56.7 ±0.3 ^d	4.5	14.9 ±0.3 ^d

Differential^b

Table 2 (cont'd.)

^aValues reported were means $\pm$ standard deviations of triplicate analyses. With the exception of the fat contents in 45%- and 60%-soy substituted beef loaves, significantly lower ($p<0.05$) moisture and fat contents were found in the cooked versus the raw products. Within each level of soy-substitution, values followed by the same letter in columns were not significantly different ($p<0.05$).

^bExpressed as $\frac{\% \text{ in raw} - \% \text{ in cooked}}{\% \text{ in raw}} \times 100\%$

function in retention of fat, but do bind and retain moisture. The amount of fat lost during cooking depended upon the level of fat originally present in ground beef before cooking. Wolf (1970) explained that soy proteins are hydrophilic and would, therefore, be expected to absorb and retain water.

Cooking Characteristics

At all substitution levels, significant differences ($p < 0.05$) in total cooking losses were observed between the all-beef (control) product and the soy-substituted beef loaves. However, no significant differences ($p < 0.05$) were found between beef loaves substituted with flavored soy extrudate and those with unflavored soy extrudate (Table 3). The total cooking loss was determined as the combined total of drip and volatile losses.

In general, the total cooking losses decreased with increasing level of soy-substitution, apparently leveling off at the 45% substitution (Table 3). Minimal drip losses were associated with the 45% and 60% soy-substituted beef loaves. The cooking drippings were reported to contain approximately 3.5% protein, 50.3% fat, and 45.2% moisture, for the 30% TSP-substituted beef patties by Kotula and Berry (1986). The volatile losses were attributed to losses in moisture and aroma volatiles (Williams and Zabik, 1975).

The cooking yields were determined by difference and were positively affected by increasing level of soy-substitution (Table 3). Up to a 6% increase in yield was obtained with soy-substituted beef loaves as compared to the all-beef product (control). The results are in

Table 3. Effects of increasing substitution with flavored (15HH) and unflavored (UFC) soy extrudates on the cooking losses of ground beef loaves.

Percent level of soy- substitution	Ground beef loaf	Cooking losses (%) ^a			
		Total	Drip	Volatile	Yield (%) ^a
30	All-beef (Control)	13.2 ±0.1 ^b	4.7 ±0.2 ^b	8.5 ±0.1 ^b	86.8 ±0.1 ^b
	Beef + 15HH	10.9 ±0.5 ^c	0.4 ±0.1 ^c	10.5 ±0.4 ^c	89.1 ±0.8 ^c
	Beef + UFC	10.2 ±1.0 ^c	0.6 ±0.3 ^c	9.7 ±0.7 ^c	89.8 ±0.4 ^c
45	All-beef (Control)	13.3 ±0.2 ^b	4.5 ±0.3 ^b	8.8 ±0.1 ^b	86.7 ±0.6 ^b
	Beef + 15HH	7.2 ±0.5 ^c	<0.05 ^c	7.2 ±0.5 ^c	92.8 ±0.4 ^c
	Beef + UFC	7.9 ±0.4 ^c	<0.05 ^c	7.9 ±0.4 ^c	92.1 ±0.3 ^c
60	All-beef (Control)	13.6 ±0.1 ^b	4.7 ±0.1 ^b	8.9 ±0.1 ^b	86.4 ±0.1 ^b
	Beef + 15HH	8.6 ±0.6 ^c	<0.05 ^c	8.6 ±0.6 ^b	91.4 ±0.1 ^c
	Beef + UFC	8.4 ±0.2 ^c	<0.05 ^c	8.4 ±0.2 ^b	91.6 ±0.5 ^c

^aValues reported were means±standard deviations of triplicate analyses. Within each level of soy-substitution, values bearing the same letter in columns were not significantly different ($p < 0.01$).

agreement with those of Judge et al. (1974), Williams and Zabik (1975), Bowers and Engler (1975), Drake et al. (1975), Seideman et al. (1977), Ray et al. (1981), and Miles et al. (1984).

