A Review of Flavor Investigations Associated with the Soy Products Raw Soybeans, Defatted Flakes and Flours, and Isolates

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Soy products such as those mentioned in the title represent excellent protein sources and are readily available. However, one of the primary limitations on their more widespread use is the objectionable flavor normally associated with these products. Thus the primary objective of this review is to bring together some of the more pertinent published reports on the flavor aspects of the above soy products. It is hoped that this will provide a historical review of what has been done and also stimulate additional research in other soy flavor related areas in order that soy flavor can be more fully understood and appreciated.

During the past decade, increased attention has been devoted to the use of numerous protein supplements as a potential source of additional food protein. Primarily, this is the result of the increased concern over present and predicted food protein deficiencies exemplified by the ever-growing global population.

Therefore, it would seem logical that certain vegetable proteins could and will have an important impact upon the global food economy. Because of the quantity produced, the developed technology associated with its processing, its low cost, and high nutritive value, the soybean is receiving major attention. Aside from its potential use as a basic protein source, which could be used to combat malnutrition in developing areas of the world, the food technologists and food processors have become increasingly aware that the soybean is also a basic source of a variety of products which have present food utility, has considerable potential as minor ingredients in conventionally processed foods, and is the key for new processed foods for both domestic and foreign use.

Although the soybean has been used for human consumption for centuries in certain parts of the world, little progress has resulted in the development of large food markets for the soybean and its products in the United States and Europe. This is the result of several factors. First, it should be noted that most current soybean foods and drinks are native to the Orient and are, therefore, foreign to domestic food consumption patterns. Second, the health food image that has developed around the soybean has not been helpful in gaining further widespread acceptance. Third, legal limitations in certain common foods continue to curb utilization. Fourth, and probably the most important factor, is that characteristic soybean flavor has prevented the positive utilization of soy products in present day American and European food patterns. This flavor is often described as being bitter, beany, and astringent.

This review will attempt to summarize some of the more pertinent soy flavor reports appearing in the literature. However, due to the variety of soy products currently available, discussion will be limited to the flavor aspects of raw soybeans, defatted flakes and flours, and isolated soy protein(ate)s.

RAW SOYBEANS

De and Russell (1967) have divided soybean varieties into three basic groups (commercial, forage, and garden or vegetable varieties). They reported that the commercial and forage varieties do not cook easily and have a raw, beany flavor, whereas the garden varieties can be characterized as having a milk or nutty flavor. Woodruff (1938) reported that Oriental varieties are somewhat milder than domestic varieties. Moser *et al.* (1967) also reported that garden varieties are less beany and more mild than commercial varieties. Apparently little or no detectable differences in flavor exist among commercial varieties nor does the geographic location of the growing crop affect flavor. In theory, it would be possible to manipulate factors such as yield, harvesting losses, and oil content of garden varieties and still maintain their milder flavor.

Numerous investigators have attempted to isolate and identify the compound(s) responsible for soy flavor. Mattick and Hand (1969) reported that a typical soy flavor was associated with ethyl vinyl ketone. They stated that this compound was not present in the intact raw bean, but was a byproduct of enzymatic activity when raw soybeans are macerated.

Volatile neutral compounds have been isolated from ground raw soybeans (Arai *et al.*, 1967). The compounds identified included methanol, ethanol, 2-pentanol, isopentanol, pentanol, hexanol, heptanol, and pentanol acetate. Of these, the authors considered isopentanol, hexanol, and heptanol to be important contributors to raw soybean flavor since they were characterized as having green bean-like odors.

The contribution of volatile fatty acids and volatile amines to raw soybean flavor has been investigated (Arai *et al.*, 1966b). The volatile fatty acid fraction isolated had a weak but characteristic odor and was composed of acetic, propionic, isovaleric, valeric, isocaproic, caproic, caprylic, nonanoic, and capric acids. However, due to the small amounts isolated, the authors concluded that volatile fatty acids contribute little to soy flavor. A total of 1.5 ppm of volatile amines was isolated. The entire amine fraction resembled the odor of a dried fishery product and was found to contain ammonia, monomethylamine, dimethylamine, piperidine, and cadaverine.

