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I am submitting herewith a dissertation written by Myung Joo Han entitled "Flavor and Stability of Potato Chips Fried in Soybean , Cottonseed and Palm Olein Oils". I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Food Technology and Science.

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**FLAVOR AND STABILITY OF POTATO CHIPS
FRIED IN SOYBEAN , COTTONSEED AND PALM OLEIN OILS**

**A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville**

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May 1989

AG-VET-MED.

Thesis

89b

.H252

Dedicated to my father, Gook Hyun Han (1924-1981) who has
always been my inspiration.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to my major professor, Dr. Sharon L. Melton for her continuous encouragement, assistance and guidance throughout this study.

I would like to express my appreciation to my committee members, Dr. F. A. Draughon, Dr. J. R. Mount and Dr. J. T. Smith for their aid and assistance during this study.

I would also like to express my appreciation to Dr. H. O. Jaynes for his assistance and understanding as the department head.

I would like to extend my gratitude to all other departmental faculty, staff and students for their assistance and help at several stages in this study.

Special appreciation goes to my mother: Ryen Worle Lee, my husband: Dong Hyun Kim, sister, brothers, uncles and aunts for their love, encouragement and support during this course of study.

ABSTRACT

The objective of this study was to determine effects of cottonseed oil, soybean oil and palm olein on stability and flavor of potato chips. This study consisted of potato chips fried in 3 different oils: partially hydrogenated soybean (PHSO), cottonseed (CS) and palm olein (PO); then stored for 0, 2 or 4 weeks (3 storage times) in sealed glass jars under fluorescent light or in the dark (2 treatments) at 23°C. A single replication consisted of the 3 oils, 3 storage times and 2 treatments. Two replications were performed. The moisture and oil contents, peroxide value (PV), Hunter color values (L, "a" and "b"), sensory scores for flavor and acceptability, and volatile compounds of the potato chips were analyzed as a function of oil, storage and treatment. The fatty acid composition of the oils during use was also determined.

The PV of potato chips averaged across oil and treatment increased 57% during 2 weeks storage and 131% during 4 weeks storage, and the PV of chips stored in the light (10.8) was significantly higher than the PV of chips stored in the dark (6.5). The PV of chips fried in each of the three oils increased linearly with increasing storage time under light. The PV of chips fried in PHSO or PO and stored in the dark did not change significantly ($p>0.05$) during storage, but the PV of chips fried in CS increased linearly at a slower rate with increasing storage time than the same chips stored in the light. Potato chips fried in CS were lighter (Hunter color L=59.3) in color than chips fried in PHSO (57.5) or

PO(57.1) and were less red (Hunter color "a"=4.2) than chips fried in PO (5.5). Potato chips fried in CS had significantly ($p<0.05$) more desirable flavor and were more acceptable to a sensory panel of 48 inexperienced members than chips fried in PHSO or PO. However, potato chips stored for four weeks in the light had significantly less desirable flavor and lower acceptability than fresh potato chips (0 week) or those stored for four weeks in the dark. Among the three oils, PO was the most saturated, PHSO contained the highest level of monounsaturated fatty acids and CS contained the highest level of diunsaturated fatty acids. Twenty compounds were identified in the volatiles of the potato chips and significant differences were found among the oils for five of the identified compounds and five volatiles classified only as pyrazines or aldehydes by mass spectra. In general, storage of chips for four weeks in light or dark decreased the levels of the volatile compounds isolated from the chips ($p<0.05$). The most abundant volatiles found in the chips included 2-methyl pyrazine, 2,5-dimethyl pyrazine, 3-ethyl-2-methyl pyrazine, 2,3,5-trimethyl pyrazine, 2-ethyl-5,6-dimethyl pyrazine, phenylacetaldehyde, and t,t-2,4-decadienal. Correlation of the flavor desirability score with the levels of volatiles ($n=18$) indicated that higher levels of 3-ethyl-2-methyl pyrazine and t,t-2,4-heptadienal contributed to less desirable flavor, and decanal and t,t-3,5-octadien-2-one (both found in chips fried in CS only) contributed to a more desirable chip flavor ($p<0.05$).

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CHAPTER I

INTRODUCTION

Deep fat frying is a widely used food preparation method in the home and in the food industry. A major portion of the 10 billion pounds of fats and oils consumed by Americans each year is used for frying foods (Chang et al., 1978a).

The fat used for deep fat frying acts as the medium for heat transfer and becomes an important ingredient of the fried food (Alim and Morton, 1974; Stevenson et al., 1984b). During deep fat frying, the fat is exposed to a high temperature in the presence of air and moisture. Many chemical reactions, such as autoxidation and hydrolysis, occur and form volatile decomposition products (VDP) and nonvolatile decomposition products (NVDP) during the frying process. The deep fat fried flavor is essentially contributed by VDP which can originate either from the oil, from the food, or from the interaction between the oil and the food. Thus, the flavor of the frying oils contributes to the total flavor of fried food (Chang et al., 1978b). The formation and accumulation of NVDP in frying fat are responsible for physical changes in the fat, such as increases in viscosity, foaming, and color darkening, and for chemical changes, such as the increase in % free fatty acids, carbonyl value, hydroxyl content, saponification value and decrease in level of fatty acid unsaturation (Stevenson et al., 1984b).

Unhydrogenated cottonseed oil is the favored oil for cooking potato chips (Weiss, 1983). However, because of limited availability, cottonseed oil may become too expensive for large scale industrial frying applications and the more economical vegetable oils, such as soybean oil and palm olein, in their natural or modified forms, are used instead (Morton and Chidley, 1988). Cottonseed oil is often blended with soybean oil to reduce production cost of potato chips. This blend can be used without loss of flavor quality because cottonseed oil masks the reversion flavor of soybean oil. Although there were a few reports of investigations in which the flavor and stability of potato chips fried in different oils were studied, no reports were found in which the characteristics of potato chips fried in cottonseed oil, soybean oil, or palm olein were compared. Therefore, the objective of this study was to investigate the effects of cottonseed oil, soybean oil and palm olein on the stability and flavor of potato chips during production and storage.

CHAPTER II

REVIEW OF THE LITERATURE

A. DEEP FAT FRYING-General

Deep fat frying is one of the most commonly used procedures for preparation of food in the world (Chang et al., 1978a; Chang et al., 1978b; Robertson, 1968). According to Stevenson et al. (1984b), over 500 million lbs of fats and oils are used yearly for potato chip production in the United States. In deep fat frying, the fat acts as a conductor of heat, is absorbed and becomes an important ingredient of fried food. Potato chips contain about 40% absorbed fat; potato sticks, 35%; doughnut, 20-25%; fried shrimp and scallops, 12-15%; fish sticks, 10-12%; and French fried potatoes, 7-10% (Alim and Morton, 1974; Baeuerlen et al., 1968; Robertson, 1968)

Frying fats are subjected to three primary environmental conditions in the frying process which are the frying, the standby and the storage periods (McGill, 1980; Roth and Rock, 1972a). The storage period starts as soon as the fat is produced and ends when it is placed in the frying kettle. During this time, the fat may be exposed to air at room temperature. The standby period occurs when the fat is heated in the kettle and includes the time required to bring the fat up to frying temperature and the time necessary to cool the fat when frying is finished. During this time the fat is

exposed to air at high temperatures (Roth and Rock, 1972a). The frying period is the time during which the fat is actually being used for frying. During this time the fat is exposed to air and steam. During all three periods the frying fat can undergo autoxidation, the rate of which increases with increasing temperature. Hydrolysis of the triglycerides resulting in the formation of free fatty acids occurs only during the frying period or when water comes into contact with the hot oil.

Because the fat is exposed to high temperatures in the presence of air and moisture during deep fat frying, oxidative and thermal decomposition of the oil takes place with the formation of volatile decomposition products (VDP) and nonvolatile decomposition products (NVDP). The formation rate of decomposition products differ with the food being fried, the fat being used, the fryer design and the nature of the operating conditions (Alim and Morton, 1974; Bracco et al., 1981; Chang et al., 1978a; McGill, 1980; Peers and Swoboda, 1982; Stevenson et al., 1984b). The formation and accumulation of NVDP in the frying fat are responsible for physical changes in the fat, such as increases in viscosity, foaming and color darkening, and for chemical changes, such as the increase in levels of free fatty acids, carbonyl value, hydroxyl content, saponification value and decrease in level of fatty acid unsaturation (Stevenson et al., 1984b). VDP also can contribute to the increase in free fatty acid and carbonyl contents. The NVDP can be absorbed by the fried food. The VDP are also found in the deep fat fried foods and originate either from the oil, the food

or the interaction between the oil and the food (Chang et al., 1978b). Chang et al. (1978a) identified 211 VDP produced by corn oil, hydrogenated cottonseed oil, trilinolein, and triolein, under simulated deep fat frying conditions.

The life of a frying fat depends upon several factors. According to Waliking and Zmachinski (1970), commercial frying involves both the replacement of the frying oil to replace oil absorbed by the food and the evolution of steam. The life of a frying fat is enhanced by the dilution resulting from oil replenishment and by protection of an inert atmosphere and distillation of degradation products provided through evolution of steam. Daily filtration of the oil and regular cleaning of the frying equipment are also necessary to prolong the life of a frying fat (Baeuerlen et al., 1968; McGill, 1980; Robertson, 1968; Roth and Rock, 1972b). The condition and the amount of food fried at one time also affect the frying fat life. The food to be fried should be as dry as possible before frying since wet foods, particularly potatoes, tend to increase the rate of triglyceride hydrolysis (McGill, 1980). The correct amount of food to fry is generally one part of food in six parts of oil (McGill, 1980). If too much food is fried at one time, the temperature of the oil will drop and moisture evolved from the food will remain longer in the frying fat resulting in increased triglyceride hydrolysis. If too little food is fried at one time, only a small amount of fat is lost by absorption and the turn-over rate of frying fat will be too low to maintain high quality frying fat with repeated frying.

Several changes occur in the food that is cooked in the frying fat. These fried foods have inner and outer zones. The outer zone surface of fried food is changed to an even golden brown color resulting from browning or a Maillard reaction which occurs when the sugars and proteins present in the product react in the presence of heat (Robertson, 1968; Stevenson et al., 1984b). The degree of browning depends on the time and temperature of frying in combination with the chemical composition of the food being fried rather than on the type of fat used in the fryer. Thin deep fried items, such as potato chips, have essentially only the outer zone or one continuous crust. When the food is freshly fried, the outer zone is a crisp exterior skin, shell or crust produced by dehydration of the outer portion of the food being fried. The crust is formed at a moisture content of 3% or less in fried food. Also some of the frying fat enters the outer zone during frying and partly fills the void created by the loss of water (Robertson, 1968).

B. DEGRATIVE REACTIONS OF FAT DURING DEEP FAT FRYING

Autoxidation

Autoxidation is a natural chemical reaction between atmospheric oxygen and unsaturated compounds. Unsaturated fatty acids are generally more labile to the development of off flavor than the more saturated fatty acids (Chan et al., 1982; Paquette et al., 1985). Autoxidation is the main reaction causing oxidative

deterioration of the frying fat. Factors affecting the rate of oxidation are degree of unsaturation, oxygen concentration, temperature, moisture, prooxidants, light exposure and antioxidant (Chan et al., 1982; deMan, 1980; Nawar, 1985). Nawar (1985) indicated that the relative rates of oxidation in linolenate, linoleate and oleate are 20, 10, and 1, respectively. In general, the rate of oxidation increases as the temperature is increased. During deep fat frying, the fat is heated in the presence of air, thus, the process of autoxidation becomes much faster (McGill, 1980).

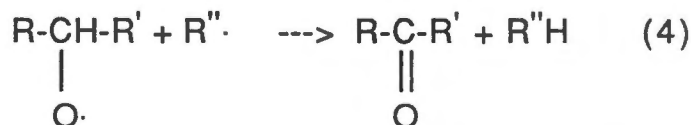
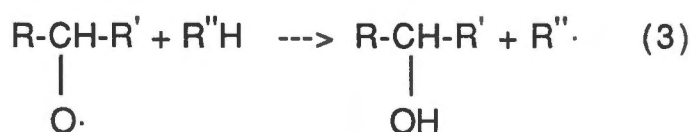
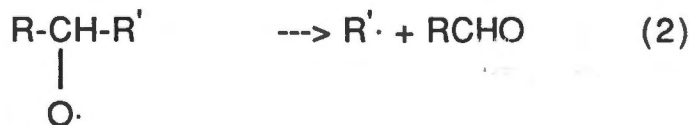
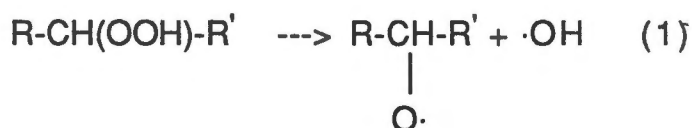
There are two steps involved in autoxidation of fatty acids; (1) the formation of hydroperoxides and (2) the further reactions of hydroperoxides which give the manifestations of autoxidation in foods (Chan et al., 1982). The oxidation of unsaturated fatty acids proceeds through the following free radical reaction (Melton, 1983):



The production of free radicals may take place by direct thermal dissociation, by hydroperoxide decomposition, by metal catalysis and by exposure to light with or without the presence of a photosensitizer. The susceptibility of unsaturated fatty acids to autoxidation is dependent on the availability of allylic hydrogens for reactions with peroxy radicals. The hydrogen on the carbon

adjacent to the double bond is favored due to the formation of a very stable allylic radical (Frankel, 1980; Nawar, 1985; Paquette et al., 1985). According to McGill (1980), a molecule with two double bonds close to each other is likely to be more unstable than one with three double bonds positioned well apart from each other.

Hydroperoxides, the primary products of autoxidation, are relatively unstable. A variety of volatile and nonvolatile secondary products are formed from hydroperoxide breakdown and the following reactions are the major pathway (Frankel, 1980; Paquette et al., 1985):



The homolytic cleavage of the oxygen-oxygen bond yields the alkoxy and hydroxy free radicals (1). The alkoxy radical can split to form an aldehyde and a new free radical (2). The carbon-carbon bond scission of this reaction can occur on either side of the radical. These volatile aldehydes play a major role in the oxidized flavor of fats. The abstraction of a hydrogen atom by the alkoxy radical from

another molecule yields an alcohol and a new free radical (3). These free radicals from reactions (2) and (3) may participate in propagation reaction or interact to yield nonradical products which occurs in the termination reaction. The abstraction of a hydrogen atom from the alkoxy radical yields a ketone (4). The cyclic peroxides or the hydroperoxy cyclic peroxides, which are commonly formed during the oxidation of polyunsaturated fatty acids, also decompose yielding a variety of compounds (Nawar, 1985).

Hydrolysis

The presence of moisture in the food being fried causes hydrolysis of triglycerides resulting in the formation of free fatty acids, mono- and di-glycerides and glycerol (Stevenson et al., 1984b). Higher levels of moisture in the food being fried tends to accelerate hydrolysis. Residues of caustic soda and other alkali used for cleaning the frying kettle promote hydrolysis. Therefore, the frying kettle should be well rinsed after cleaning (McGill, 1980).

According to Baeuerlen et al. (1968), hydrolysis is not the main cause of the formation of free fatty acids in normal frying operation. They demonstrated that the formation of free fatty acids increased to only 0.2% in a fat protected from air, compared with 1% in a fat exposed to air. The higher the initial free fatty acid content of a frying fat, the greater will be the amount of free fatty acids formed by hydrolysis. Fritsch (1981) found that hydrolytically generated free fatty acids up to at least 2% from nonlauric acid oils, such as soybean, cottonseed, peanut and palm

oils, had no adverse effect on the odor or the flavor of foods, whereas, the free fatty acids of lauric acid oils, such as coconut oil, produced a soapy flavor at ca. 0.5%. The determination of free fatty acids by titration does not differentiate between acids formed by oxidation and acids formed by hydrolysis (Baeuerlen et al., 1968; Fritsch, 1981).

During deep fat frying, moisture in the food also helps to create a steam blanket over the frying kettle, thereby, minimizing frying oil contact with air. Steam evolution also helps to volatilize and remove peroxides, flavors and odors (Landers and Rathmann, 1981; Stevenson et al., 1984b).

C. VEGETABLE OILS FOR DEEP FAT FRYING

Most finished vegetable oils contain high percentages of unsaturated fatty acids in the triglyceride molecule, therefore, they are very susceptible to oxidative deterioration. The secondary oxidation products, such as aldehydes, ketones, alcohols and acids, are responsible for the off odor and flavor characteristics of oxidative rancidity in vegetable oil (deMan, 1980; Nawar, 1985; Sherwin, 1976).

Tocopherols in vegetable oils resist development of oxidative rancidity. At least seven types of tocopherols have been isolated with the alpha, gamma and delta homologs predominant in vegetable matter. Of these homologs, the alpha tocopherol has the highest Vitamin E activity and also inhibits oxidation in oils. The gamma

and delta tocopherols are more effective antioxidants than the alpha tocopherol but they have lower Vitamin E activity. The antioxidant activities of these homologs decrease in the following order: delta, gamma and alpha. However, the order of these antioxidants in vegetable oils is dependent on the temperature and light (Nawar, 1985). A high proportion of the existing tocopherols survive oil processing and are present in the finished vegetable oils. These residual levels of tocopherols appear to be optimum for providing oxidative stability (Sherwin, 1976).