Sensory Evaluation

At the 30% substitution level, no significant differences in the sensory qualities ($p < 0.05$) were found between the all-beef (control) and the soy-substituted beef loaves, except for juiciness (Table 4). Beef loaves substituted with 30% unflavored soy extrudate were significantly less juicy ($p < 0.05$) than the control, but not significantly different ($p < 0.05$) from those with the flavored extrudate. However, no significant differences in juiciness have been reported by other researchers who compared all-beef and beef/soy patties or loaves (Bowers and Engler, 1975; Williams and Zabik, 1975; Smith et al., 1976; Seideman et al., 1977; Gardze et al., 1979; Ziprin et al., 1981; Berry et al., 1985).

At the 45% level of soy substitution, beef + UFC loaves were rated significantly lower ($p < 0.05$) in aroma, flavor, juiciness, mouthfeel and overall acceptability than the control beef loaves. In contrast, beef + 15HH loaves were not significantly different ($p < 0.05$) in the aroma, flavor, and juiciness ratings than those of the control, although they were rated significantly lower ($p < 0.05$) in mouthfeel and overall acceptability. In comparing the flavored versus the unflavored soy-substituted beef loaves, the flavored products were significantly higher ($p < 0.05$) in aroma and flavor. Substitution with soy extrudates at the 45% level did not significantly affect the color ($p < 0.05$) of the

Table 4. Effects of increasing substitution with flavored (15HH) and unflavored (UFC) soy extrudates on the sensory ratings^a of ground beef loaves.

Sensory attribute	Percent level of soy-substitution	Ground beef loaf		
		All-beef (Control)	Beef + 15HH	Beef + UFC
Aroma	30	6.7±1.4 ^b	5.8±1.6 ^b	5.7±1.5 ^b
	45	6.8±1.2 ^b	5.8±1.5 ^b	5.3±1.5 ^c
	60	6.3±1.2 ^b	5.3±1.5 ^b	4.7±1.5 ^c
Flavor	30	7.3±1.4 ^b	6.0±1.6 ^b	5.8±1.2 ^b
	45	7.3±1.2 ^b	5.8±1.6 ^b	4.8±1.6 ^c
	60	7.3±1.2 ^b	4.7±4.7 ^b	4.2±1.0 ^c
Juiciness	30	6.7±1.2 ^b	6.0±1.4 ^{b,c}	5.0±1.1 ^c
	45	6.7±1.6 ^b	6.0±1.7 ^{b,c}	5.3±1.5 ^c
	60	7.3±1.2 ^{b,*}	5.8±1.5 ^{c,*}	5.7±1.0 ^{c,*}
Mouthfeel	30	7.0±1.1 ^b	6.3±1.2 ^b	6.3±1.4 ^b
	45	7.5±1.3 ^b	6.0±1.3 ^c	6.0±1.4 ^c
	60	7.7±1.0 ^{b,*}	4.7±1.2 ^{c,*}	5.0±1.4 ^{c,*}
Color	30	6.5±1.5 ^b	6.5±1.1 ^b	6.0±1.3 ^b
	45	7.0±1.3 ^b	6.0±1.3 ^b	5.7±1.2 ^c
	60	6.8±1.5 ^{b,*}	6.0±1.1 ^{b,*}	4.8±1.5 ^{c,*}
Overall Acceptability	30	6.8±1.3 ^b	6.0±1.3 ^b	5.8±1.3 ^b
	45	7.2±1.2 ^{b,*}	5.0±1.1 ^{c,*}	4.5±1.5 ^{c,*}
	60	7.2±1.7 ^b	4.8±1.3 ^c	4.0±1.1 ^d

^aValues reported were the means±standard deviations of the ratings of six panelists. The sensory attributes were rated on a 10-point scale where 1-lacking or masked to 10-very full for aroma and flavor, 1-very dry to 10-very juice for juiciness, 1-very undesirable to 10-very desirable for mouthfeel and color, and 1-very poor to 10-very good for overall acceptability. Values followed by the same letter in rows were not significantly different ($p<0.05$ or $p<0.01$ as denoted by a * following the letter).

ground beef loaves.