Ethanol, 2-propanone, and hexanal were isolated as volatiles from ground raw soybean (Fujimaki *et al.*, 1965) and it was postulated that, due to its low flavor threshold, hexanal was one of the main components giving rise to the green bean-like flavor in raw soybean. In a similar study (Sessa *et al.*, 1969), raw full-fat soy flakes were steam distilled and acetone, hexanal, acetaldehyde, 2-heptenal, and hexene-3-dial-1,6 were identified.

In a recent study (Arai *et al.*, 1970a) pentanol, heptanol, and heptanal were isolated as volatiles from raw soybean cotyledons. Further enzymatic studies demonstrated that pentanol and hexanal could result as degradation products of linoleic acid hydroperoxides.

Sensory evaluation of raw soy flour (Moser *et al.*, 1967) demonstrated that this product was 100% detectable by a panel at a level of 1 part in 500 parts wheat flour and 44% detectable at a level of 1 part in 1250 parts wheat flour.

It is generally conceded that typical raw soybean flavor decreases with heat application. However, with steaming or toasting, protein dispersibility decreases and color darkens (Wilcke, 1967). Toasting also results in formation of carbonyl compounds (Hrdlieka and Janicek, 1964).

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The carbohydrates of raw soybeans and their possible role in soy flavor have been investigated. Sucrose, raffinose, and stachyose are the main sugars in raw and heated soybeans (Kasai and Kawamura, 1966). Kawamura (1967b) pointed out that when subjected to heat, especially during roasting, the carbohydrates present in soybeans may undergo hydrolysis and other forms of degradation, including dextrinization and carmamelization which, in turn, affect flavor.

The possibility that nonenzymatic browning may also occur was demonstrated (Kawamura, 1967a) when parallel decreases of sugars, whiteness, and available lysine occurred upon autoclaving at 100 and 120°. Intact soybean sugars are of the nonreducing variety but, upon degradation, the reducing sugar galactose can be released, which can then participate in nonenzymatic browning.

Several patents propose infrared heating to improve flavor. Conventional heating improves flavor but may also affect nutritional and functional soy properties. However, by using infrared heat, Guidarelli *et al.* (1964) achieved the same improvement as by heating for 15 min at 205°F. However, there are several limitations. First, the moisture content is critical, and for the above conditions approximately 20% moisture in the bean is required. Also, a layer 2 to 4 beans thick is all that can be processed for effective radiation penetration.

A highly palatable whole bean product is claimed by Guidarelli (1968) when processed by swelling the bean to 35–75% moisture and then employing infrared radiation to toast the bean.

A physical process involving streaming water has been patented to remove soybean hulls and thus a portion of the bitter ingredients (Kovasznay and Kovasznay, 1962).

Since heat treatment generally improves soy flavor, Wilkens and Lin (1970) analyzed the volatile flavor components of deep fat-fried soybeans. They positively identified 28 compounds, with 4-vinylguaiacol, 2-ethyl-3,6-dimethylpyrazine, and 1-octen-3-ol being present in the largest quantities. Numerous derivatives of pyrazine, pyrrole, and furan were also identified. This study is one of the few that has been able to identify pleasing flavor compounds from soy products.

The compound 1-octen-3-ol was reported by Badenhop and Wilkens (1969) to be enzymatically formed during the soaking of soybeans, which is a preliminary step in the processing of soy milk. The odor of this specific compound has been reported to be characteristic of mushroom, musty, and earthy. Badenhop and Wilkens (1969) reported its odor threshold in soy milk to be 0.5–1 ppm.