Cottonseed Oil

Unhydrogenated summer cottonseed oil is the favored oil for frying potato chips (Weiss, 1983). Before processing, crude cottonseed oil extracted from glanded seeds has a strong characteristic flavor and odor and a dark reddish brown color from the presence of the colored gossypol pigments in the seed. After refining, bleaching and deodorization, the cottonseed oil is light yellow in color with a pleasant odor and flavor and is very suitable as a frying oil (Mounts, 1985; Weiss, 1983).

Cottonseed oil contains 17.6% oleic acid (18:1), 53.3% linoleic acid (18:2), and 0.3% linolenic acid (18:3w3) according to Sherwin (1976) and has an iodine value from 99 to 121. These high levels of unsaturated fatty acid make cottonseed oil very susceptible to oxidation during frying. However, cottonseed oil also contains 870 to 950 ppm of tocopherols, naturally occurring antioxidants (Sherwin, 1976). Cottonseed oil also seems to maintain higher levels of its

tocopherols than other oils during frying. Du Plessis et al. (1981) evaluated cottonseed and peanut oils for deep fat frying in relation to their tocopherol levels. In their study during 103 hrs of frying, peanut oil lost about 55% of its original tocopherol content (38.9 and 27.4 mg of alpha- and gamma-tocopherols/100g oil, respectively), whereas cottonseed oil maintained its original levels of 50.7 mg alpha tocopherol/100g oil and 48.2 mg gamma tocopherol/100g oil.

Upon reversion, cottonseed oil has a nutlike flavor which is very acceptable to consumers in mayonnaise and potato chips as well as other fried foods. The reversion flavor of cottonseed oil is fairly strong in intensity and masks the less desirable reversion flavors of other oils if they are blended with cottonseed oil (Weiss, 1983). However, the availability of cottonseed oil has declined along with the decrease in planted cotton acreage, which was maximum at 46 million acres in 1925, but by 1980 had decreased to 13-14 million acres annually (Pryde, 1980). Thus, other vegetable oils, such as soybean oil and palm olein, have been utilized in their natural or modified forms either for cost reasons or to meet improved performance demands as a substitute for cottonseed oil (Morton and Chidley, 1988). The effect of palm olein on the flavor of snack food, however, from a chemical and sensory evaluation by United States consumers has not been reported.

Soybean Oil

Soybean oil contains 23.4% oleic acid, 53.2% linoleic acid and 7.8% linolenic acid (Sherwin, 1976) and has an iodine value of 125 to

128. Even though unhydrogenated soybean oil contains 940 to 1000 ppm tocopherols, it still reverts in flavor because of its linolenic acid content (Smouse and Chang, 1967; Smouse, 1985). The most important precursor of the reverted flavor is the terminal pentene radical in linolenic acid. Reverted soybean oil flavor is described as beany and grassy in its early stage, and fishy and painty in later stages. It is not affected by the presence of antioxidants and occurs with very little exposure to oxygen. The first perceptible reversion flavor compound identified from soybean oil was 3-cis hexenal which causes the beany flavor and is derived from the decomposition of both 12- and 13-linolenate hydroperoxides. (deMan, 1980; Frankel, 1980; Nawar, 1985; Sherwin, 1976; Weiss, 1983). According to Smouse (1985), flavor reversion of soybean oil is due mainly to linolenate oxidation at extremely low levels followed by decomposition and polymerization. The low levels of linolenic hydroperoxides can catalyze the oxidation of linoleate, the predominant fatty acid in soybean oil, which can dismutate to off odors and flavors. Also, phospholipids, sterols, hydrocarbons and pigments can have detrimental effects on the flavor depending upon their relative concentration. The photochemical activated oxygen and the elimination of double bond at carbon-15 also were both considered important in reversion flavor development (Smouse, 1985).

Light hydrogenation of soybean oil can improve its flavor stability since it reduces the 7.0% linolenic acid in the oil to less than 3.0% (Sherwin, 1976). However, hydrogenation of linolenic

acid in soybean oil also produces isolinoleic acids, a mixture of isomeric dienes. Upon oxidation, these dienes produce compounds similar to those formed from linolenic acid and impart an objectionable odor and flavor to soybean oil called hardening flavor (deMan, 1983; Frankel, 1980; Nawar, 1985; Smouse and Chang, 1967). However, because it prevents the development of fish odors in the air, hydrogenated soybean oil is usually used for frying instead of unhydrogenated which can be used for production of mayonnaise and salad dressing (Weiss, 1983).

Palm Olein

Palm olein, the liquid fraction obtained from fractionation of palm oil, is an important deep frying medium in Malaysia (Augustin et al., 1987). Palm oil contains 48% palmitic acid, 38.8% oleic acid, 9.4% linoleic acid, and 0.3% linolenic acid (deMan, 1980; Sherwin, 1976) and has an iodine value range of 45 to 56 and a tocopherol content of 560 ppm.

Bracco et al. (1981) studied the frying performance of palm olein. They concluded that palm olein has low degradation and produces fried foods with acceptable qualities. According to Sakata et al. (1985), the total consumption of palm oil in Japan reached nearly 150,000 tons in 1982, a 50% increase over that used in 1973. They indicated that palm oil has excellent properties against oxidation and has been generally accepted by Japanese consumers. There seems to be a high potential for increasing consumption of palm oil in fried food in the U.S.A. Robertson et al. (1978) reported

that the use of low priced palm oil in frying snack foods increased rapidly from 1974 to 1975. In 1975, the United States imported about 436,000 tons of palm oil which was 133% over 1974 imports. The use of palm olein as a frying oil in the U.S.A. is dependent not only on a low price but also overcoming adverse publicity that palm olein causes undesirable flavor in snack foods (Covington, 1987).

D. POTATO CHIPS

According to Min and Schweizer (1983), the production of potato chips is 35 billion lbs annually which is 11% of the potato crop in the U.S.A. A significant problem in potato chips is the development of stale or rancid flavor during storage. The potato chip processor is interested in the highest yield of chips possible in producing an acceptable colored chip and in maintaining a desirable, fresh flavor in chips (Smith, 1987). The yield of potato chips is controlled by their oil content.

Yield and Oil Content

The specific gravity of the raw potatoes is the measure of potential processed quality of potato products. The specific gravity of potatoes differs among cultivars grown under similar conditions, and within the same cultivars, is dependent on different soil, cultural and environmental conditions (Porter et al., 1964). The chip yield was found to increase and the oil content to decrease linearly through the specific gravity range of 1.060 to 1.110 (Lulai

and Orr, 1979; Porter et al., 1964; Smith, 1987).

The oil content of the chip contributes desirable sensory characteristics. High oil content in the chip is not only costly to the processor but also renders the chips oily or greasy and less desirable to consumers (Smith, 1987). Also, it is possible to make the oil content of the chips so low that they lack desirable flavor (Smith, 1987).

Many factors affect the oil content of the chip. Drying potato slices before frying decreases the oil content of chips by lowering the moisture content and increasing the specific gravity of raw potato slices. Slice thickness also affects the oil content of chips. Decreasing slice thickness (1/12, 1/15, 1/18, 1/21, and 1/24 in.) increases the oil content of chips (43.85, 44.68, 46.81, 47.61, and 49.93%, respectively) (Smith, 1987). Temperature of fat and frying time also affect the oil content of chips (Gamble et al., 1987; Smith, 1987). According to Gamble et al. (1987), the moisture loss and oil uptake of potato slices are dependent upon frying temperature. They studied the variations in moisture and oil content of 1.5 mm thick slices of potato after different frying times at 145, 165 and 185°C. They showed that the total yield of potato chips decreased with increased frying time up to 5 min after which it remained nearly constant at 33%. During the first 5 min of frying, the moisture loss was more rapid than oil uptake. They also found that yield decreased with increasing temperature. The oil content of chips was not directly related to frying temperature but was more closely related to the remaining moisture present in the chips.

Color

Color is one of the most important attributes of quality for potato chips, and producing a uniform and desirable potato chip color throughout the year is a problem for potato chip producers (Maga, 1973). Control of potato chip color is difficult because it is determined by the chemical composition of the tubers from which they are made. Fluctuations in the composition of tubers due to cultivar, maturity, storage temperature and other factors result in variations in chip color (Smith, 1987).

The Maillard reaction between the reducing sugars and amino acids plays a major role in the browning of potato chips (Fitzpatrick and Porter, 1966; Habib and Brown, 1957; Smith, 1987). In potatoes, high levels of sugars cause an undesirable sweet taste and excessive browning during frying (Hoover and Xander, 1961; Ewing et al., 1981). The synthesis of starch or its degradation to simple sugars in postharvest potatoes is controlled by storage temperature. The conversion of starch to sucrose and reducing sugars is promoted in most potato cultivars when they are stored at nonfreezing temperatures below 5°C (Nawar, 1985).

Fitzpatrick and Porter (1966) studied the effects of long term cold storage of potatoes on the sugars and amino acids in chips. Cold storage of the potatoes increased the reducing sugars to 90% of the total potato sugars. Chips fried from these potatoes decreased 88.4% in amino acid nitrogen with a corresponding decrease of 88.7% in reducing sugars. Acid hydrolysis of the chips indicated that part of these losses was due to reaction of amino acids with sugars.

The level of sugars in postharvest potatoes is controlled by the activity of the invertase. According to Pressey (1969), freshly harvested potatoes contain low levels of total invertase and high levels of invertase inhibitor. Total invertase increases sharply when potatoes are placed in cold storage, but the inhibitor is not depleted in all varieties.

Flavor

Potato chip flavor is dependent to some extent on the flavor of the raw potatoes and on the fat absorbed during frying in combination with reactions caused by the high temperature short time frying period. Preventing the reversion and oxidation of the fat in the chips during storage is a necessity to maintain a desirable chip flavor. Reversion and oxidation of the fat result in undesirable rancid and off flavors (Smith, 1987).

Flavor, in general, is controlled by the odor and aroma of volatile compounds present at given concentrations in the food. Analysis of these volatile compounds is complicated. The volatiles measured depend not only on the food product from which they are isolated but also on the method of isolation. Buttery et al. (1970) analyzed steam volatile oils obtained from potatoes both under vacuum and at atmospheric pressure. They showed that the major volatile potato components obtained under vacuum include 1-octen-3-ol, trans-2-octenal, trans-2-octenol and geraniol, and those obtained at atmospheric pressure include 2-pentylfuran, phenylacetaldehyde, trans-2-nonenal, furfural, hexanal and pyridine.

Buttery et al. (1971) also analyzed the basic fraction of the steam volatile oil from potato chips and identified 18 pyrazine and pyridine compounds. Buttery and Ling (1972) analyzed the nonbasic fraction of the steam volatile oil from potato chips and identified 46 volatile compounds that were not present in the basic fraction.

Several other investigators have also measured the volatile compounds isolated from potato chips. Mookherjee et al. (1965) identified 18 monocarbonyl compounds in fresh potato chips and 19 monocarbonyl compounds in stale potato chips. Deck et al. (1973) identified 53 volatile compounds from potato chips including 8 nitrogen containing compounds, 14 hydrocarbons, 13 aldehydes, 2 ketones, 1 alcohol, 1 phenol, 3 esters, 1 ether and 8 acids.

Although many volatiles have been identified and measured from potato chips, not all are important to the fresh, desirable flavor of the chip. Mookherjee et al. (1965) reported that compared with fresh potato chips, stale chips had increased concentrations of saturated aldehydes, saturated ketones and 2-enals and decreased levels of the 2,4-dienals. They indicated that the development of a stale flavor was due not simply to the formation of undesirable carbonyl compounds but also to the disappearance of the 2,4-dienals, which contribute to the fresh potato chip flavor. Buttery and co-worker (1971) showed that in the basic fraction of potato volatiles, 2-ethyl-3,6-dimethyl pyrazine was a major contributor to the odor intensity. Buttery and Ling (1972) showed that in the nonbasic fraction of potato volatiles, methional, 3-methyl butanol, phenylacetaldehyde and trans,trans-2,4-decadienal were important

aroma compounds to chip flavor. Deck et al. (1973) showed that the alkyl substituted pyrazines, the 2,4-dienals, phenylacetaldehyde and furyl methyl ketone were important to the desirable flavor of potato chips. They also reported the description of the aroma of these various volatile compounds. In their study, the aroma of 2,5-dimethyl pyrazine and 2-ethyl pyrazine was described by the organoleptic panel as either strong potato or roasted peanut. The aroma of 2-ethyl-5-methyl pyrazine, with a trace of 2,3,5-trimethyl pyrazine, was described as baked potato or peanut like. The aroma of 2-ethyl-3,6-dimethyl pyrazine, with a trace of 2,5-diethyl pyrazine, was described as earthy potato. //

According to Lee et al. (1973), many of the flavor compounds of potato chips were evidently produced by the components of the potato when they are treated under deep fat frying conditions. Amino acids and sugars are the major precursors of potato chip flavor. These investigators determined the flavor characteristics and the chemical composition of the volatile compounds produced by various amino acids, particularly methionine, when they were deep fat fried. A strong pleasant potato chip-like aroma was produced by methionine alone without glucose and without the development of a dark color. They concluded that potato chip flavor might not be entirely due to Maillard browning reaction, since it could also be produced by simple thermal decomposition of amino acids, such as methionine. //

E. PEROXIDE VALUE

According to Stevenson (1984b), the most commonly used chemical tests for measurement of oxidation in a food processing operation include the determination of free fatty acids, peroxide value and thiobarbituric acid test. However, none of these tests is completely satisfactory for monitoring changes in fat quality. Since degradation products in the fat change over time and different food-fat combinations form different compounds at different rates, a test suitable for monitoring fat changes in one operation will not necessarily be useful for another operation.

Fritsch (1981) did not recommended the peroxide value for measuring frying fat deterioration because peroxides under deep fat frying conditions are unstable and may increase after the sample is taken from the fryer and before it is analyzed.

Although the peroxide value is not a good indicator of fat stability during frying and measures only the hydroperoxides, the primary products of lipid oxidation, it is the most commonly used chemical measure of oxidative rancidity in potato chips. Quast and Karel (1972) showed that the peroxide value is a fairly reliable index of the extent of the early stages of oxidative deterioration in potato chips. However, Min and Schweizer (1983) indicated that the peroxide value alone is not a very good flavor quality indicator in chips, because the peroxide values increased to a maximum and then decreased with increasing storage time. However, linear relationships have been observed between peroxide and flavor scores

during the initial stages of lipid oxidation in oil and lipid rich foods by many investigators (Fioriti, 1977; Quast and Karel, 1972; Robertson et al., 1972).

The peroxide value is an applicable measurement for peroxide content during the early stages of oxidation according to Nawar (1985). However, peroxides or hydroperoxides are primary products of lipid oxidation and are very unstable (Gary, 1978). They decompose to form volatile aldehydes, ketones, acids, alcohols, hydrocarbons and other compounds (Perkins, 1967). When the rate of decomposition is greater than the rate of peroxide formation in stored potato chips, the peroxide value will decrease with increasing storage time and no longer be a valid measurement of oxidative rancidity. The length of time required for a peroxide value to decrease in an oxidizing food fat is also dependent on the storage temperature. Paquette et al. (1985) reported the rate of peroxide decomposition is increased by elevated storage temperatures.

The peroxide value of a fat is a measure of its reactive oxygen content expressed in terms of milliequivalents of oxygen per kg of fat or as millimoles of peroxide per kg of fat (Mehlenbacher, 1960). According to Gray (1978) and Rossell (1986), there are many analytical procedures for the measurement of the peroxide value. The results and stability of the test depend on the experimental conditions and the reducing agent employed. Therefore, the method used in the determination of peroxide value should also be given with the results. The iodometric method of Lea and Wheeler is

widely used and is based on the measurement of free iodine produced from potassium iodide by the peroxides present in the oil (Gray, 1978). The two principal sources of error in this method are the absorption of iodine by unsaturated bonds of the fatty materials, and the liberation of iodine from potassium iodide by oxygen present in the solution to be titrated. The AOCS (1983) official iodometric method Cd 8-53 for peroxide value determination is applicable to all normal fats and oils. However, this method is highly empirical and any variation in the procedure may cause variation in the results. The official method fails to adequately measure low peroxide values because of difficulties with the determination of the titration end point. Thus, the official method has been modified to increase its sensitivity at low peroxide values (Gray, 1978). In the modification, the titration step is replaced with an electrochemical technique in which the liberated iodine is reduced at a platinum electrode maintained at a constant potential. Peroxide values ranging from 0.06 to 20 have been determined with this modified method. However, detecting the sodium thiosulfate titration end point of iodine by the disappearance of the blue color due to the starch free iodine complex is still a commonly used method by potato chip processors (Strickland, 1988) because it is simple and requires no special equipment. This end-point detection method was used in the determination of peroxide value by Mehlenbacher (1960).

When peroxides in fat containing foods are to be determined, it is necessary to extract the fat from the solid material before

determining the peroxide value, in order to avoid the possible interference of water or other materials with the reaction. Heat should be avoided if possible because peroxides increase rapidly when heat is applied. A preferable method is to extract the sample in a Waring blender (Waring Products, New Hartford, CT) with the solvent (Mehlenbacher, 1960). According to Mehlenbacher (1960), fat containing foods were extracted with chloroform in a Waring blender, and then the chloroform extract was analyzed for peroxide value. The peroxide value should be determined on the extract as rapidly as possible to prevent additional peroxide formation.