At the 60% level of soy substitution, beef loaves containing the soy extrudates were rated significantly lower in flavor ($p<0.05$), juiciness ($p<0.01$), and mouthfeel ($p<0.01$) than the all-beef product. While substitution with 60% flavored soy extrudate did not affect the aroma ($p<0.05$) and color ($p<0.01$) ratings of the ground beef loaves, substitution with the unflavored extrudate had a significant undesirable effect ($p<0.05$) on these attributes. Overall, beef loaves substituted with the flavored extrudate were rated more acceptable ($p<0.05$) than those containing the unflavored extrudate, but less acceptable ($p<0.05$) than the all-beef product.

In general, the all-beef products received an average rating of 7 for all sensory attributes evaluated. They were characterized as being moderately juicy and having a full aroma and flavor, and as being moderately desirable in color/mouthfeel. In contrast, the soy-substituted beef loaves received an average sensory rating which decreased from 6 to 4 with increasing levels of soy-substitution. The soy-substituted ground beef loaves were generally described as being slightly dry and having a mealy mouthfeel, which intensified as the amount of soy added was increased. The juiciness and mouthfeel ratings of the ground beef loaves were highly dependent on the level of soy-substitution. Generally, beef + UFC loaves were perceived as being slightly dry, having a slightly weak aroma/flavor, and an undesirable color/mouthfeel. On the other hand, beef + 15HH loaves were described as being slightly dry, having a moderately full aroma but a slightly weak flavor, a moderately desirable color, and an undesirable mouthfeel.

The decrease in aroma and flavor ratings with increasing soy levels in ground beef patties has been reported by other researchers (Bowers and Engler, 1975; Gardze et al., 1979; Seideman et al., 1977). Seideman et al. (1977) also reported that the addition of TSP in excess of 10% was associated with light-colored, less desirable patties.

Oxidative Stability

Substitution with soy extrudates significantly increased ($p < 0.05$) the oxidative stability of cooked ground beef loaves during refrigerated storage ($\sim 4^{\circ}\text{C}$) for 6 days (Figure 1a-c) when compared to the all-beef products. This observation agrees well with those of Bowers and Engler (1975), Seideman et al. (1977), Thompson et al. (1978), and Ray et al. (1981). However, there were no significant differences ($p < 0.05$) in the oxidative stability between beef + UFC and beef + 15HH loaves at all substitution levels.

The TBA values increased significantly ($p < 0.05$) for the all-beef product (control) and the 30% soy-substituted beef loaves at day 2 of refrigerated storage ($\sim 4^{\circ}\text{C}$) as was reported by Williams and Zabik (1975). At the 45% and 60% substitution level, storage time had no significant effect ($p < 0.05$) on the TBA values of soy-substituted beef loaves. Ray et al. (1981) also reported that storage time (0 to 10 days, at 0°C) had no significant effect on the TBA numbers of soy-substituted (up to 26%) beef patties.

Some irregularities in the TBA storage data were observed for soy-substituted beef loaves. This "zig-zag" effect has appeared in several publications (Williams and Zabik, 1975; Seideman et al., 1977; Thompson