DEFATTED SOY FLAKES AND FLOURS

Both extrusion and solvent extraction techniques can be used to remove oil from soybeans. Today a vast majority of the soybeans processed are extracted with solvent, mainly due to its greater efficiency. Various solvents have been proposed and Eldridge (1969) has prepared a bibliography on the solvent extraction of soybeans. Presently, most commercial operations use hexane due to its economy and efficiency. However, although hexane may be efficient in removing the oil portion of the soybean, hexane usually does not remove the characteristic bitter beany flavor normally associated with soybeans.

Therefore, numerous investigators have suggested the use of other solvents or additional treatments to remove these characteristic flavors. Hexane-defatted flakes were treated with 80% concentrations of various alcohols and 20 min of steaming (Moser *et al.,* 1967). It was concluded that ethanol plus steaming resulted in the best flavored product. Earlier Beckel *et al.* (1948a) concluded that ethanol extraction gave the best results with respect to the color of oil, meal, and protein, and it also served as a debittering agent for the flakes. The advantages of ethanol extraction include an improvement in color and flavor, low free fatty acid content in the oil, the possibility of additional byproducts, greater safety, and low toxicity of the residual solvent (Beckel *et al.*, 1948b). Mustakas and coworkers (1961) used countercurrent alcoholic washing and flash desolventization to make a bland-flavored soybean flake.

However, mainly due to economics, the major soybean processors have felt that the improvement in flavor resulting from these and related treatments does not warrant the additional processing time and expense.

Sessa *et al.* (1969) steam-distilled defatted flakes and found 3.2 ppm of hexanal, 0.25 ppm of acetone, and 0.11 ppm of acetaldehyde. They concluded that the volatile carbonyl compounds isolated, at the level recovered by this method, did not significantly contribute to soybean flavor since their removal did not affect the original flavor. This same study also measured lipid oxidation during processing and storage by use of the thiobarbituric acid (TBA) assay. Toasting greatly reduced TBA values, probably due to the inactivation of lipoxidase. No significant change in TBA values was found to occur with storage for 1 month at 5°. Analytical results demonstrated that approximately 88% of the TBA reactive substances was retained in the flakes, with the other 12% being associated with the oil. The authors were able to detect the presence of hydroperoxides in ether and azeotropic extracts of defatted flakes. Thus, it was concluded that some lipid degradation occurs during the preparation of full-fat and defatted flakes and that the extraction of the original soybean flavor is closely associated with the removal of the highly unextractable lipids.

Rackis *et al.* (1967) reported that the total volatile carbonyl content of defatted flakes was 3.6 ppm. However, taste tests with 3 ppm of hexanal in water showed neither the odor nor the flavor present in the original product.

Fujimaki and coworkers (1965) believe that the flavor problem is connected with fat decomposition products since, in commercial defatted flakes, they found as much as 0.5% residual fat. They state that it is quite probable that a part of the fat existing in soybeans is easily autoxidized in the defatting process and/or during storage, partly because of the chemical environment, such as decomposition of natural antioxidants or higher contents of metal catalysts. Physical factors such as increased surface area in contact with atmospheric oxygen and humidity may also contribute to further degradation since they report that the carbonyl compounds found in defatted flakes are the same as those produced in reverted soybean oil. They identified methanal, ethanal, hexanal, 2-propanone, 2-pentanone, 2-hexanone, 2-heptenal, and 2,4-decadienal as volatile carbonyl compounds in defatted flakes.

The role of lipids in defatted soybean flake chemistry has also been investigated by Honig *et al.* (1969). They reextracted defatted flakes with increasingly polar solvents in an effort to characterize the bound lipids. This group tasted milligram amounts of the isolated fractions and concluded that the quantity of volatile degradation products and derived flavors formed from the isolated lipid fractions could be expected to be of little importance in their contribution to soy flavor. Fatty acid analysis revealed that the residual lipids in defatted flakes had a lower percentage of unsaturated fatty acids than soybean oil and it was concluded that defatted flakes would be less susceptible to oxidation during processing. However, this lower proportion of unsaturated fatty acids may have been due to the fact that oxidation may have already occurred in processing from the bean to the defatted flake or there was a selective unsaturated fatty acid extraction in the defatting process. They also postulated that the formation of nonvolatile lipid products, which was not investigated, could be significant in flavor contribution.