CHAPTER III

MATERIALS AND METHODS

A. EXPERIMENTAL PLAN

The experiment consisted of potato chips fried in 3 different oils (soybean, palm olein and cottonseed), then stored in dark or light (2 treatments) for 0, 2 or 4 weeks (3 storage times) at 23°C. A single replication consisted of the 3 different oils, 2 treatments and 3 storage times, and 2 replications were completed. The order in which each oil was used in the fryer was randomized across replication. For each oil-replication combination, enough potato chips were fried to complete all analyses in this experiment.

B. SOURCES OF OILS AND POTATOES

For this experiment, enough oil was obtained at one time to complete the experiment. Lots of 36.3 kg of partially hydrogenated soybean oil, 36.3 kg of cottonseed oil and 108.9 kg of fresh potatoes were obtained from Tom's Snack Food, Knoxville, TN. Also, 36.3 kg of palm olein was obtained from a Tennessee oil processor. The potatoes were obtained in three different equal lots, with each lot containing enough potatoes for frying in two consecutive oil-replication combinations. The specific gravities of the potatoes

were 1.072 (lot 1), 1.095 (lot 2) and 1.085 (lot 3). The partially hydrogenated soybean oil contained 0.02 % free fatty acids (FFA) and had a 0.75 peroxide value (meq/kg oil) or PV; cottonseed oil contained 0.02 % FFA and had a 1.40 PV and palm olein contained 0.03 % FFA and had a 0.2 PV. The cultivar of potatoes was Atlantic (FL) and was the cultivar used by Tom's Snack Food for chip production. The potatoes were stored at 15°C until used for potato chip production.

C. SAMPLING AND FRYING PLAN

In this experiment the fryer was not large enough to produce all of the needed potato chips for planned analyses. The planned analyses in this experiment for each oil-replication combination required twenty-four 125 g samples sealed in 1.89 liter glass jars. These 24 glass jars were for 12 planned analyses in duplicate. The planned analyses included chemical and physical analyses at 0-week storage (A-0) and at 2- and 4-weeks of storage time in dark (A-1D and A-2D, respectively) and in light (A-1L and A-2L, respectively); sensory analysis at 0-week (B-0) and at 4-weeks storage in dark (B-2D) and light (B-2L); and volatile analysis at 0-week (C-0) and 4-weeks storage in dark (C-2D) and light (C-2L). A spare sample (S) was also obtained. A randomized complete block design was used to minimize the effects of frying oil deterioration and potato chip oxidation during the necessary frying time (approximately 6 hrs) to produce all of the potato chips. Within each oil-replication

combination, each jar of a duplicate was assigned one number selected from 1 through 12, and each jar was filled with 125 g of potato chips. The type of analyses that was done on each pair of jars or duplicate number was randomized for each oil-replication as shown in Table 1.

During the 6 hrs frying period for each oil-replication combination, 6 blocks of potato chips were fried, and one block consisted of 4 consecutive fry times with 400 g of potato slices fried each time. Each frying block consisted of 4 numbers. Each number was selected at random from 1 through 12 and represented a single jar of a duplicate pair. The assignment of these numbers to each block are shown in Table 2. At the end of each block of frying, the resulting 500 g of potato chips were mixed thoroughly in a closed container before being divided into four 125 g sample. Each sample was placed in the assigned numbered jar for that block, and further designated by the analyses that would be run on that sample of potato chips according to the plan shown in Table 1.

D. PREPARATION AND STORAGE OF POTATO CHIPS

For each oil-replication combination, 18.14 kg of raw potatoes were washed and peeled by an abrasive potato peeler, Model 6015P (Hobart Manufacturing Co., Troy, OH). The peeled potatoes were sliced into 0.127 cm thick slices using a Hobart slicer, Model 84142 (Hobart Manufacturing Co., Troy, OH). The potato slices were washed in warm water two times to get rid of surface starch,

TABLE 1.

RANDOMIZED COMPLETE BLOCK ASSIGNMENT OF DUPLICATE PAIR NUMBER TO TYPE OF ANALYSES AND STORAGE TIME AND TREATMENT COMBINATION^a FOR EACH OIL AND REPLICATION.

Duplicate number	Soybean oil		Palm olein		Cottonseed oil	
	Rep1	Rep2	Rep1	Rep2	Rep1	Rep2
1	S	A-2D	B-2L	B-2L	B-2D	A-0
2	A-2L	C-0	C-0	A-1D	A-2D	C-2L
3	B-2D	C-2L	A-2L	C-0	B-2L	B-0
4	B-2L	A-0	C-2D	A-0	A-0	C-0
5	A-0	B-0	B-0	B-2D	A-2L	C-2D
6	C-2D	A-1D	A-2D	A-1L	S	S
7	A-2D	A-1L	C-2L	C-2D	A-1D	A-1D
8	B-0	S	A-1D	B-0	B-0	B-2D
9	C-2L	C-2D	B-2D	A-2D	C-2L	A-2D
10	A-1D	B-2L	S	S	C-0	A-2L
11	A-2L	B-2D	A-0	C-2L	A-1L	A-2L
12	C-0	A-2L	A-1L	A-2L	C-2D	B-2L

^aA-0=chemical and physical analyses at 0-week; A-1D and A-2D are for chemical and physical analyses after 2- and 4-weeks storage in the dark; A-1L and A-2L are for chemical and physical analyses after 2- and 4-weeks storage in the light; B-0 is for sensory analysis at 0-week; B-2D and B-2L are for sensory analysis after 4 weeks storage in dark and light, respectively; C-0 is for volatile analysis at 0-week; C-2D and C-2L are for volatile analysis after 4 weeks storage in dark and light, respectively, and S is a spare sample.

TABLE 2.
RANDOMIZED COMPLETE BLOCK DESIGN^a FOR POTATO CHIP
SAMPLE PROCUREMENT FOR EACH OIL-REPLICATION.

Block number	Duplicate number			
1	12	6	5	4
2	9	12	11	7
3	2	9	5	1
4	8	1	10	7
5	6	8	11	3
6	10	3	4	2

^aSanders (1988).

drained, spread in a single layer in a shallow pan and dried for 8 min at room temperature under forced air flow.

Before frying of the potato slices was started, 13.6 kg of oil were placed in a Gold Medal Model FW-12 Shallow Fryer (Gold Medal Products Co., Cincinnati, OH), heated to 163°C and held at that temperature for 4 hrs. The temperature was increased to 194.4°C and frying was started. At each fry time, 400 g of the partially dried potato slices were placed in a single layer between two doughnut frying racks and lowered into the frying oil. Upon addition of the potato slices, the temperature of the oil dropped to 165.6°C and after 4 min of frying, increased to 180°C. After 4 min of frying, the potato chips (approximately 125 g) were removed, drained on paper towels for 1.5 min, transferred to a plastic container and mixed with 1.0% (w/w) of salt. The 400 g sample of partially dried fresh potato chips yielded approximately 125 g of fried potato chips. After four 400 g samples of potato slices were fried which represented a block, the potato chips were treated as previously described. After completion of 3 blocks of frying, fresh oil (1.36 kg) was added to the fryer to make up the oil absorbed by the chips during frying, and the frying was continued. Six blocks of frying were completed in a single day.

For each oil-replication combination, the following procedure was followed for storage of potato chips. For each storage time of potato chips without light, two sealed 1.89 liter glass jars containing 125 g potato chips each were placed in a cardboard box which was sealed and stored at 23°C for the required length of time.

For each storage time of potato chips with light, two sealed 1.89 liter glass jars of potato chips were placed upside down on a table exposed to fluorescent light at 23°C for the required length of time. The intensity of the fluorescent light on the table as measured by a LI-185 Photometer (Lambda Instruments Corporation, Lincoln, NE) ranged from 1.51 to 1.69 foot candles.

Once samples had been stored for the required length of time, the following procedure was followed. For all jars of potato chips except those to be used for sensory analysis, five g silica gel wrapped in cheesecloth was placed in the top of each jar, and the jar was flushed with nitrogen, sealed and stored in the dark at -18°C until samples were analyzed. The silica gel was added to absorb any moisture that condensed in the jar during frozen storage. A disposable Dessicant Plate (Spectrum, Los Angeles, CA) containing silica gel was substituted for the cheesecloth wrapped silica gel in jars of potato chips to be used for sensory analysis, and then they were stored in the same way as the other jars.

E. FRYING OIL SAMPLING

Frying oil samples (10 g) were taken from the fryer for each oil-replication combination at the beginning and after completion of 3 and 6 blocks of frying. These samples were used for fatty acid analyses.

F. CHEMICAL AND PHYSICAL ANALYSES

Prior to any analyses, the potato chips from duplicate jars for chemical and physical were thoroughly mixed.

For moisture and fat analyses, approximately 40 g of potato chips were frozen in liquid nitrogen and powdered in a Waring blender equipped with a 0.9 liter stainless steel jar. Powdered samples were placed in a polyethylene bag and stored in the dark at -18°C until analyzed.

Moisture Content

The percentage of moisture in the potato chip was determined according to A.O.A.C. (1980). Numbered aluminum pans with lids were placed in the oven at 100°C for 1 hour, transferred to a desiccator, cooled and weighed. Two grams of powdered potato chip were weighed into the pan with a lid. The covered pan containing 2.0 g of potato chip was placed into the vacuum oven at 95°C and 584.2 mmHg for 5 hours. Then the samples were transferred to a desiccator, cooled and weighed.

Fat Content

The percentage of fat in potato chip was determined by a modified Babcock procedure (Hefnawy et al., 1978) as follows. One ml of N-amyl alcohol and 15 ml of HCl (about 30 %) were added into a Babcock test bottle (50 %) containing 2.25 g of powdered potato chip. The contents of the bottle were mixed thoroughly by shaking.

Then the bottle was placed in a water bath at 80°C. At 30 sec intervals, the bottle was removed, shaken and replaced in the water bath. This was continued for a total of 3 min or until solid material was digested. Hot water (80°C) was added to about 1 cm below the bottle neck. The bottle was shaken well and hot water was added to approximately the 40 % mark in the bottle neck. The bottle was centrifuged for 5 min in the Babcock centrifuge and tempered in a water bath at 60°C for 2-3 min. The percent oil from the calibration in the bottle neck was read. To obtain percentage of oil in potato chip, this reading was multiplied by 4.

Peroxide Value

The peroxide value of the potato chips was determined according to Mehlenbacher (1960) as follows. Thirty grams of potato chips were blended for 30 sec in a Waring blender with 250 ml of chloroform. The mixture of potato chips and chloroform was filtered through Whatman No. 1 filter paper in a Buchner funnel with suction. Two-50 ml beakers were placed in the oven at 100°C for 30 min, cooled in a desiccator and weighed. Twenty-five ml of the chloroform extract was placed in each previously weighed beaker and chloroform was evaporated on a water bath under a stream of nitrogen. The beakers were placed in the vacuum oven at 95°C and 584.2 mmHg for 30 min, cooled in a desiccator and weighed. The average weight of fat in 25 ml of the chloroform extract was calculated and used as the sample weight for calculation of peroxide value.

A 25 ml sample of the chloroform extract was also analyzed for peroxide value. Thirty-seven ml of glacial acetic acid and 1 ml of a saturated solution of potassium iodide were added to a 25 ml sample. This mixture was placed in the dark for 1 min with occasional swirling, then 30 ml of distilled water was added and the sample was titrated with approximately 0.001 N sodium thiosulfate, using starch as an indicator. The actual concentration of the thiosulfate solution was determined according to Mehlenbacher (1960). The peroxide value of each potato chip sample was calculated from the following equation.

$$\text{Peroxide value (meq/kg of fat)} = \frac{\text{ml} \times \text{N} \times 1000}{\text{wt of sample}}$$

where ml = volume used for titration and N = normality of sodium thiosulfate.

Color

The color of potato chips was measured by using the Hunter Color Difference Meter (Model D25M-2). The Hunter Color Difference Meter was standardized using the white tile No. C2-21125 with L = 91.03, "a" = -1.3 and "b" = 1.6. The 25 g of chips were crushed and placed in a glass cuvette immediately prior to measurement. The Hunter color values, L, "a" and "b" were recorded (Anon., 1978).

Fatty Acid Composition of Frying Oil

The fatty acid composition of the frying oil samples was

determined by converting the triglycerides to methyl esters of their fatty acids according to A.O.C.S. (1983) Official Method Ce 2-66 as follows. Four ml of 0.5 N methanolic sodium hydroxide and boiling beads were added to a 125 ml Erlenmeyer flask with 24/40 ground glass neck which contained 100 mg of frying oil sample and 1 ml of nonadecanoic acid solution (mg/ml of methanol) as an internal standard. The flask was attached to a water cooled condenser and its contents refluxed for 10 min. Five ml of 14% (w/v) Boron Trifluoride-methanol reagent (Supelco Inc., Bellafonta, PA) were added to the reaction flask through the condenser and the contents boiled for 2 min. The flask was cooled before 5 ml of pentane was added to it through the condenser and the contents of the flask refluxed for an additional min. The flask was removed from the heater and condenser, and enough saturated NaCl solution was added to the flask to float the pentane solution containing the methyl esters in the neck of the flask. Three to four ml of the pentane solution was transferred into a test tube and a small amount of anhydrous sodium sulfate was added to dry the pentane solution. One to 2 μ l of this dry pentane solution was analyzed by the gas chromatographic (GC) method A.O.C.S. (1983) Official Method Ce 1-62 using a 30 m x 0.25 mm fused silica SP-2350 capillary column (Supelco Inc., Bellafonta, PA). The GC run was temperature programmed from 150 to 220°C at 20°C/min on a Shimadzu Model 6 AM gas chromatograph equipped with flame ionization detector and a Shimadzu E-1B data processor.

Selected fatty acid methyl ester samples were also analyzed

on the same capillary column using a Shimadzu Model 9 AM gas chromatograph interfaced with a Shimadzu QP-1000 mass spectrometer (MS) set at 70 eV. The temperature program for the GC-MS run was 150 to 188°C at 2°C/min, followed by a rate of 5°C/min from 188 to 220°C. Identification of individual compounds in each sample was determined by comparison of their retention times from GC analysis with those of known standards. Positive identification of an individual compound in a sample included not only matching retention time with the known standard but also matching mass spectra. A standard solution containing known concentrations of the major fatty acids, similar to concentrations present in the sample, was analyzed by the GC method. The concentrations of the fatty acids in standard are shown in Table 3. Correction factors for the fatty acids in this standard shown in Table 3 were determined relative to methyl palmitate according to A.O.C.S. (1983). The correction factor for all other known and unknown acids was assumed to be 1.00.

The percentage of the fatty acids: 10:0, 14:0, 15:0, 16:0, 16:1, 16:1 isomer, 17:0, 18:0, 18:1, 18:1 isomer, 18:2, 18:2 isomer, 18:3 w6, 20:0, 18:3 isomer, 18:3 w3, 20:1, 22:0, 24:0 and unknown acids in each frying oil sample was determined.

G. VOLATILE ANALYSIS

The volatiles of the potato chips fried in each oil were isolated from the fresh chips and the chips stored in the light and

TABLE 3.
CONCENTRATION AND CALIBRATION FACTOR
OF FATTY ACIDS IN STANDARD.

Acid	Concentration (% by wt)	Calibration Factor
16:0	6.0	1.000
18:0	3.0	0.9357
18:1	35.0	0.9540
18:2	50.0	0.9809
18:3	3.0	0.9290
20.0	3.0	0.9076

dark for 4 weeks by the modified simultaneous distillation extraction method of MacLeod and Cave (1975). For the volatile analysis of potato chips, 125 g of potato chips, 700 ml of HPLC grade water (60-70°C) and 1 ml of palmitic acid methyl ester (mg/ml of methanol) as an internal standard were blended in a Osterizer commercial blender for 5 min. The mixture was poured into 1000 ml round bottom flask with a side tube. The round bottom flask was attached to a Likens and Nickerson extraction apparatus with nitrogen flow in the side tube and lowered into a silicon oil bath. A 125 ml Erlenmeyer flask containing 45 ml of HPLC grade methylene chloride was attached to the collection part of Likens and Nickerson extraction apparatus, and a Corning PC-35 hot plate was elevated to the bottom of the Erlenmeyer flask. A rheostat (Staco, Inc. Dayton, OH) set at 43 held the silicon oil bath temperature at 128°C, and the hot plate was set to 2. Every 15 to 20 min, dry ice was added to carbon dioxide-ethanol condenser of the extraction apparatus to prevent loss of volatiles. After turning on the heat sources, 2.5 hours was required for extraction of volatiles. The extraction apparatus was cooled for 30 min and the volatile compounds in the 45 ml of HPLC grade methylene chloride in the collection flask were collected. One ml of pyrogallol solution (0.1 mg/ml in methanol) was added to the extract to prevent oxidation of volatiles. The modifications to the method of MacLeod and Cave (1975) were the deletion of stirring, the addition of nitrogen bubbling through the emulsion and the addition of the pyrogallol. The extract was concentrated to 1.0 ml by a gas entrainment method

(MacLeod and Cave, 1975) as follows. The extract was placed in an ice bath under reduced pressure with a positive nitrogen flow, and solvent distilled into a trap at liquid nitrogen temperature. A blank was extracted and treated in the same manner as the sample.