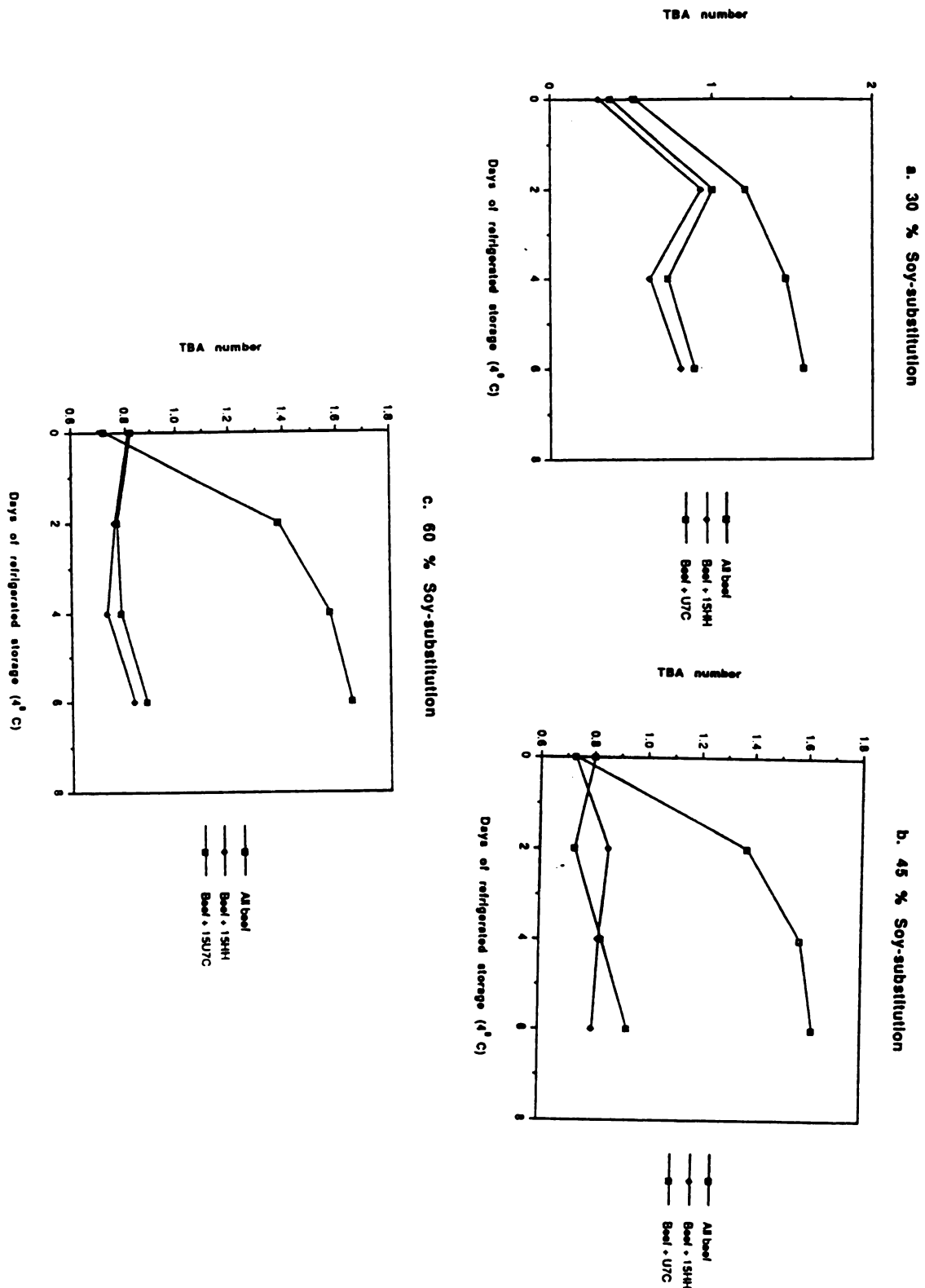


Figure 1. Effects of increasing substitution with flavored (15HH) and unflavored (UFC) soy extrudates on the TBA numbers of ground beef loaves stored at $\sim 4^{\circ}\text{C}$ for up to 6 days.

et al., 1978; Ray et al., 1981). Although no obvious explanations are evident, some plausible explanations may include: (a) unaccounted moisture loss during storage, (b) presence of interfering compounds derived from non-enzymatic browning reactions, and (c) binding of malonaldehyde to soy proteins. More definitive analyses such as hexanal measurement are needed to support TBA data in the quantitation of lipid oxidation in beef/soy systems.

Although the phenolic antioxidative activity in soy protein products has well been established (Pratt, 1972; Hayes et al., 1977; Pratt and Birac, 1979; Pratt et al., 1981), one may speculate that the decrease in malonaldehyde concentration was, in part, the result of lower fat contents in the soy-substituted beef loaves (Bowers and Engler, 1975; Ray et al., 1981). Maillard reaction products between amino acids and reducing sugars have also been shown to possess antioxidative properties in model systems (Lingnert and Eriksson, 1981), and may be involved in improving the oxidative stability of the soy-substituted products. However, these effects were not observed in beef + 15HH loaves.