Rackis *et al.* (1967) reported that only traces of phenolic acids are present in fractions that possess typical soybean flavors and that, since pure phenolic compounds have very little taste, phenolics are not important flavor contributors to soy products. However, Arai and coworkers (1966a) identified nine phenolic acids (syringic, vanillic, ferulic, gentisic, salicylic, para-courmaric, para-hydroxygenzoic, isochlorogenic, and chlorogenic acids) which they reasoned had some influence on soy flavor since they possessed sour, bitter, and astringent characteristics. They postulated that these phenolic compounds originated from the raw bean and were not removed or decomposed during oil extraction and other processing treatments due to their low solubility in hexane and their relative stability to heat.

Several groups have investigated the types of saponins in soy flour. Birk *et al.* (1963) reported finding sapogenols A, B, C, D, and E. Rackis and coworkers (1970), using the isolation procedure of Gestetner *et al.* (1966), found sapogenols B, D, and E in a hexane–methanol azeotropic extract of defatted flakes. Taste tests conducted by Rackis *et al.* (1967) found that highly purified saponins have no taste, and thus the absence of taste would imply that impurities in other saponin preparations contained the bitter principle normally associated with saponins.

Teeter *et al.* (1955) extracted defatted flakes with 95% ethanol. This resulted in a clear brown solution having a pronounced beany odor. This fraction was found to contain phenolic acids, fatty acids, acetone, and methyl propyl ketone.

Wang (1969) studied the effect of alcohol washing and autoclaving on the nucleotide content of defatted flakes and its possible effect on flavor. He found that both autoclaving and washing with 80% ethanol increased the nucleotide content. It was postulated that since certain nucleotides are flavor enhancers, their increased presence could influence soy flavor.

Kawamura (1967c) reported that Japanese soybean varieties are higher in sucrose, raffinose, and stachyose than American varieties. Therefore, the possibility exists that different flavors, possibly due to nonenzymatic browning, could result upon further processing or storage among the two basic varieties.

In another study Kawamura (1967d) evaluated the effect of autoclaving on the sugars in defatted flakes. He found that upon autoclaving, total sugars decreased, reducing sugars increased, nonreducing sugars decreased, the main oligosaccharides decreased, and glucose, fructose, and galactose increased or appeared. This would again indicate that nonenzymatic-type flavor fractions can occur with soy processing.

The effect of added sugars and amino acids on browning reaction rates in defatted flakes has been evaluated (Kamada and Sakurai, 1957a,b). Mixtures of defatted flakes and 10% added sugars were stored at 20, 28, and 38° for 40 days. Only slight browning was found at 20°, as compared to the higher temperatures. It was found that a moisture level above 5.7% was required for browning to occur. Glycine was the most reactive added amino acid.

Lipoxidase enzymes have been isolated from defatted flakes (Koch *et al.*, 1958). These data indicated that lipoxidases occur in two groups, those active on triglycerides and those active on fatty acids.

In a recent study Eldridge *et al.* (1971) reevaluated the role of hexane–alcohol–azeotrope mixtures in removing flavor from defatted soybean flakes and concluded that complete removal of objectionable soy flavor was not possible using these solvent mixtures.

A sensory study by Kalbrener *et al.* (1971) on seven commercially available soy flours reported that their odor blandness scores ranged from 5.8 to 7.5 on a 10-point scale, with 1 being strong and 10 bland. Flavor blandness scores on these same flours ranged from 4.2 to 6.7 on the same 10-point scale. Thus, they concluded that a truly bland soy flour is not yet commercially available.