Two μl of the concentrated extract were analyzed by a gas chromatographic method using a 30 m x 0.25 mm fused silica SP-2350 capillary column (Supelco Inc., Bellafonta, PA). The GC run was temperature programmed from 50 to 220°C at 2°C/min a Shimadzu Model 6 AM gas chromatograph equipped with flame ionization detector (FID) and a Shimadzu E-1B data processor. Selected concentrated extracts were also analyzed on the same capillary column using a Shimadzu Model 9 AM gas chromatograph interfaced with a Shimadzu QP-1000 mass spectrometer set at 70 ev. The temperature program for the GC-MS run was 25 to 220°C at 2°C/min. Positive identification of the compounds for each peak was made by matching sample peak spectra and retention times with corresponding spectra and retention times of known standards analyzed in the same way as the sample. Tentative identification of a volatile compound included the matching of its mass spectrum with that of a known compound from the computerized library of flavor volatiles with a similarity index of 57 or greater. Selected unknown volatiles are also included if the data of their concentrations were significantly affected by oil, storage or treatment. The mass spectrum of each unknown volatile is included in the Appendix D. The concentration of each volatile (C_x) was determined from GC analyses with FID from the following equation.

$$C_x = \frac{A_x C_s}{A_s}$$

where A_x = peak area of volatile, A_s = peak area of methyl palmitate and C_s = 1 mg methyl palmitate/125 g potato chips. C_x is determined as mg methyl palmitate equivalents/125 g potato chips. The relative response ratio of each volatile to the methyl palmitate was assumed to be 1.00 and the recovery of each volatile and the methyl palmitate was assumed to be equal for all samples.

H. SENSORY ANALYSIS

Each sample for sensory evaluation was coded with a randomly chosen 3-digit number and served to a 48 member inexperienced sensory panel. In all, 18 samples were served to each panelist. These samples consisted of fresh potato chips fried in each oil, and potato chips fried in each oil and stored in light or dark for 4 weeks at 23°C from each replication. Six samples were served to each panelist per day between 1:30 pm and 4:30 pm. Panelists were asked to rinse their mouth with water between samples. Samples were served one at a time under a white light, and panelists received a score card (Appendix A) with each sample. Each sample was evaluated for flavor and general acceptability on an 8 point hedonic scale where 1=like extremely and 8= dislike extremely. A questionnaire (Appendix B) was distributed to each panelist with the first sample asking for the gender and age of panelist, the frequency

of eating chips and the naming of 3 types of chips which they consumed most frequently.

I. STATISTICAL ANALYSIS

The moisture content, fat content, peroxide value and color of potato chips were analyzed according to the analysis of variance shown in Table 4 by the General Linear Model (GLM) program using the Statistical Analysis System (Anon., 1982). Significant differences among means for oil and storage were determined by the Student Newman-Kuel (SNK) technique at $p < 0.05$ level. When a significant interactions of oil with storage or treatment at the $p < 0.05$ level were found, means were separated by the SNK test for each oil ($p < 0.05$).

Sensory characteristics and the level of each volatile compound isolated from the chips were analyzed according to the analysis of variance shown in Table 5. Significant differences among means for oil and treatment (fresh or 0 day storage and storage in light or dark for 4 weeks) were determined by SNK test at the $p < 0.05$ level. When a significant oil x treatment was found ($p < 0.05$) for each oil and treatment, means were separated by the SNK test for each oil ($p < 0.05$).

Fatty acid compositions in frying oils were analyzed according to the analysis of variance shown in Table 6. Significant differences among means for oil and time (fresh, middle and end of frying) were determined by the SNK test at the $p < 0.05$ level. When a

TABLE 4.
ANALYSIS OF VARIANCE FOR MOISTURE CONTENT,
FAT CONTENT, PEROXIDE VALUE AND COLOR
OF POTATO CHIPS.

Source	Degree of Freedom
Oil (O)	2
Storage ^a (S)	2
Treatment ^b (T)	1
O x S	4
O x T	2
S x T	2
O x S x T	4
Replication (R)	1
Error ^c	17
Total	35

^a0, 2, or 4 weeks of storage.

^bLight or dark.

^cError = (R x O) + (R x S) + (R x T) + (R x O x S) +
(R x O x T) + (R x S x T) + (R x O x S x T).

TABLE 5.
ANALYSIS OF VARIANCE FOR SENSORY SCORES AND
VOLATILE COMPOUNDS OF POTATO CHIPS.

Source	Degree of Freedom
Oil (O)	2
Treatment ^a (T)	2
O x T	4
Replication (R)	1
Error ^b	8
Total	17

^aFresh, 4 weeks of storage in light or dark.

^bError = (R x O) + (R x T) + (R x O x T).

TABLE 6.
ANALYSIS OF VARIANCE FOR FATTY ACID COMPOSITION
OF FRYING OILS

Source	Degree of Freedom
Oil (O)	2
Time (T) ^a	2
O x T	4
Error	9
Total	17

^aAt beginning and after 3 and 6 blocks of potato chips were fried.

significant oil x time was found for each oil and time, means were separated by SNK test for each oil ($p < 0.05$).

In addition, correlation coefficients of the mean flavor score of potato chips for each oil, treatment and replication combination ($n=18$) were determined with the peroxide value and levels of isolated volatiles of the potato chip samples.

CHAPTER IV

RESULTS AND DISCUSSION

A. MOISTURE AND OIL CONTENTS OF POTATO CHIPS

The analysis of variance for the effects of oil, storage and treatment on the moisture content of potato chips is shown in Table 7. There was a significant difference ($p < 0.001$) in moisture content among the oils. No significant ($p > 0.05$) differences in the moisture content were found among the storage times or between the treatments.

Mean values of moisture content of potato chips for oil, storage and treatment are shown in Table 8. Potato chips fried in soybean oil contained significantly ($p < 0.05$) higher moisture content than potato chips fried in palm olein or cottonseed oil. The frying process is considered a rapid combination of drying and cooking. According to Gamble et al. (1987), moisture content of the raw potato tubers is approximately 80%, whereas moisture content of potato chips is less than 2%. They demonstrated that the outer surface of the potato slice contains both bound water and cellular moisture released during slicing. When the slice is placed in hot oil, this loosely held moisture is rapidly lost in a stream of steam bubbles, and the moisture content falls rapidly. This outer surface moisture is lost during the first minute of frying with further loss

TABLE 7.
SUM OF SQUARES FROM ANALYSIS OF VARIANCE
FOR MOISTURE AND OIL CONTENTS AND PEROXIDE VALUE
OF POTATO CHIPS.

Source	df	Sum of Squares		
		Moisture (%)	Oil (%)	Peroxide value (meq/kg oil)
Oil (O)	2	1.51 ^{***}	8.00	39.24 ^{**}
Storage (S)	2	0.07	9.64	272.98 ^{***}
Treatment (T)	1	0.01	1.52	115.28 ^{***}
O x S	4	0.09	13.02	36.28 [*]
O x T	2	0.01	3.44	19.81 [*]
S x T	2	0.02	3.56	98.94 ^{***}
O x S x T	4	0.03	3.12	11.24
Replication	1	0.24	0.09	0.19
Error	17	1.13	40.25	38.55
Total	35	3.11	82.65	632.43

* Significant at the $p < 0.05$ level.

** Significant at the $p < 0.01$ level.

*** Significant at the $p < 0.001$ level.

TABLE 8.
MEAN VALUES OF MOISTURE AND OIL CONTENTS AND
PEROXIDE VALUE OF POTATO CHIPS FOR EACH OIL,
STORAGE TIME AND TREATMENT.

<u>Source</u> Variable	Moisture (%)	Oil (%)	Peroxide value (meq/kg oil)
<u>Oil</u>			
Soybean	1.89 ^a	40.47	6.9 ^a
Palm olein	1.41 ^b	40.62	8.4 ^b
Cottonseed	1.52 ^b	41.53	9.5 ^b
<u>Storage(weeks)</u>			
0	1.67	40.37	5.1 ^a
2	1.61	40.67	8.0 ^b
4	1.56	41.58	11.8 ^c
<u>Treatment</u>			
Light	1.62	40.67	10.8 ^a
Dark	1.59	41.08	6.5 ^b

a,b,c For any one source, means in a column followed by different superscripts are significantly different at the $p < 0.05$ level.

possible as the moisture moves from the lower cell layer of the chip.

The randomized order of frying for each oil-replication had replications 1 and 2 for soybean oil in sequence such that a single lot of raw potatoes was used for both replications. This lot of potatoes had a lower specific gravity (1.072) than those fried in replication 2-cottonseed oil and replication 1-palm olein (1.085) or replication 1-cottonseed oil and replication 2-palm olein (1.095). This lower specific gravity indicates that raw potatoes fried in soybean oil had a higher moisture content than raw potatoes fried in cottonseed oil or palm olein, resulting in the higher moisture content in the potato chips fried in soybean oil. The frying time and temperature were not responsible because they were the same for each oil-replication combination.

Oil content of potato chips was not affected by oil, storage or treatment (Table 7). This is in disagreement with Smith (1987) who indicated that oil content of potato chips may be influenced by the type of fat or oil used, although this was not considered to be a major factor. Several investigators (Lulai and Orr, 1979; Porter et al., 1964; Smith, 1987) reported that the specific gravity of potatoes affects the oil content of potato chips. In the present study, the specific gravity of the raw potatoes ranged from 1.072 to 1.095, and the oil content of potato chips agreed with the results obtained by Lulai and Orr (1979). Gamble et al. (1987) reported that the amount of oil entering the potato slice during frying is directly proportional to the amount of moisture lost in the potato slice

rather than frying temperature. Husain (1986) observed that potatoes had higher moisture and lower fat contents than fish patties before frying, but found the reverse after frying. The study of Husain (1986) indicated that the greater loss of moisture from the potatoes during frying resulted in a greater absorption of oil in the voids created by the moisture loss.

Mean values of oil content of potato chips fried in soybean oil, palm olein and cottonseed oil were 40.47, 40.62 and 41.53%, respectively (Table 8). These results agree fairly well with Robertson et al. (1978) who reported that the oil contents of potato chips fried in sunflower, cottonseed and palm oil were 39.6, 39.4 and 37.4%, respectively. The oil content of potato chips obtained by Robertson et al. (1978) was a little lower than the result of the present study. However, the average moisture content of chips in their study was 3.1 %, which is higher than the average moisture content of chip in this study of 1.61 %. Robertson et al. (1978) fried their chips at 185°C for 2 min compared with 194.4°C for 4 min, respectively, in the present study. This lower frying temperature and less time is the reason for the higher moisture in their chips.

B. PEROXIDE VALUE OF OIL FROM POTATO CHIPS

The analysis of variance for the effects of oil, storage and treatment on peroxide value of the potato chips is shown in Table 7. There were significant differences in peroxide value among the oils ($p < 0.01$), the storage times ($p < 0.001$), and between the light and dark

treatments ($p < 0.001$). Also, significant interactions in peroxide value were found between oil and storage ($p < 0.05$), oil and treatment ($p < 0.05$), and storage and treatment ($p < 0.001$) (Table 7).

Mean peroxide values of potato chips for oil, storage and treatment are shown in Table 8. Potato chips fried in soybean oil had a significantly ($p < 0.05$) lower peroxide value than potato chips fried in palm olein or cottonseed oil. The peroxide value of potato chips fried in soybean oil was 6.94 meq/kg oil compared with 8.4 and 9.5 for potato chips fried in palm olein and cottonseed oil, respectively. There was not a significant ($p > 0.05$) difference between the peroxide value of potato chips fried in palm olein and cottonseed oil. In addition, when averaged across oil and treatment, the peroxide value of potato chips increased 57% during 2 weeks storage and 131% during 4 weeks of storage ($p < 0.05$) as shown in Table 8. Treatment also caused a significant difference in the peroxide value of potato chips. The average peroxide value of all potato chips in the light (10.8 meq/kg oil) was significantly ($p < 0.05$) higher than the average peroxide value of all chips stored in the dark (6.5).

To really interpret statistical information concerning the peroxide value of potato chips for oil, storage and treatment, the significant interactions of oil x storage, oil x treatment and storage x treatment must be considered. The peroxide value sum of squares due to storage were partitioned by orthogonal polynomials into linear and quadratic effects for each oil-treatment combination and tested for significance by the original error term for the overall

analysis of variance (Table 7). This partitioning is shown in Table 9. Figure 1 clearly shows the linear effect of storage on the peroxide value of potato chips fried in each oil and stored in the light, and Figure 2 shows the effect of storage on the peroxide value of potato chips fried in each oil and stored in the dark.

For the potato chips stored in the light, there was a linear relationship between peroxide value of the chips fried in each oil over storage (Figure 1). From 0 to 4 weeks, the peroxide value of chips fried in cottonseed oil increased from 5.3 to 20.5 meq/kg oil, the peroxide value of chips fried in palm olein increased from 5.6 to 15.6, and the peroxide value of chips fried in soybean oil increased from 4.3 to 11.3. These data indicates that potato chips fried in cottonseed oil underwent more extensive oxidation during storage in light than potato chips fried in palm olein or soybean oil.

For potato chips fried in each oil and stored in the dark, the peroxide value of chips fried in palm olein or soybean oil did not change significantly across storage, but the peroxide value of chips fried in cottonseed oil increased linearly from 5.3 to 8.9 meq/kg.oil (Table 9 and Figure 2). This 68% increase in peroxide value of chips fried in cottonseed oil and stored in the dark for 4 weeks, however, was much less than 287% increase found when the chips were stored in the light for 4 weeks (Figure 1). The greater increase in peroxide value of chips stored in the light indicates that the fluorescent light under which the chips were stored increased the oxidative deterioration of the chip. This finding that storage under fluorescent light increases oxidative deterioration of the potato

TABLE 9.
PARTITIONING OF PEROXIDE VALUE SUM OF SQUARES
FOR STORAGE FOR EACH OIL AND TREATMENT.

Source	df	Sum of squares ^a
<u>Soybean oil (Light)</u>		
Storage	1	49.70 ^{**}
Storage x Storage	1	0.33
<u>Soybean oil (Dark)</u>		
Storage	1	3.52
Storage x Storage	1	6.09
<u>Palm olein (Light)</u>		
Storage	1	99.50 ^{**}
Storage x Storage	1	4.03
<u>Palm olein (Dark)</u>		
Storage	1	7.84
Storage x Storage	1	0.12
<u>Cottonseed oil (Light)</u>		
Storage	1	229.52 ^{**}
Storage x Storage	1	4.56
<u>Cottonseed oil (Dark)</u>		
Storage	1	12.43 [*]
Storage x Storage	1	1.80

^aError sum of squares = 38.55 with 17 df.

^{*}Significant at the $p < 0.05$ level.

^{**}Significant at the $p < 0.01$ level.

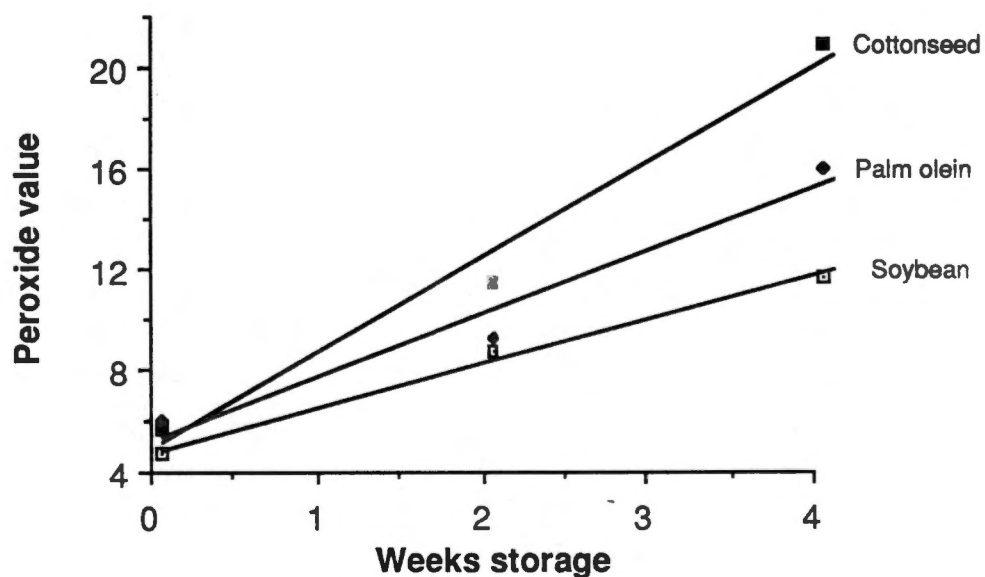


Figure 1. Peroxide value (meq/kg) of oil from potato chips fried in different oils and stored in light for 0 to 4 weeks at room temperature. Equation for cottonseed is $Y=4.7 + 3.9X$, for palm olein, $Y=5.0 + 2.5X$ and for soybean, $Y=4.4 + 1.8X$ where Y =peroxide value and X =weeks storage.