CONCLUSIONS

Increasing substitution (30 to 60%) with the flavored soy extrudate had no significant effect on the raw and cooked composition (% moisture and % fat), cooking characteristics (% total cooking, drip and volatile losses), and oxidative stability of ground beef loaves as compared to those containing the unflavored soy extrudate. In contrast, substitution with soy extrudates at levels of 30 to 60%, irrespective of whether flavored or unflavored extrudates were used, resulted in higher moisture and lower fat products with reduced cooking losses and enhanced oxidative stability as compared to the all-beef product (control).

Sensory data indicated that increasing substitution with flavored soy extrudate had a significantly positive effect on aroma and color, but a limited effect on the flavor of ground beef loaves in comparison to those containing the unflavored extrudate. At increasing levels of soy-substitution, ground beef loaves substituted with the flavored soy extrudate were generally more acceptable than those containing the unflavored extrudate, but less acceptable than the all-beef product. The sensory attributes (juiciness and mouthfeel) of ground beef loaves were significantly affected by increasing soy-substitution, and conceivably, may have strongly influenced the overall acceptability scores.

In conclusion, pre-extrusion addition of meat flavor precursors in soy extrudates has the definite potential in improving the flavor of SPPs for use as meat extenders or analogs. Therefore, innovative research efforts should be continued in this area.

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SUMMARY AND CONCLUSIONS

The major conclusions from these studies are as follows:

- (a) The meaty aromas thermally generated from the synthetic mixtures of meat flavor precursors were superior to those of the commercial flavor samples and comparable to that of the natural beef extract. Toasted/burnt, sulfurous, and cooked vegetables-like nonmeaty aroma qualities were frequently identified with the synthetic flavor mixtures.
- (b) The pre-extrusion addition of flavor precursors effected a moderate but significant improvement in the meaty flavor of extruded soy protein products. However, under the existing extrusion conditions, the flavor precursor system was not entirely successful in masking the typical green/beany off-flavors of soy protein products.
- (c) Generation of several new heterocyclics (pyrazines, furanoid compounds, and thiazole) and substantial increases of 2-pentanone, dimethyltrisulfide, and the Strecker aldehydes of leucine and isoleucine, were evident in the soy extrudate pre-extrusionally added with meat flavor precursors. These compounds may have significant implications to the meaty flavor perceived in the extrudate.
- (d) Increased level of substitution (30 to 60%) of the flavored soy extrudate (15HH) had a significantly positive effect on the aroma

and color but a limited effect on the flavor of ground beef loaves. The juiciness and mouthfeel of the products were adversely affected by increasing levels of soy-substitution regardless of whether flavored (15HH) or unflavored (UFC) soy extrudate was used. Overall, all soy-substituted beef loaves had higher cooking yields, lower fat, and enhanced oxidative stability.

FUTURE RESEARCH

From the results of the studies on meat flavor generation in extruded soy protein products, the following future research is suggested:

- (a) More discriminatory testing should be carried out to monitor meat flavor development under varying combinations of precursor formulations and extrusion conditions. Varying combination levels of sulfur-containing meat flavor precursors (hydrogen sulfide, cysteine, methionine, taurine, thiamine), amino-containing compounds (glycine, β -alanine, aspartic and glutamic acids, lysine, histidine, proline, and 5'-nucleotides), and sugar/carbonyl compounds (arabinose, glucose, fructose, ribose, xylose, ribose-5-phosphate) should be investigated. Surface response methodology may prove to be an invaluable tool. Due to the short residence time encountered in the extruder, the reactivity of the meat flavor precursors is of primary consideration.
- (b) Alternately, the use of microencapsulated Maillard reaction meat flavors should be investigated. Microencapsulation offers the advantages of preventing or minimizing (a) soy flavor-protein interactions, (b) thermal degradation of flavor compounds, and possibly (c) steam volatilization of flavor compounds at the exit port of an extruder.

- (c) Due to the extensive information generated in the area of Maillard reactions and their products, research efforts should be expended in constructing a computerized database for storing, ease of retrieving, and cross referencing of the literature data.

APPENDIX

APPENDIX

MASS SPECTRA OF SOME MEAT FLAVOR VOLATILES