The sensory blandness properties of soy flour in relation to other vegetable, milk, and marine protein sources were reported by Maga and Lorenz (1972). They concluded that the blandness of the soy flour they evaluated was significantly inferior to that of all the milk protein sources evaluated.

Numerous patents have been granted in the area of flavor improvement during the manufacturing of soy flakes and flours. Several of these are discussed below.

Acid digestion has been proposed to produce bland and odorless soy products. Moshy (1964) patented a process whereby a water–soy flour slurry is treated with acid to adjust the pH to the isoelectric point. The mixture is then heated for 10 min at 176°F and the supernatant, which now contains the objectionable flavor, is removed. However, if the process is permitted to proceed further increased degradation occurs, which in turn raises the bitterness level of the product. Another portion of the same patent describes a process involving steam-leaching a slurry of soybean flour with acidified water. Moshy (1965) expanded the above patent by incorporating an organic solvent to wash the acid-treated filter cake.

Several patents have been granted to Paulsen for the use of protonic acids (acetic, citric, phosphoric, and hydrochloric acids) or their salts (sodium and calcium) with or without peroxide treatment as a means of eliminating soy odor and taste (Paulsen, 1963, 1968a,b).

A patent has been assigned whereby soy is extracted with water in the presence of a cation-exchange resin which binds water-soluble impurities which can contribute to soy flavor (Ajinomoto Co., 1963).

In 1960, Bradof patented the treatment of soy flour in an aqueous medium by the action of yeast in combination with oxidizing and neutralizing agents. In theory, organic compounds responsible for objectionable flavor are oxidized by catalytic influence of yeast enzymes to form less objectionable organic acids. These acids were then neutralized by the addition of neutralizing agents.

Mustakas *et al.* (1962) devised a method to debitter hexane-extracted soybean meal into a product that possessed whipping properties. This method employed countercurrent extraction of the meal with alcohols such as 95% ethanol and 91% isopropyl alcohol. Time and temperature of the treatment were approximately 18 min at 38°, which resulted in little denaturation but improved flavor properties.

Enzymatic addition under alkaline cooking conditions has been proposed by Rambaud as a means of removing bitter soy flavor components (Rambaud, 1965). In this process ammonia is added to bring the pH of a soy slurry to between 8 and 9, a proteolytic enzyme is added, and the mixture is heated to 80°. Upon drying, the ammonia is driven off and a bland product remains.

A bland and debittered full-fat soy product results from a process outlined by Mustakas and Griffin (1966) whereby steamed flakes or grits are processed through a steam-jacketed screw type extruder under certain time and temperature relationships. The extruded product is dried and milled into a bland full-fat flour.

Cavanagh (1966) patented an eight-stage countercurrent solvent system capable of extracting fat, taste, and odor compounds from soybeans. The solvents used included equal volumes of ethanol, ethyl acetate, and acetone.

The inoculation and growth of nonpathogenic, saprophytic bacteria in a soy slurry was patented by Hoersch and Shank (1968) as a means of removing the characteristic taste and odor of soy and related products. Incubation was for 16 to 144 hr at 75–90°F. Bacterial action was terminated by heating or blast freezing.

Although the above methods and many more are available to improve the taste, odor, color, and keeping qualities of soy products, few, if any, are completely satisfactory when measured by modern American food patterns.

ISOLATED SOY PROTEIN(ATE)S

Edible isolated soy protein has only been commercially available since 1959 (Meyer, 1967). Therefore, little published flavor information is available on this product.

It has been postulated (Yamashita *et al.*, 1969) that the major flavor components in soybean protein may be in a protein-bound state and that these flavor factors can be liberated by the action of *endo*-peptidases. They were able to demonstrate the removal of bitterness from a bitter hydrolyzate of soybean protein by the addition of specific proteolytic enzymes.