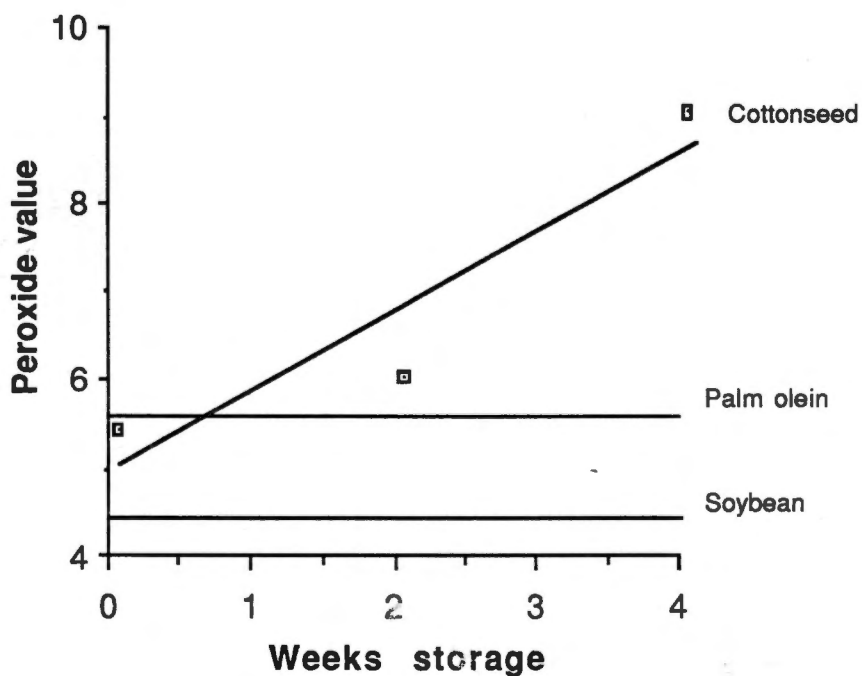


Figure 2. Peroxide value (meq/kg) of oil from potato chips in different oils and stored in dark for 0 to 4 weeks at room temperature. Equation for cottonseed is $Y=4.9 + 0.9X$ where Y =peroxide value and X =weeks storage.

chips is supported by the significant increases ($p < 0.05$) across storage of the peroxide value of chips fried in soybean oil or palm olein and stored in the light (Figure 1) compared with no increase in the peroxide value of the same chips stored in the dark.

These results are in partial disagreement with results obtained by Robertson et al. (1978) who fried potato slices (specific gravity of 1.086 to 1.089) in sunflower, cottonseed and palm oils and stored the potato chips in wax-coated glassine bags (240 g/bag) for 10 weeks in the dark. These investigators reported that the peroxide value of chips in their study was not affected by the oils in which they were fried. However, the oils in their study contained 0.076% Tenox 6 as an antioxidant, and no antioxidants were used in the frying oils in the present study.

The results of the present study agree with those obtained by Fuller et al. (1971) who reported that fluorescent light is an effective accelerator of oxidation at ambient temperature. At an intensity of 13 foot candles, this researcher showed that the acceleration was at least three fold over storage in air in the dark with additional acceleration at higher light intensities (100 foot candles) being relatively small. Other investigators also have found that light increases the rate of oxidation in stored potato chips. Quast and Karel (1972) reported that both artificial room light and sunlight significantly increased the oxygen uptake rate by potato chips during storage.

Potato chips fried in cottonseed oil had higher peroxide values when stored in the light or dark than chips fried in soybean oil or

palm olein. In comparison of oleic and linoleic acid levels, cottonseed oil is more unsaturated than soybean oil or palm olein in the present study (Table 10). According to Paquette et al. (1985), more unsaturated fatty acids are generally more labile to oxidative deterioration. Nawar (1985) indicated that the relative rates of oxidation in linolenate: linoleate: oleate are 20: 10: 1. Also, cottonseed oil had higher initial peroxide value (1.40) than soybean oil (0.75) or palm olein (0.2).

Potato chips fried in palm olein showed higher peroxide values in light than the chips fried in soybean oil. No reason is known for this observation at the present time. Palm olein actually had a lower initial peroxide value (0.2) than soybean oil (0.75) and it is more saturated than soybean oil (Table 10). Therefore, palm olein should be more stable to oxidation than soybean oil.

C. COLOR

The analysis of variance for the effects of oil, storage and treatment on Hunter color values (L, "a" and "b") of potato chips is shown in Table 11. There were significant differences ($p < 0.05$) in Hunter color L and "a" values among the oils, but not in the "b" value. Mean values for Hunter color values (L, "a" and "b") of potato chips are given in Table 12. Potato chips fried in cottonseed oil (59.3) had a significantly higher ($p < 0.05$) Hunter color L value than potato chips fried in soybean oil (57.5) or palm olein (57.1). This indicates potato chips fried in cottonseed oil were lighter in color than potato

TABLE 10.
MEAN PERCENTAGE OF FATTY ACIDS AVERAGED ACROSS
FRYING TIME FOR EACH FRYING OIL.

Fatty acid	Oil		
	Soybean	Palm olein	Cottonseed
	-----%-----		
10:0	0.02	0.03	0.03
12:0	0.00 ^c	0.23 ^a	0.12 ^b
14:0	0.08 ^c	0.93 ^a	0.83 ^b
15:0	0.02 ^c	0.04 ^a	0.03 ^b
16:0	10.59 ^c	38.29 ^a	24.37 ^b
16:1I	0.02	0.03	0.02
16:1	0.08 ^c	0.15 ^b	0.52 ^a
17:0	0.09 ^b	0.09 ^b	0.11 ^a
18:0	7.41 ^a	4.90 ^b	3.16 ^c
18:1	44.61 ^a	42.40 ^a	22.78 ^b
18:1I	10.42 ^a	0.26 ^b	4.27 ^b
18:2	21.12 ^b	10.55 ^c	40.61 ^a
18:2I	3.08 ^a	0.29 ^b	1.32 ^b
18:3W6	0.05 ^a	0.00 ^b	0.00 ^b
18:3I	0.08	0.00	0.00
20:0	0.65 ^a	0.43 ^b	0.36 ^c
18:3w3	0.61 ^a	0.25 ^b	0.25 ^b
20:1	0.29 ^a	0.19 ^b	0.28 ^a
20:1I	0.00 ^b	0.00 ^b	0.19 ^a
22:0	0.35 ^a	0.09 ^c	0.13 ^b
24:0	0.13 ^a	0.07 ^c	0.10 ^b
unknowns ^d	0.29	0.17	0.52

a,b,c means in a row followed by different superscripts are significantly different at the $p < 0.05$ level.

^dConsists of 7 unidentified fatty acids.

TABLE 11.
SUM OF SQUARES FOR ANALYSIS OF VARIANCE
FOR HUNTER COLOR VALUES (L, "a" and "b") OF POTATO CHIPS.

Source	df	Sum of Squares		
		L	"a"	"b"
Oil (O)	2	33.85*	9.37*	1.49
Storage (S)	2	4.87	1.18	0.04
Treatment (T)	1	1.21	0.18	0.00
O x S	4	8.56	0.53	2.24
O x T	2	4.73	0.38	0.78
S x T	2	1.73	0.10	0.41
O x S x T	4	4.34	0.89	0.59
Replication	1	0.19	0.37	0.77
Error	17	59.71	14.01	4.16
Total	35	119.19	27.01	10.48

*Significant at the $p < 0.05$ level.

TABLE 12.
MEAN VALUES OF HUNTER COLOR VALUES OF POTATO CHIPS
FOR OIL, STORAGE AND TREATMENT.

Source	Hunter Color Values		
Variable	L	"a"	"b"
<u>Oil</u>			
Soybean	57.5 ^b	4.78 ^{ab}	24.69
Palm olein	57.1 ^b	5.49 ^a	25.05
Cottonseed	59.3 ^a	4.24 ^b	25.18
<u>Storage(weeks)</u>			
0	58.42	4.60	24.94
2	58.00	4.88	24.95
4	57.52	5.04	25.02
<u>Treatment</u>			
Light	58.16	4.77	24.97
Dark	57.79	4.91	24.97

a,b For any one source, means in a column followed by different superscripts are significantly different at the $p < 0.05$ level.

chips fried in soybean oil or palm olein. As shown in Table 12, potato chips fried in cottonseed oil had a significantly lower ($p < 0.05$) Hunter color "a" value (4.24) than potato chips fried in palm olein (5.49). This observation indicates that potato chips fried in cottonseed oil had a lower amount of red coloration compared to the chips fried in palm olein. There were no significant differences in the Hunter color "a" value of potato chips between soybean oil and palm olein, or soybean oil and cottonseed oil. In the study of Maga (1973) potato chips, described as regular colored chips, had an average Hunter color L value of 40, and dark colored chips, an average Hunter color L value of 25. In comparison with this reference, the potato chips of the present study all would be considered light colored. The surface color of deep fried foods is generally an even, golden brown color resulting from the browning or Maillard reaction which occurs when the sugars and proteins present in the food react in the presence of heat (Stevenson et al., 1984b). The degree of browning depends largely on the time and temperature of frying in combination with the chemical composition of the food being fried rather than on the type of fat in the fryer. However, palm olein has been found to darken in color more rapidly than other oils during heating (Tan et al., 1985), and that may be the reason for the darker, redder color of potato chips fried in palm olein compared with the chips fried in cottonseed oil.

No differences ($p > 0.05$) among the storage time or between the treatments were observed for Hunter color L, "a" and "b" values of potato chips (Table 11). These data disagree with Robertson et al.

(1978) who reported that during 10 weeks of storage potato chips initially lightened and then darkened.

D. SENSORY EVALUATION

The analysis of variance for the effects of oil and treatment on sensory flavor and general acceptability scores of potato chips is shown in Table 13. Flavor and general acceptability scores were significantly ($p < 0.01$) affected by oil and treatment, but not by the interaction between oil and treatment (Table 13). The lack of a significant interaction indicates that the flavor of the chips fried in each oil changed in a uniform manner during storage.

Mean flavor and acceptability scores of potato chips for different oils are given in Table 14. Potato chips fried in cottonseed oil had a more desirable flavor and higher acceptability than chips fried in soybean oil or palm olein ($p < 0.05$). The mean flavor score of the potato chips fried in cottonseed oil was 3.44; in palm olein, 3.98; and in soybean oil, 4.34. These results show that acceptability was based on flavor. The mean acceptability score of potato chips fried in cottonseed oil was 3.43; in palm olein, 3.94; and in soybean oil, 4.32. There were no significant differences in the flavor or acceptability of chips fried in palm olein versus those fried in soybean oil.

Mean flavor and acceptability scores of potato chips stored 0 week or stored in the light or dark for 4 weeks at ambient temperature are given in Table 15. Potato chips stored for 4 weeks

TABLE 13.
SUM OF SQUARES FOR ANALYSIS OF VARIANCE
FOR SENSORY SCORES OF POTATO CHIPS.

Source	df	Sum of Squares	
		Flavor	Acceptability
Oil (O)	2	2.41**	2.41**
Treatment (T) ^a	2	3.56**	2.54**
O x T	4	0.35	0.32
Replication	1	0.00	0.01
Error	8	0.97	0.93
Total	17	7.09	6.22

^aIncludes storage for 0 week and storage in dark and light for 4 weeks.

**p<0.01 level.

TABLE 14.
MEAN SENSORY SCORES OF POTATO CHIPS
FRIED IN DIFFERENT OILS.

Sensory Scores ^a	Oil		
	Soybean	Palm olein	Cottonseed
Flavor	4.34 ^b	3.98 ^b	3.44 ^c
Acceptability	4.32 ^b	3.94 ^b	3.43 ^c

^a8-point scale where 1 = like extremely and 8 = dislike extremely.

^{b,c}Means in a row followed by different superscripts are significantly different at the $p < 0.05$ level.

TABLE 15.
MEAN SENSORY SCORES OF POTATO CHIPS
FROM DIFFERENT STORAGE TREATMENTS.

Sensory Scores ^a	Treatment ^b		
	1	2	3
Flavor	3.57 ^d	4.53 ^c	3.67 ^d
Acceptability	3.61 ^d	4.43 ^c	3.65 ^d

^a8-point scale where 1 = like extremely and 8 = dislike extremely.

^b1 = 0 week storage.

2 = 4 weeks of storage in light.

3 = 4 weeks of storage in dark.

^{c,d}Means in a row followed by different superscripts are significantly different at the $p < 0.05$ level.

under fluorescent lights had less ($p < 0.05$) desirable flavor and acceptability than the fresh chips (0 week) or the chips stored in the dark for 4 weeks. Chips stored in dark for 4 weeks, however, had as a desirable flavor and were as acceptable as the fresh chips.

“The results of sensory evaluation of the stored chips compared with their peroxide values show that the peroxide value is not a good indicator of flavor desirability when comparing chips fried in different oils. Although chips fried in cottonseed oil had the highest peroxide value of all the chips fried in the three oils (Table 8, p. 48), those chips had the most desirable flavor of all chips in the present study (Table 14).”

“The less desirable flavor of chips fried in soybean oil may be related to the oxidation of soybean oil. According to Smouse and Chang (1967), soybean oil and many products containing soybean oil tend to develop an undesirable flavor and odor known as reversion flavor when the peroxide number is still as low as a few meq/kg. This reversion flavor is characterized as beany, grassy, fishy, painty or hay-like, and linolenic acid is considered as the precursor of the reversion compounds. Even partially hydrogenated soybean oil still has tendency to form off-flavors from isolinoleic acid formed during the hydrogenation. According to Nawar (1985), this flavor, known as hardening flavor, develops in hydrogenated soybean oil during storage. The autoxidation of isolinoleic acid results in the formation of 6-cis- and 6-trans-nonenal, 2-trans-6-trans-octadecadienal, ketones, alcohols, and lactones. Weiss (1983) indicated that nonreverting soybean oil has not been made

commercially available. The partially hydrogenated soybean oil used to fry the chips contained 3.08% of isolinoleic and 0.61% of linolenic acids, the highest concentrations of these acids of the three frying oils (Table 10, p. 58). This most likely is the cause of the less desirable flavor of chips fried in soybean oil compared with the flavor of chips fried in cottonseed oil. The flavor of cottonseed oil has been described as nutlike in fried foods, and the flavor of chips fried in cottonseed oil is particularly well-liked by the consumers in Southern United States (Weiss, 1983). For frying of potato chips, cottonseed oil may be blended with soybean oil to reduce cost of production because the flavor of cottonseed oil is fairly strong and masks the reversion flavor of soybean oil in blends (Weiss, 1983).

The development of a less desirable flavor in potato chips stored in light compared with storage in the dark agrees with other researchers. In the study of Dornseifer and Powers (1965), potato chips fried in cottonseed oil and stored in sunlight for 5 days at room temperature developed an off flavor which was described by a sensory panel as rancid or oxidized. According to Fuller et al., (1971), their sensory panel differentiated between potato chips stored in fluorescent light (13 and 100 foot candles) and those stored under nitrogen in the dark after only 3 days storage. The lack of a significant decrease in flavor quality of chips stored in the dark for 4 weeks (Table 15, p. 65), also agrees with Robertson et al., (1978). These latter investigators reported that their sensory data indicated only a gradual degradation of the flavor of potato chips

with increasing storage time from 0 to 10 weeks in the dark at 31°C.

The 48-member sensory panel in the present study consisted of 31 females and 17 males. The majority of the panelists (65%) were in the age range between 18 and 34 years old; 2% were less than 18 years old; 17% were in the age range between 35 and 44 years old; 10% were from 45 to 54 years old and 6% of panelists were more than 55 years old. As shown in Table 16, 23% of the panelists ate chips several times a week; half of the panelists ate chips several times a month and 25% ate chips several times a year. One of the panelists (2%) did not indicate how often potato chips were consumed.

E. FATTY ACID COMPOSITIONS OF FRYING OIL

The analysis of variance for percentage fatty acids of frying oils as a function of frying time and oil is shown in Appendix C-Table 1. Twenty one identified fatty acids and seven unknown fatty acids were found in the frying oils. The percentages of the following fatty acids: 12:0, 14:0, 15:0, 16:0, 16:1, 17:0, 18:0, 18:1, 18:1 Δ , 18:3 ω 6, 18:2, 18:2 Δ , 20:0, 18:3 ω 3, 20:1, 20:1 Δ , 22:0 and 24:0 were significantly different ($p < 0.05$) among the frying oils. The concentration of only one fatty acid, 10:0, was affected by frying time, and the oil x time interaction was not significant ($p > 0.05$) for the percentages of any of these acids (Appendix C-Table 1).

Percentages of fatty acids in each frying oil averaged across

TABLE 16.
FREQUENCY OF EATING CHIPS BY THE SENSORY PANEL^a.

Eating Frequency	% of Panel
several times a week	23
several times a month	50
several times a year	25
unknown	2

^a_n = 48(31 females and 17 males).

frying time are shown in Table 10 (p. 58). Of the three oils, soybean oil contained the highest concentrations ($p < 0.05$) of 18:0 (stearic acid), 18:1I (oleic acid isomer), 18:2I (linoleic acid isomer), 18:3w6 (linolenic acid isomer), 18:3w3 (linolenic acid), 20:0 (arachidic acid), 22:0 (behenic acid) and 24:0 (tetraeicosanic acid) and lowest percentages of 12:0 (lauric acid), 14:0 (myristic acid), 15:0 (pentadecanoic acid), 16:0 (palmitic acid) and 16:1 (palmitoleic acid). Compared with soybean and cottonseed oils, palm olein contained the highest levels ($p < 0.05$) of 12:0, 14:0, 15:0, and 16:0 and the lowest percentages of 18:1I, 18:2 (linoleic acid), 20:1 (gadoleic acid), 22:0 and 24:0. Cottonseed oil, among the three oils, contained the highest percentages ($p < 0.05$) of 16:1, 17:0 (margaric acid), 18:2, and 20:1I (gadoleic acid isomer) and lowest levels of 18:1 (oleic acid), 18:0 and 20:0. In addition, no significant differences existed between soybean and cottonseed oils for the level of 20:1, between soybean oil and palm olein for percentages of 17:0, 18:1 and 20:1I or between palm olein and cottonseed oil for the levels of 18:1I, 18:2I, 18:3w6, and 18:3w3. No significant differences were found among the three oils for the percentages of 10:0 (decanoic acid), 16:1I (palmitoleic acid isomer), 18:3I (linolenic acid isomer), or the total percentages of the unknowns. As shown in Table 10 (p. 58), 18:1 was the most abundant fatty acid in soybean oil (44.61%) and in palm olein (42.40%), but the most abundant fatty acid in cottonseed oil was 18:2 (40.61%).

Percentages of fatty acids in frying oils averaged across oils for each frying time are shown in Table 17. No significant

TABLE 17.
MEAN PERCENTAGE OF FATTY ACIDS AVERAGED ACROSS
FRYING OILS FOR EACH FRYING TIME.

Fatty Acid	Frying time ^a		
	Start	Middle	End
	-----%-----		
10:0	0.016 ^c	0.030 ^{bc}	0.034 ^b
12:0	0.12	0.12	0.11
14:0	0.62	0.62	0.60
15:0	0.03	0.03	0.02
16:0	24.48	24.50	24.27
16:1I	0.02	0.02	0.03
16:1	0.25	0.25	0.25
17:0	0.10	0.10	0.10
18:0	5.10	5.17	5.30
18:1	37.06	35.52	37.21
18:1I	4.37	6.52	4.66
18:2	24.52	23.67	24.09
18:2I	1.54	1.65	1.49
18:3w6	0.01	0.02	0.02
18:3I	0.00	0.04	0.04
20:0	0.49	0.47	0.49
18:3w3	0.41	0.35	0.35
20:1	0.25	0.25	0.25
20:1I	0.06	0.06	0.07
22:0	0.20	0.19	0.18
24:0	0.10	0.10	0.09
unknowns ^d	0.33	0.32	0.34

^aFrying oil was sampled at start of frying potato chips, after 3 blocks had been fried (middle) and after 6 blocks had been fried (end).

^{b,c}Means in a row followed by different superscripts are significantly different at the $p < 0.05$ level.

^dSee Table 10.

differences ($p>0.05$) in the percentages of fatty acids in frying oils among frying times were found except for capric acid (10:0). There was, however, an increasing trend ($p<0.12$) in the percentages of 18:0 with increased frying time. McGill (1980) indicated that during standby and frying periods, when the oil is heated to about 191°C in the presence of air, the double bonds in the fatty acids of the oil molecules are broken and new substances, such as shorter chain fatty acids, are formed in the frying kettle. This most probably is the reason for the increase in percentage of 10:0 across frying time in the present study. In the study of Kilgore and Bailey (1970), the percentage of linoleic acid in cottonseed oil decreased from 55.5 to 49.0% in 7.5 hrs during which 4.54 kg of potatoes were fried. As a result of this decrease in unsaturated fatty acid content of the oil, the saturated fatty acid levels usually increase. This is probably the reason for the trend towards increased levels of 18:0.

The small change in the fatty acid composition of the frying oils with increasing frying time shows that there was not much deterioration in the frying oils during frying of the potato chips in the present study. This lack of deterioration might be due to the presence of tocopherol content in the oils. Sherwin (1976) indicated that levels of tocopherols in vegetable oils appear to be optimum for providing oxidative stability, but if they are depleted or stripped from the vegetable oils, then the oxidative stability of the oils is reduced to an extremely low level.

F. VOLATILE COMPOUNDS ISOLATED FROM POTATO CHIPS

The analysis of variance for concentrations (mg equivalents methyl palmitate/125 g potato chips) of volatile compounds isolated from potato chips is shown in Appendix C-Table 2. Nineteen identified volatile compounds and thirteen unknown volatile compounds are found in this study. The mass spectra for these unidentified compounds are presented in Appendix D. An unknown beside which a type of compound is written in parentheses, such as unknown 4 (pyrazine), in Table 18 was identified as a specific compound in that class of compounds via a computer search of a library of mass spectra. When the identified pure compound was analyzed by GC-MS under identical conditions as the sample, its retention time was not the same as that of the sample compound. However, the mass spectrum of the reference pure compound was similar to that of the sample compound and it is very likely the sample unknown compound is in the same class of compounds as the reference standard. [The concentrations of following volatile compounds: nonanal, t-2-octenal, decanal, t,t-2,4-heptadienal, t,t-3,5-octadien-2-one, c,t-2,4-decadienal, t,t-2,4-decadienal, and unknowns 4, 6, 7, 8, 10 and 12 were significantly ($p < 0.05$) affected by oil.] Mean concentrations (mg equivalents methyl palmitate/125 g potato chips) of volatile compounds isolated from potato chips fried in different oils are shown in Table 18. Chips fried in soybean oil had higher levels of t-2-octenal, t,t-2,4-heptadienal, and unknown 7 (pyrazine) than chips fried in palm olein or cottonseed

TABLE 18.

MEAN^a CONCENTRATIONS (mg EQUIVALENTS METHYL PALMITATE/125g POTATO CHIPS) OF VOLATILE COMPOUNDS ISOLATED FROM POTATO CHIPS FRIED IN DIFFERENT OILS.

Compound	Retention time (min)	Oil		
		Soybean	Palm olein	Cottonseed
2-methyl pyrazine	15.0	5.02	7.19	5.33
2,5-dimethyl pyrazine	18.6	10.88	14.70	10.82
2,6-dimethyl pyrazine	20.1	1.20	1.51	1.32
unknown1	21.2	0.12	0.10	0.06
3-ethyl-2-methyl pyrazine	22.5	3.43	5.63	4.26
2,3,5-trimethyl pyrazine	23.1	4.26	5.16	4.72
Nonanal	24.5	2.92 ^x	2.53 ^x	1.36 ^y
2-ethyl-5,6-dimethyl pyrazine	24.9	4.73	5.43	3.76
unknown2	25.2	0.23	0.27	0.20
unknown3	27.3	0.68	0.79	0.68
t-2-octenal	28.1	2.53 ^x	1.57 ^y	1.80 ^y
Cyclohexen-2-one	29.2	0.52	0.43	0.43
Decanal	29.5	0.00 ^y	0.00 ^y	0.65 ^x
unknown4 (pyrazine)	29.6	0.66 ^x	0.61 ^x	0.00 ^y
1-octanol ^t	30.7	0.90	0.91	1.21
Benzaldehyde ^t	31.0	0.72	0.70	0.86
t,t-2,4-heptadienal	31.9	0.67 ^x	0.41 ^y	0.35 ^y
unknown5 (aldehyde)	33.9	1.22	0.62	0.87
t,t-3,5-octadien-2-one ^t	34.3	0.00 ^y	0.00 ^y	0.27 ^x
unknown6 (pyrazine)	34.9	0.31 ^x	0.30 ^x	0.00 ^y
unknown7 (pyrazine)	36.4	0.11 ^x	0.03 ^y	0.00 ^y
unknown8 (aldehyde)	39.6	3.09 ^y	4.55 ^x	0.88 ^z
Phenylacetaldehyde	40.6	5.67	6.06	8.42

TABLE 18.(continued)

Compound	Retention time(min)	Oil		
		Soybean	Palm olein	Cottonseed
2-ethyl-6-vinyl pyrazine ^t	41.6	0.28	0.30	0.25
t,t-2,4-nonadienal	43.3	0.30	0.17	0.28
unknown9	43.7	0.09	0.04	0.08
unknown10 (aldehyde)	45.0	2.58 ^x	1.90 ^x	0.76 ^y
c,t-2,4-decadienal ^t	47.4	2.58 ^x	1.32 ^y	3.33 ^x
unknown11	47.8	0.40	0.41	0.44
t,t-2,4-decadienal	49.0	14.07 ^x	6.32 ^y	16.02 ^x
unknown12	50.4	1.53 ^x	0.54 ^y	1.11 ^x
unknown13	53.0	0.26	0.16	0.23

^an=6

^tTentative identification

^{x,y,z}Means in a row followed by different superscripts are significantly different at the $p < 0.05$ level.

oil. Chips fried in soybean oil also had higher levels of nonanal, unknown 4 (pyrazine), unknown 6 (pyrazine), unknown 7 (pyrazine), unknown 8 (aldehyde), and unknown 10 (aldehyde) and lower levels of decanal and *t,t*-3,5-octadien-2-one than chips fried in cottonseed oil. Chips fried in palm olein contained higher levels of nonanal, unknown 4 (pyrazine), unknown 6 (pyrazine), unknown 8 (aldehyde), unknown 10 (aldehyde) and lower levels of decanal, *t,t*-3,5-octadiene-2-one, *c,t*-2,4-decadienal, *t,t*-2,4-decadienal and unknown 12 than chips fried in cottonseed oil. Compared with chips fried in soybean oil, chips fried in palm olein had higher levels of unknown 8 (aldehyde) and lower levels of *c,t*-2,4-decadienal, *t,t*-2,4-decadienal and unknown 12. Potato chips in this study contained relatively high concentrations of 2-methyl pyrazine, 2,5-dimethyl pyrazine, 3-ethyl-2-methyl pyrazine, 2,3,5-trimethyl pyrazine, 2-ethyl-5,6-dimethyl pyrazine, phenylacetaldehyde and *t,t*-2,4-decadienal.

☞ The results of the present study regarding the most abundant volatiles agree with the results obtained by Deck et al. (1973), and Buttery and Ling (1972). Deck et al. (1973) reported that alkyl-substituted pyrazines, 2,4-decadienal and phenylacetaldehyde are important volatiles in the flavor of potato chips. Buttery and Ling (1972) indicated that the aroma of potato chips is a complex mixture of volatile compounds. However, they showed that methional, 3-methylbutanal, phenylacetaldehyde and *t,t*-2,4-decadienal were some of the more important volatile compounds in the potato flavor. In the present investigation, the methional and

3-methyl butanal eluted with the solvent, methylene chloride, and could not be analyzed.

The concentrations of following volatile compounds; 3-ethyl-2-methyl pyrazine, 2-ethyl-5,6-dimethyl pyrazine, t-2-octenal, cyclohexen-2-one, 1-octanol, t,t-2,4-heptadienal, phenylacetaldehyde, c,t-2,4-decadial, t,t-2,4-decadial, and unknown1, 2, 3, 4, 5, 8, 9, 10 and 11 were significantly ($p < 0.05$) affected by storage (Appendix C-Table 2). Mean concentrations (mg equivalents methyl palmitate/125 g potato chips) of volatile compounds isolated from potato chips stored for in dark or light for 4 weeks at room temperature (23°C) are shown in Table 19.

Fresh chips (0 week storage) had higher levels of 2-ethyl-5,6-dimethyl pyrazine; unknowns 2, 3, 4, 5, 9, 10, 11, and 12; cyclohexen-2-one, and 1-octanol than chips stored in the light or dark for 4 weeks at ambient temperature. Fresh chips also had higher concentrations of unknown 1; t-2-octenal; unknown 8 (aldehyde); t,t-2,4-decadial and unknown 13 than chips stored in the dark. Chips stored in the light for 4 weeks had higher concentrations of unknown1; t-2-octenal and t,t-2,4-heptadienal than chips stored in the dark for 4 weeks. Chips stored in the light for 4 weeks also had higher concentrations of 3-ethyl-2-methyl pyrazine and unknown 8 (aldehyde) than either fresh chips or chips stored in the dark. No significant differences were found between fresh chips and chips stored in the light for the concentrations of unknown 1; t-2-octenal; t,t-2,4-heptadienal or t,t-2,4-decadial. Generally, storage for 4 weeks reduced the level of most volatiles in

TABLE 19.

MEAN^a CONCENTRATIONS (mg EQUIVALENTS METHYL PALMITATE/125g POTATO CHIPS) OF VOLATILE COMPOUNDS ISOLATED FROM POTATO CHIPS STORED IN DARK OR FLUORESCENT LIGHT FOR 4 WEEKS AT ROOM TEMPERATURE (23°C).

Compound	Retention time(min)	0-week storage	4-weeks storage in light	4-weeks storage in dark
2-methyl pyrazine	15.0	7.60	4.67	5.26
2,5-dimethyl pyrazine	18.6	16.25	9.55	10.60
2,6-dimethyl pyrazine	20.1	1.81	1.09	1.12
unknown1	21.2	0.10 ^{XY}	0.15 ^X	0.03 ^Y
3-ethyl-2-methyl pyrazine	22.5	3.91 ^Y	6.85 ^X	2.55 ^Y
2,3,5-trimethyl pyrazine	23.1	6.86	3.47	3.81
Nonanal	24.5	3.05	1.93	1.82
2-ethyl-5,6-dimethyl pyrazine	24.9	6.68 ^X	3.36 ^Y	3.88 ^Y
unknown2	25.2	0.39 ^X	0.15 ^Y	0.17 ^Y
unknown3	27.3	1.06 ^X	0.52 ^Y	0.57 ^Y
t-2-octenal	28.1	2.33 ^X	2.16 ^X	1.42 ^Y
Cyclohexen-2-one	29.2	0.72 ^X	0.29 ^Y	0.37 ^Y
Decanal	29.5	0.43	0.13	0.09
unknown4 (pyrazine)	29.6	0.64 ^X	0.29 ^Y	0.34 ^Y
1-octanol ^t	30.7	1.72 ^X	0.55 ^Y	0.76 ^Y
Benzaldehyde ^t	31.0	0.88	0.69	0.70
t,t-2,4-heptadienal	31.9	0.46 ^{XY}	0.66 ^X	0.31 ^Y
unknown5 (aldehyde)	33.9	1.38 ^X	0.71 ^Y	0.61 ^Y
t,t-3,5-octadien-2-one ^t	34.3	0.11	0.07	0.09
unknown6 (pyrazine)	34.9	0.27	0.14	0.21
unknown7 (pyrazine)	36.4	0.03	0.07	0.04

TABLE 19.(continued)

Compound	Retention time(min)	0-week storage	4-weeks storage in light	4-weeks storage in dark
unknown8 (aldehyde)	39.6	2.76 ^Y	4.36 ^X	1.40 ^Z
Phenylacetaldehyde	40.6	10.05	5.46	5.63
2-ethyl-6-vinyl pyrazine ^t	41.6	0.35	0.22	0.25
t,t-2,4-nonadienal	43.3	0.27	0.28	0.20
unknown9	43.7	0.12 ^X	0.02 ^Y	0.07 ^{X,Y}
unknown10 (aldehyde)	45.0	2.60 ^X	1.26 ^Y	1.37 ^Y
c,t-2,4-decadienal ^t	47.4	2.89	2.75	1.59
unknown11	47.8	0.62 ^X	0.31 ^Y	0.31 ^Y
t,t-2,4-decadienal	49.0	16.21 ^X	11.20 ^{X,Y}	9.01 ^Y
unknown12	50.4	1.63 ^X	0.74 ^Y	0.81 ^Y
unknown13	53.0	0.34 ^X	0.13 ^Y	0.19 ^{X,Y}

^an=6

^tTentative identification

^{x,y,z}Means in a row followed by different superscripts are significantly different at the $p < 0.05$ level.

the potato chips.

The concentration of several of the volatile compounds had a significant interaction (Appendix C-Table 2), and the mean concentration of each of these compounds are shown for each oil and storage treatment in Table 20. The rather large level of 3-ethyl-2-methyl pyrazine in chips stored for 4 weeks in the light (Table 19) is due mainly to a rather large amount of that compound isolated from chips fried in palm olein only. The level of t-2-octenal actually decreased during any 4 weeks storage treatment in chips fried in soybean oil and was not affected by storage in chips fried in cottonseed oil, but in palm olein fried chips it was greater after 4 weeks storage in the light than at 0 week or 4 weeks storage in the dark. Cyclohexen-2-one in palm olein chips was not affected by storage, but in cottonseed oil fried chips the level of this compound decreased during any 4 week storage treatment ($p < 0.05$). In chips fried in soybean oil, the level of cyclohexen-2-one was significantly lower after 4 weeks storage in the light compared with 0 week storage, but not after 4 weeks storage in the dark. Decanal and t,t-3,5-octadien-2-one were present only in chips fried in cottonseed oil, and the effect of storage on the concentration of these compounds has already been discussed. The levels of unknown 4 and 6 were affected by storage only in chips fried in soybean oil. They were not present in chips fried in cottonseed oil and were not affected by storage in chips fried in palm olein. In soybean oil fried chips, both unknown 4 and 6 decreased in level during any 4 weeks storage treatment compared with fresh chips. The rather large

TABLE 20.

MEAN CONCENTRATIONS (mg EQUIVALENTS METHYL PALMITATE/125g POTATO CHIPS) OF VOLATILE COMPOUNDS ISOLATED FROM POTATO CHIPS AS A FUNCTION OF OIL AND STORAGE TREATMENT.