Arai *et al.* (1970b) cite the fact that hexanol and hexanal are quite resistant to vacuum distillation. This resistance could be due to their binding with protein through hydrophobic bonds. They claim that enzymatic proteolysis loosens these bonds, thus making these two specific compounds more easily removed.

Arai and coworkers (1970b) point out that enzymatic proteolysis can result in the formation of bitter compounds. They concluded that this bitterness was caused by dialyzable peptides containing leucine at the C-terminal end. This study also found that initial peptic hydrolysis resulted in a nondialyzable bitter peptide.

In a similar study (Noguchi *et al.*, 1970), soybean curd was partially digested with aspergillopeptidase A. It was found that enzyme-treated curd released more ether-soluble compounds, total carbonyl compounds, volatile reducing substances, lipids, pigments, and saponins than nonenzymatically treated curd.

Pepsin has also been used to treat soy protein (Fujimaki *et al.*, 1970b). The bitterness found in a diffusible fraction was due to free amino acids such as isoleucine, leucine, phenylalanine, and valine and its diffusible peptides, most of which had leucine at one end.

Fujimaki and coworkers (1970a) prepared edible polypeptides from crude proteins which originally had unfavorable odor or color. After partial hydrolysis with pepsin, odorants, fats, and pigments were removed with ether and the product treated with α-chymotrypsin to remove the bitter characteristics.

In an earlier study, Fujimaki *et al.* (1968) evaluated proteolytic enzyme treatments on a commercially available isolated soy proteinate and their affects on flavor. It was found that beany flavor generally decreased in the early stages of digestion and bitter flavor increased with time. Other flavor notes included oily and maltol-like, which resulted from the breakdown of residual lipids and carbohydrates by lipase and amylase contaminants in the proteolytic enzyme preparations.

Previously, Abdo and King (1967) demonstrated the use of enzymes in the extraction of soy protein which possessed improved flavor. They reported that normal water extraction of defatted flakes recovered 74% of the total protein. However, when water-extractable enzymes derived from *Pestalotiopis westerdijkii* were used, 95% of the total protein was extracted. The resulting protein was judged to be of an equal or superior quality than protein prepared without enzymatic treatment. The enzymatic mixture included carbohydrases, proteases, lipases, oxidases, and pectinases.

The ether-soluble volatile neutral and acidic compounds from hydrolyzed soy protein have been investigated (Manley and Fagerson, 1970b). From this mixture 10 neutral and 28 acidic compounds were identified. Types of compounds isolated included aldehydes, ketones, lactones, alcohols, acetates, acids, and furans. Another similar study by Manley and Fagerson (1970a) reported that alkylated pyrazines were the major volatile components found in the basic fraction of hydrolyzed soy protein.

Wolf *et al.* (1966) fractionated soy protein and found that all fractions gave a positive carbohydrate test. Since defatted flakes are high in carbohydrates, the authors questioned whether the carbohydrate isolated with the protein was a contaminant or an integral part of the protein molecule. They found that washing the protein with alcohol removed carbohydrate not removed by dialysis, which indicated that the carbohydrate fraction must be tightly complexed with the protein.

The alcohol washing of isolated soy protein from hexane-defatted flakes as a means of improving color and flavor has been proposed by Eldridge and coworkers (1963). They found that treatment of isolated soy protein with 95 to 97% methanol, 84 to 88% ethanol, or 78 to 88% isopropyl alcohol extracted 2 to 4% of a phospholipid-like material which could not be removed by isoelectric precipitation, washing with water, dialysis, or ammonium sulfate precipitation.

The reports of Eldridge *et al.* (1963) and Honig *et al.* (1969) have been further evaluated with respect to alcohol washing as a means of improving flavor (Maga, 1970). Commercial isolated soy protein and the same material treated with 79 parts hexane and 21 parts ethanol were compared by the flavor profile analysis method (Caul, 1957). Results from this study (Maga, 1970) demonstrated that additional washings with solvents and water removed some but not all of the objectionable soy flavor.