Compound	Storage ^a	Oil		
		Soybean	Palm olein	Cottonseed
3-ethyl-2-methyl pyrazine	0	3.49	3.70 ^c	4.54
	4-light	4.37	10.00 ^b	6.13
	4-dark	2.42	3.12 ^c	2.11
t-2-octenal	0	3.47 ^b	1.22 ^c	2.30
	4-light	2.08 ^c	2.39 ^b	2.00
	4-dark	2.03 ^c	1.10 ^c	1.11
Cyclohexen-2-one	0	0.86 ^b	0.40	0.90 ^b
	4-light	0.26 ^c	0.42	0.17 ^c
	4-dark	0.41 ^{bc}	0.48	0.21 ^c
Decanal	0	0.00	0.00	1.29 ^b
	4-light	0.00	0.00	0.38 ^c
	4-dark	0.00	0.00	0.28 ^c
Unknown 4	0	1.22 ^b	0.70	0.00
	4-light	0.33 ^c	0.55	0.00
	4-dark	0.43 ^c	0.58	0.00
t,t-3,5-octadien- 2-one ^t	0	0.00	0.00	0.33 ^b
	4-light	0.00	0.00	0.21 ^c
	4-dark	0.00	0.00	0.26 ^{bc}

TABLE 20. (Continued)

Compound	Storage ^a	Oil		
		Soybean	Palm olein	Cottonseed
Unknown6	0	0.60 ^b	0.20	0.00
	4-light	0.12 ^c	0.31	0.00
	4-dark	0.22 ^c	0.41	0.00
Unknown 8	0	4.54 ^b	2.30 ^c	1.44
	4-light	2.65 ^c	9.68 ^b	0.76
	4-dark	2.08 ^c	1.66 ^c	0.45
Phenylacet- aldehyde	0	8.62	6.28	15.25 ^b
	4-light	5.29	6.20	4.89 ^c
	4-dark	6.10	4.69	5.11 ^c
Unknown 9	0	0.19 ^b	0.00	0.17 ^b
	4-light	0.03 ^c	0.00	0.02 ^c
	4-dark	0.04 ^c	0.11	0.06 ^c

^a0=0 week storage; 4-light=4 weeks storage in light and 4-dark=4 weeks storage in dark.

^{b,c}For any one compound, means within a column bearing unlike superscripts are significantly different at the $p<0.05$ level.

^tTentative identification.

level of unknown 8 (aldehyde) at 4 weeks storage in the light (Table 19) is mainly due to a large amount of this compound present in chips fried in palm olein (Table 20) which was significantly greater than that present in fresh chips or after storage 4 weeks in dark. The levels of unknown 8 actually decreased in chips fried in soybean oil and stored for any 4 weeks storage period. Although phenylacetaldehyde was not affected by storage when the levels were averaged across oils, there was a significant oil by storage interaction. Phenylacetaldehyde concentration was not affected by storage in chips fried in soybean oil or palm olein, but it decreased in level in cottonseed oil fried chips for any 4 weeks storage period. In contrast to what was found as a storage effect on all chips, the concentrations of unknown 9 were decreased by any 4 weeks storage period in chips fried in soybean oil or cottonseed oil only, but not in palm olein.

Even though phenylacetaldehyde, one of the most abundant volatiles found in the chips, can be produced from phenylalanine in the potato by Strecker degradation during deep fat frying (Deck et al., 1973), oxidation of unsaturated fatty acids is the main source of the carbonyl compounds found in the chips. Significant differences in levels of the volatile carbonyl compounds among the chips fried in different oils or during storage in the dark or light are due chiefly to the different levels of unsaturated fatty acids in the oils (Table 10, p. 58). Upon oxidation, oleic acid is the precursor of nonanal; linoleic acid of t-2-octenal and t,t-2,4-decadienal; and linolenic acid of t,t-2,4-heptadienal (deMan, 1980; Mookherjee et al., 1965).

Soybean oil and palm olein contained 44.61 and 42.40% of oleic acid, respectively, compared with 22.78% in cottonseed oil. This difference in oil oleic acid levels is most likely the cause of chips fried in soybean oil and palm olein having higher levels of nonanal than those fried in cottonseed oil (Table 18, p. 74). Soybean oil and cottonseed oil have 21.1% and 40.46% linoleic acid, respectively, compared with 10.55% in palm olein. This difference relates well to the higher levels of t,t-2,4-decadienal found in chips fried in soybean or cottonseed oils compared with those fried in palm olein (Table 18, p. 74). Soybean oil also contained significantly higher levels of linolenic acid than palm olein or cottonseed oil, and that is the reason that chips fried in soybean oil contained higher levels of t,t-2,4-heptadienal.

The formation of pyrazines is more complicated than the aldehydes previously discussed. Maga and Sizer (1973) reported that pyrazines, which are heterocyclic nitrogen containing compounds, are formed late the frying process, because it took 4 min at 150°C to form appreciable amounts of pyrazines. Nitrogen atoms are incorporated into pyrazine by two possible pathways. Free ammonia can combine with reducing sugars to form pyrazines, or nitrogen not in the free state (from alpha-amino acids) can also react. In addition, dicarbonyls from any source, even from oxidized lipids, can react with these nitrogen sources to form pyrazines (Maga and Sizer, 1973). The substituent groups on the heterocyclic ring are determined by these dicarbonyls.

The first pyrazine compound identified in potato chips was

2,5-dimethyl pyrazine with an earthy, raw potato flavor when present at a concentration of 10 ppm (Maga and Sizer, 1973). This compound was present in the chips in the present study at approximately 100 ppm (Table 18, p. 74); however, this does not represent a headspace concentration. In the present study, 10 pyrazines were detected in the volatiles isolated from the chips, and no pyridines were identified. In comparison, Buttery et al. (1971) identified 18 pyrazine and pyridine compounds from the basic fraction of the steam volatile oil from potato chips.

The only significant differences in levels of pyrazine compounds found among the potato chips fried in different oils in the present study were for unknown 4, 6 and 7 (Table 18, p. 74), and the actual identity of the side groups in these compounds are not known at this time. Without the identity of the side groups, it is not possible to determine if differences in the fatty acid composition of the oils could be responsible for their formation.

A total volatile concentration of 107 mg equivalents of methyl palmitate/125 g potato chips was isolated from fresh potato chips compared with 71 from potato chips stored in the light and 62 from potato chips stored in dark for 4 weeks. This shows that there was a trend toward decreased levels of volatiles with storage. The concentration of eleven volatiles isolated from the chips did decrease significantly ($p < 0.05$) in concentration during 4 weeks storage in dark or light at ambient temperature (Table 19, p. 78). There are three possible ways for volatiles to be lost from the chips. The volatiles could have dissipated into the air, reacted to

give other products or be bound by some nonvolatile component in the chips. The first way is possible; however, the chips were stored in sealed glass jars, and the volatiles lost would have to have dissipated when the jars were opened prior to frozen storage for insertion of the silica dessicant or at the time of analysis. The second possibility is also very likely. Mookherjee et al., (1965) reported that the disappearance of such volatiles as t,t-2,4-decadienal during storage was probably due to either polymerization with itself or autoxidative decomposition to other compounds. The third possibility has not been discussed in the loss of volatiles from potato chips. According to Schoch (1965), the loss of bread flavor occurs during staling because the linear fraction of the wheat starch slowly forms helical complexes with flavor elements, rendering them insoluble and imperceptible to the taste. Potato chips contain this linear starch fraction, amylose, and it might bind some of the volatiles in the same manner as the wheat starch.

The correlation coefficients of the potato chip flavor score with the peroxide value and levels of volatile compounds in the chips are given in Table 21. Since flavor undesirability increases with increasing score in the present study, a negative correlation coefficient indicates that higher levels of that factor contribute to a more desirable potato chip flavor, and a positive correlation coefficient shows that higher levels of the factor contribute to a more undesirable potato chip flavor. The levels of the following volatiles had positive correlation coefficients with the potato chip flavor score ($p < 0.05$ or lower): unknown 1 (.60), 3-ethyl-2-methyl

TABLE 21.

SELECTED CORRELATION COEFFICIENTS OF PEROXIDE VALUE AND
VOLATILE COMPOUNDS WITH FLAVOR DESIRABILITY (n=18).

Chemical measurement	Flavor score
Peroxide value	.43
2-methyl pyrazine	-.20
2,5-dimethyl pyrazine	-.18
2,6-dimethyl pyrazine	-.22
Unknown1	.60 ^{**}
3-ethyl-2-methyl pyrazine	.48 [*]
2,3,5-trimethyl pyrazine	-.29
Nonanal	.19
2-ethyl-5,6-dimethyl pyrazine	-.13
Unknown2 (2,6-dimethyl-3-pyrazine) ^p	-.43
Unknown3 (t-2-octenal) ^p	.40
Cyclohexen-2-one	-.14
Decanal	-.54 [*]
Unknown4 (3-isoamyl-2,5-dimethyl pyrazine) ^p	.31
1-octanol ^t	-.44
Bezaldehyde ^t	-.24
t,t-2,4-heptadienal	.76 ^{***}
Unknown5 (aldehyde)	-.02
t,t-3,5-octadien-2-one ^t	-.61 ^{**}
Unknown6 (2-n-butyl-3-methyl-pyrazine) ^p	.31
Unknown7 (pyrazine)	.56 [*]
Unknown8 (aldehyde)	.62 ^{**}
Phenylacetaldehyde	-.33
2-ethyl-6-vinyl pyrazine ^t	-.09
t,t-2,4-nonadienal	.10
Unknown9	-.28
Unknown10 (aldehyde)	.21
c,t-2,4-decadienal ^t	-.03

TABLE 21. (Continued)

Chemical measurement	Flavor score
Unknown11	-.28
t,t-2,4-decadienal	-.16
Unknown12	-.13
Unknown13	-.28

*Significant at the $p < 0.05$ level.

**Significant at the $p < 0.01$ level.

***Significant at the $p < 0.001$ level.

PPossible identification.

^tTentative identification.

pyrazine (.48), t,t-2,4-heptadienal (.76), unknown 7, a pyrazine (.56), and Unknown 8, an aldehyde (.62). Significant negative correlation coefficients ($p < 0.05$ or lower) of the flavor score were found with decanal (-.54) and t,t-3,5-octadien-2-one (-.61). The t,t-2,4-heptadienal is a secondary oxidation product of linolenic acid (deMan, 1983). This acid was present at higher levels in the soybean oil than in the palm olein or cottonseed oils (Table 10, p. 58) used in the present study and may be the reason that soybean oil is not as desirable as other oils for frying potato chips. Decanal and t,t-2,4-octadien-2-one were not present in chips fried in palm olein or soybean oil (Table 18, p. 74), and therefore, could be the reason for the more desirable flavor of the potato chips fried in cottonseed oil compared with that of chips fried in the other oils (Table 18, p. 74). Although Mookherjee et al. (1965) reported that t,t-2,4-decadienal contributes to the desirable chip aroma, it was not significantly correlated with the chip flavor score in this study. Additional research is necessary to assess the contribution of the significantly ($p < 0.05$) correlated volatiles in the present study to the flavor of potato chips.

CHAPTER V

SUMMARY

In this experiment, potato chips were fried in three different oils (soybean, palm olein and cottonseed) and stored for 0, 2, or 4 weeks (3 storages) in fluorescent light or dark (2 treatments) at 23°C. Two replications were completed. Potato chips were analyzed for moisture and oil contents, peroxide value, Hunter color values, sensory scores and volatile compounds. The frying oils used for frying potato chips were analyzed for fatty acid composition.

Potato chips fried in soybean oil (1.89%) had a significantly ($p < 0.05$) higher moisture content than potato chips fried in palm olein (1.41%) or cottonseed oil (1.52%). Oil content of potato chips was not affected by oil, storage and treatment. Mean oil content of potato chips fried in soybean oil, palm olein and cottonseed oil were 40.47, 40.62 and 41.53%, respectively. The amount of oil entering the potato slice during frying was probably proportional to the amount of moisture lost from the potato slice.

Potato chips fried in soybean oil (6.9 meq/kg oil) had a significantly lower peroxide value than potato chips fried in palm olein (8.4 meq/kg oil) or cottonseed oil (9.5 meq/kg oil). Peroxide value of potato chips averaged across frying oils increased 57% during 2 weeks of storage and 131% during 4 weeks of storage. These increases were due to the oxidative degradation of the oil

contained in potato chips. Peroxide value of potato chips stored in the light (10.8 meq/kg oil) was significantly higher than peroxide value of potato chips stored in the dark (6.5 meq/kg oil).

Fluorescent light accelerated the rate of oxidation of potato chips at room temperature. During 0 to 4 weeks of storage in the light, potato chips fried in cottonseed oil underwent quicker and more extensive oxidative deterioration than potato chips fried in palm olein or soybean oil. The peroxide value of potato chips fried in cottonseed oil increased linearly from 5.3 to 8.9 meq/kg oil from 0 to 4 weeks storage in the dark but the peroxide value of potato chips fried in soybean oil or palm olein did not change significantly ($p>0.05$).

Potato chips fried in cottonseed oil (59.3) had significantly ($p<0.05$) higher Hunter color L value than potato chips fried in soybean oil (57.5) or palm olein (57.1). This indicated that the color of potato chips fried in cottonseed oil was lighter than the color of potato chips fried in soybean oil or palm olein. Potato chips fried in cottonseed oil (4.24) had a significantly lower Hunter color "a" value than potato chips fried in palm olein (5.49). This indicated that potato chips fried in cottonseed oil had a lower amount of red coloration than potato chips fried in palm olein. No significant difference was found for Hunter color "b" value of potato chips among the oils. Also, no significant differences were found for Hunter color L, "a", and "b" values among the storage times or between the treatments.

Sensory flavor and acceptability scores were significantly

($p < 0.05$) affected by oil and treatment but not by interaction between oil and treatment. Potato chips fried in cottonseed oil had more desirable flavor and were more acceptable than potato chips fried in soybean oil or palm olein, perhaps due to the nutlike flavor of cottonseed oil. Potato chips stored for 4 weeks in the light had significantly ($p < 0.05$) less desirable flavor and were less acceptable than fresh potato chips (0 week storage) or potato chips stored for 4 weeks in the dark. Potato chips stored in the dark for 4 weeks had just as desirable flavor and were just as acceptable as fresh chips.

Significant differences ($p < 0.05$) existed in the fatty acid composition among the three frying oils. Of the three oils, soybean oil contained the highest levels of 18:0, 18:1 isomer, 18:2 isomer, 18:3w6, 20:0, 18:3w3, 22:0, and 24:0; palm olein contained the highest levels of 12:0, 14:0, 15:0, and 16:0; and cottonseed oil contained the highest levels of 16:1, 17:0, and 18:2. Used frying oil had higher levels of 10:0 than fresh oil and tended to have higher levels of 18:0.

The most abundant volatile compounds isolated from potato chips were 2-methyl pyrazine, 2,5-dimethyl pyrazine, 3-ethyl-2-methyl pyrazine, 2,3,5-trimethyl pyrazine, 2-ethyl-5,6-dimethyl pyrazine, phenylacetaldehyde and t,t-2,4-decadienal. Compared with other chips, potato chips fried in soybean oil contained significantly higher concentrations of nonanal, t-2-octenal, t,t-2,4-heptadienal, c,t-2,4-decadienal, t,t-2,4-decadienal, and unknowns 4, 6, 7, 10 and 12; potato chips fried in palm olein contained significantly higher concentrations of nonanal, and unknowns 4, 6, 8

and 10, and potato chips fried in cottonseed oil contained significantly higher concentrations of decanal, t,t-3,5-octadien-2-one, c,t-2,4-decadienal, t,t-2,4-decadienal and unknown 12. The concentration of t,t-2,4-decadienal in the chips decreased significantly during 4 weeks of storage in the dark. The level of volatile compounds isolated from potato chips tended to decrease during 4 weeks storage either in light or dark. The reason for the loss of flavor volatiles during storage may be due (1) to further degradation, (2) to starch forming helical complexes with flavor elements, rendering them insoluble or (3) loss by evaporation.

Results of this study show that potato chips fried in cottonseed oil had more desirable flavor and were more acceptable than potato chips fried in soybean oil or palm olein even though those chips had higher peroxide value than potato chips fried in soybean oil. Potato chips stored in the fluorescent light resulted in higher peroxide value, and less desirable flavor and acceptability scores than potato chips stored in dark. Correlation coefficients of flavor volatiles with the flavor desirability scores indicated that higher levels of 2,6-dimethyl pyrazine, unknown 1, t,t-2,4-heptadienal and an unknown (aldehyde) contributed to less desirable flavor in the chips. However, decanal and t,t-3,5-octadien-2-one, found only in chips fried in cottonseed oil, contributed to a more desirable chip flavor.

COTTON

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APPENDIXES

APPENDIX A

CHIP SCORECARD

CHIP SCORECARD

You will receive 6 samples of chips. After tasting each of the samples please rinse your mouth with water.

Please taste the sample and describe how well you like the FLAVOR of the sample.