In this same study (Maga, 1970), the flavor profile of commercial isolated soy protein processed from defatted flakes and raw soybeans of the same source was compared. Overall intensity ratings of both aroma and flavor showed that isolated soy protein was judged to be the blandest of the three products. Processing decreased the green and bitter flavors of the products, probably to the benefit of the sweet-like flavor which appeared. Few flavor notes were detected in the raw bean. Probably the intensity of the detectable notes covered other flavors or the possibility exists that processing actually increases the number of flavors detectable in the other products. Approximately half of the descriptive terms were associated with tactile sensations. Therefore, tactile characteristics were found to play an important part in the total flavor impression of soy products.

In another study, Maga and Johnson (1972) followed the lipid composition of soy products from the raw soybean to defatted flakes and finally isolated soy proteinate as influenced by processing and storage conditions. They demonstrated that with increased processing the level of residual lipid unsaturated fatty acids was reduced and that prolonged room temperature storage also resulted in lower levels of residual unsaturated fatty acids.

Sensory studies by Kalbrener *et al.* (1971) on commercially available soy isolates reported that odor blandness scores ranged from 6.8 to 7.7 and their flavor blandness scores from 5.9 to 6.4 on a 10-point scale, with 1 being strong and 10 bland. A similar sensory study by Maga and Lorenz (1972) showed that the overall blandness properties of the soy isolate they examined were not significantly different than milk protein sources used in the study.

Thus, in conclusion, it would appear that, as with most flavor problems, the mechanisms of soy flavor are quite complex and not entirely understood at the present time. However, dedicated interest, improved instrumentation, and other advanced research techniques hold promise that soy flavor will be elucidated at a more rapid and efficient fashion in the future.

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Received for review January 3, 1973. Accepted July 19, 1973. Modified and updated from an oral presentation at a Soy Symposium sponsored by the Southern California American Association of Cereal Chemists Section at Santa Barbara, Calif., in August of 1971.

Formation of Pyrazines from Thermal Treatment of Some Amino-Hydroxy Compounds

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Some nitrogenous organic compounds were heated individually under air flow and the volatiles produced were qualitatively investigated by gc-ms. Pyrazines were obtained from heating certain amino-hydroxy compounds, such as ethanolamine, glucosamine, serine, threonine, 4-amino-3-hydroxybutyric acid, and alanylserine. This type of compound may be considered as one of the important precursors of pyrazines in foods.

To date, it is well known that pyrazines are present in a wide variety of heated foodstuffs, notably in those of fried or roasted, such as potato chips (Buttery *et al.*, 1971; Deck and Chang, 1965), coffee (Bondarovich *et al.*, 1967; Friedel *et al.*, 1971; Goldman *et al.*, 1967), cocoa (Marion *et al.*, 1967; Rizzi, 1967; van Praag *et al.*, 1968; van der Wal *et al.*, 1971), popcorn (Walradt *et al.*, 1970), deep fat-fried soybeans (Wilkens and Lin, 1970), roasted peanuts (Johnson *et al.*, 1971; Mason *et al.*, 1966; Walradt *et al.*, 1971), roasted barley (Collins, 1971; Wang *et al.*, 1969), and roasted pecans (Wang and Odell, 1972). The aroma of this class of compounds has been described as "roasted," "roasted nutty" or "cooked." Their precursors in foods have been considered as sugars with amino acids (Dawes and Edwards, 1966; Koehler and Odell, 1970; Koehler *et al.*, 1969; Mason *et al.*, 1966; van Praag *et al.*, 1968; Wang *et al.*, 1969), and a further mechanistic study of alkylpyrazine formation in model systems of α-dicarbonyls with amino acids was reported recently (Rizzi, 1972). In the previous paper, we obtained a series of pyrazines by heating a mixture of glycerol and amino acids without the presence of sugars. The present study was directed toward the identification of the pyrazines produced by thermal

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