Like extremely	_____
Like very much	_____
Like moderately	_____
Like slightly	_____
Dislike slightly	_____
Dislike moderately	_____
Dislike very much	_____
Dislike extremely	_____

Please taste the sample and describe how well you like sample in GENERAL

Like extremely	_____
Like very much	_____
Like moderately	_____
Like slightly	_____
Dislike slightly	_____
Dislike moderately	_____
Dislike very much	_____
Dislike extremely	_____

COMMENT: _____

APPENDIX B

CHIP QUESTIONNAIRE

CHIP QUESTIONNAIRE

Thank you for tasting the chip samples. We would appreciate it if you would complete the following questionnaire.

1) Gender: Male _____ Female _____

2) Age: _____ less than 18
_____ 18-24
_____ 25-34
_____ 35-44
_____ 45-54
_____ 55 and over

3) Check the frequency with which you eat chips.

_____ Several times a week
_____ Several times a month
_____ Several times a year

4) List the 3 chips that you consume most frequently.

THANK YOU FOR PARTICIPATING IN OUR SURVEY.

APPENDIX C

TABLES

TABLE C-1.

SUM OF SQUARES FOR ANALYSIS OF VARIANCE FOR PERCENTAGE
FATTY ACIDS IN FRYING OILS.

Source	df	(10:0)	(12:0)	(14:0)	(15:0)	(16:0)	(16:1)
Oil(O)	2	0.98×10^{-3} *	0.16 ***	2.60 ***	0.16×10^{-2} ***	2302.24	0.12×10^{-3} ***
Time(T)	2	0.10×10^{-2} *	0.75×10^{-3}	0.21×10^{-2}	0.14×10^{-3}	0.18	0.55×10^{-3}
OxT	4	0.41×10^{-3}	0.88×10^{-3}	0.33×10^{-2}	0.56×10^{-4}	1.17	0.22×10^{-3}
Error	9	0.98×10^{-3}	0.20×10^{-1}	0.41×10^{-1}	0.26×10^{-3}	3.73	0.13×10^{-2}
		(16:1)	(17:0)	(18:0)	(18:1)	(18:1l)	(18:3w6)
O	2	0.66 ***	0.24×10^{-2} ***	54.79 ***	1733.85 ***	281.60 ***	0.85×10^{-2} ***
T	2	0.15×10^{-3}	0.42×10^{-4}	0.24	10.47	16.30	0.14×10^{-3}
OxT	4	0.49×10^{-4}	0.12×10^{-3}	0.33	16.55	21.32	0.29×10^{-3}
Error	9	0.18×10^{-2}	0.65×10^{-3}	0.77	119.44	71.90	0.16×10^{-2}
		(18:2)	(18:2l)	(18:3l)	(20:0)	(18:3w3)	(20:1)
O	2	2790.26 ***	23.79 ***	0.25×10^{-1}	0.29 ***	0.54 ***	0.38×10^{-1} *
T	2	2.17	0.08	0.63×10^{-2}	0.14×10^{-2}	0.16×10^{-1}	0.41×10^{-4}
OxT	4	1.80	1.70	0.13×10^{-1}	0.47×10^{-2}	0.23×10^{-1}	0.18×10^{-2}
Error	9	5.99	5.86	0.57×10^{-1}	0.77×10^{-2}	0.50×10^{-1}	0.30×10^{-1}
		(20:1l)	(22:0)	(24:0)	(Unknown1)	(Unknown2)	
O	2	0.15 ***	0.25 ***	0.11×10^{-1} ***	0.15×10^{-2} **	0.22×10^{-2} ***	
T	2	0.71×10^{-3}	0.95×10^{-3}	0.33×10^{-3}	0.02×10^{-3}	0.11×10^{-3}	
OxT	4	0.14×10^{-2}	0.63×10^{-2}	0.97×10^{-3}	0.03×10^{-3}	0.42×10^{-4}	
Error	9	0.30×10^{-1}	0.54×10^{-2}	0.11×10^{-2}	0.69×10^{-3}	0.55×10^{-3}	
		(Unknown3)	(Unknown4)	(Unknown5)	(Unknown6)	(Unknown7)	
O	2	0.29×10^{-1} ***	0.12×10^{-1} ***	0.11 ***	0.39×10^{-2}	0.19×10^{-2} *	
T	2	0.11×10^{-2}	0.31×10^{-5}	0.50×10^{-4}	0.35×10^{-2}	0.34×10^{-3}	
OxT	4	0.15×10^{-2}	0.61×10^{-5}	0.73×10^{-3}	0.18×10^{-2}	0.51×10^{-3}	
Error	9	0.30×10^{-2}	0.40×10^{-3}	0.18×10^{-1}	0.72×10^{-2}	0.20×10^{-2}	

*P<0.05 level; **P<0.01 level; ***P<0.001 level.

TABLE C-2.

SUM OF SQUARES FOR ANALYSIS OF VARIANCE FOR CONCENTRATION
OF VOLATILE COMPOUNDS ISOLATED FROM POTATO CHIPS.

Source	df	2-methyl pyrazine	2,5-dimethyl pyrazine	2,6-dimethyl pyrazine	Unknown1	3-ethyl-2-methyl pyrazine
Oil(O)	2	16.49	59.34	0.29	0.01	14.86
Storage(S)	2	28.91	155.63	2.01	0.04*	58.13**
OxS	4	19.14	75.10	1.62	0.03	21.53
Error	8	34.68	153.34	2.30	0.03	16.68
		2,3,5- trimethyl pyrazine	Nonanal	2-ethyl- 5,6-dimethyl pyrazine	Unknown2	Unknown3
O	2	2.42	7.82*	8.42	0.02	0.04
S	2	41.79	5.53	38.35*	0.22*	1.05*
OxS	4	17.57	2.59	7.32	0.13	0.34
Error	8	39.34	5.81	21.76	0.15	0.73
		t-2-octenal	Cyclohexen- 2-one	Decanal	Unknown4	1-octanol†
O	2	2.96*	0.03	1.67**	1.62***	0.34
S	2	2.83*	0.63*	0.42	0.44*	4.67*
OxS	4	3.38*	0.42	0.83	0.55*	1.35
Error	8	1.71	0.31	0.63	0.26	2.70
		Benzaldehyde†	t,t-2,4- heptadienal	Unknown5	t,t-3,5- octadien- 2-one†	Unknown6
O	2	0.09	0.34*	1.10	0.28***	0.38***
S	2	0.14	0.37*	2.12*	0.00	0.05
OxS	4	0.37	0.13	1.15	0.01	0.25**
Error	8	0.91	0.22	1.27	0.00	0.01

TABLE C-2 (continued)

Source	df	Unknown7	Unknown8	phenyl- acetaldehyde	2-ethyl 6-vinyl pyrazine [†]	t,t-2,4- nonadienal
Oil(O)	2	0.04*	40.78***	17.98	0.01	0.06
Storage(S)	2	0.00	26.41***	81.20*	0.05	0.02
OxS	4	0.00	60.68***	71.42	0.06	0.08
Error	8	0.02	3.66	71.61	0.14	0.14

		Unknown9	Unknown10	c,t-2,4- decadienal [†]	Unknown11	t,t-2,4- decadienal
O	2	0.01	10.20**	12.28**	0.01	315.49**
S	2	0.03*	6.65**	6.10*	0.40**	163.31*
OxS	4	0.04*	2.75	5.20	0.18	157.82
Error	8	0.02	2.21	5.14	0.13	126.14

		Unknown12	Unknown13
O	2	2.96**	0.03
S	2	2.95**	0.14*
OxS	4	1.28	0.11
Error	8	1.19	0.01

[†]Tentative identification

*p<0.05 level

**p<0.01 level

***p<0.001 level

APPENDIX. D

FIGURES

FILENAME:M-2
 COMMENT:BGS INPUT:M-2
 .11 .01
 (*100) (*100)
 DATA R.T. PEAK BASE PEAK TOTAL
 1 21.2 196 261(43) 713
 23 261(43) 646

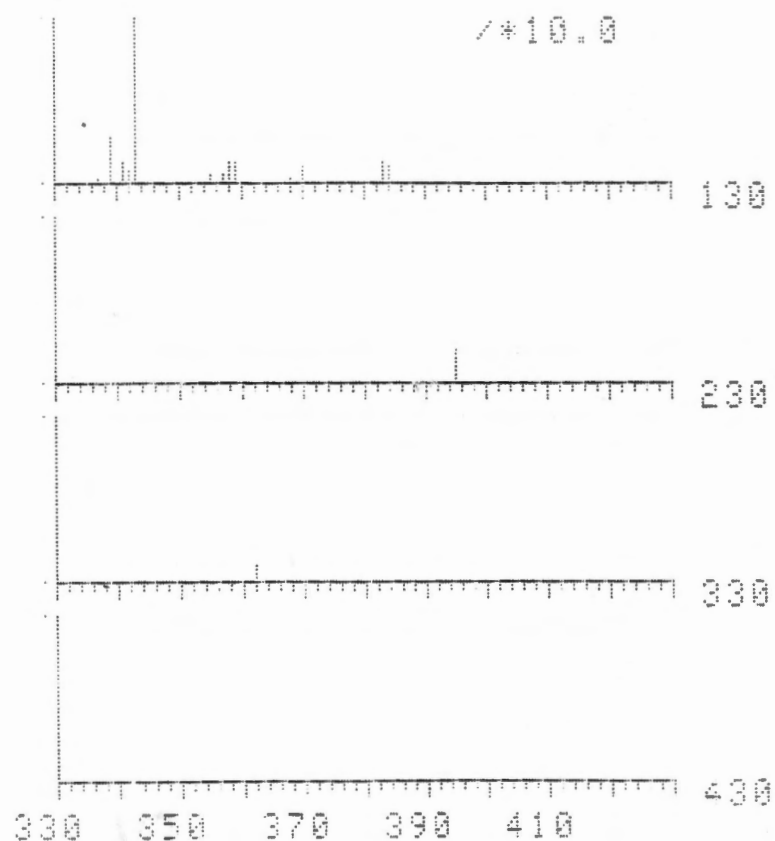


Figure D-1. Mass spectrum of unknown 1.

FILENAME:M-2
 COMMENT: BGS INPUT: M-2 .01
 (*100) (*100)
 DATA R.T. PEAK BASE PEAK TOTAL
 1 25.2 218 552(67) 2660
 32 552(67) 2561

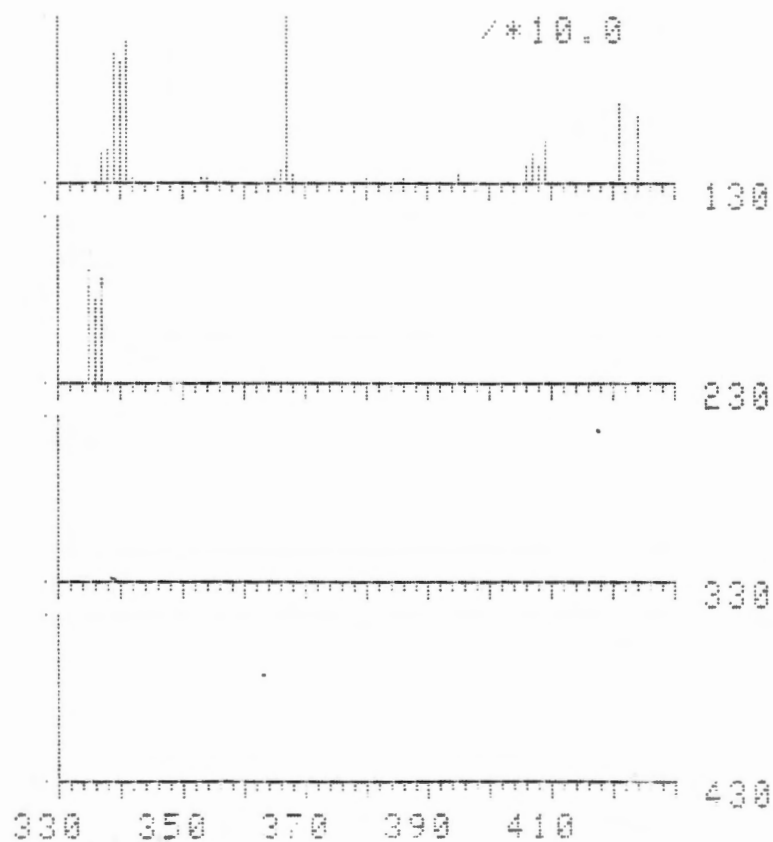


Figure D-2. Mass spectrum of unknown 2.

FILENAME:M-2
COMMENT:BGS INPUT:M-2 .01
(*100) (*100)
DATA R.T. PEAK BASE PEAK TOTAL
1 27.3 156 348(39) 2105
38 348(39) 2033

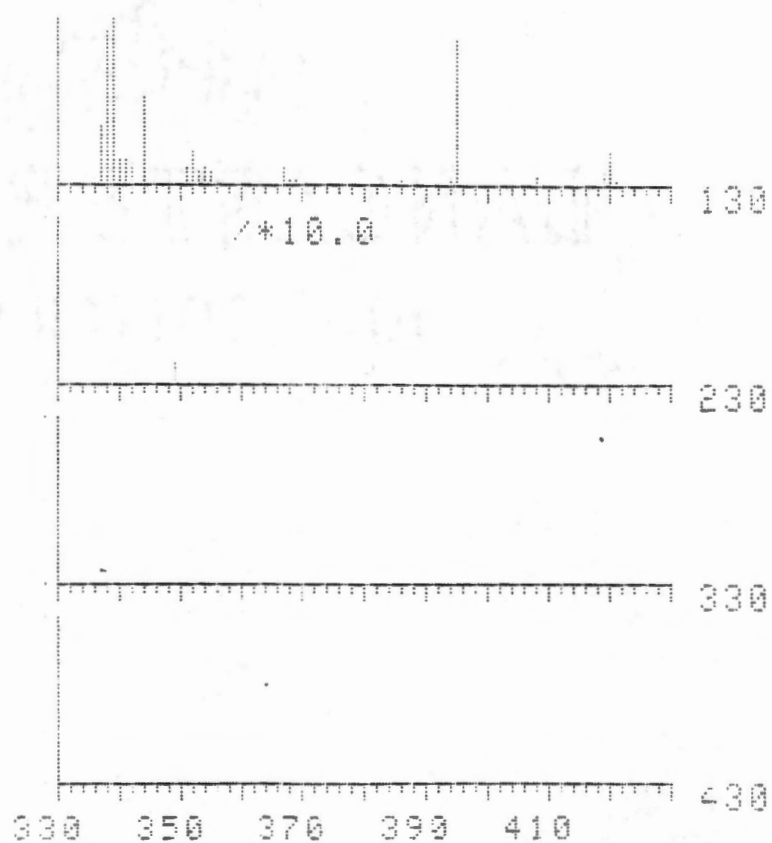


Figure D-3. Mass spectrum of unknown 3.

FILENAME:M-3
COMMENT:BGS INPUT:M-3 .01
(*100) (*100)
DATA R.T. PEAK BASE PEAK TOTAL
1 29.6 194 518(122) 1880
34 518(122) 1740

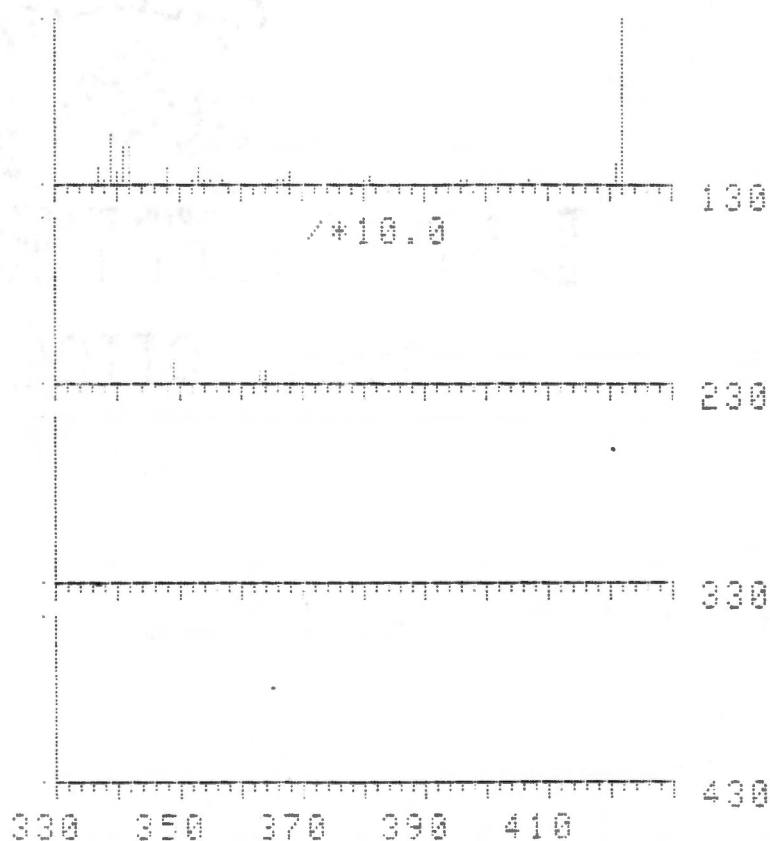


Figure D-4. Mass spectrum of unknown 4 (pyrazine).

FILENAME:M-2 .29
COMMENT:BGS INPUT:M-2 .01
(*100) (*100)
DATA R.T. PEAK BASE PEAK TOTAL
1 33.9 173 212(43) 1773
45 212(43) 1717

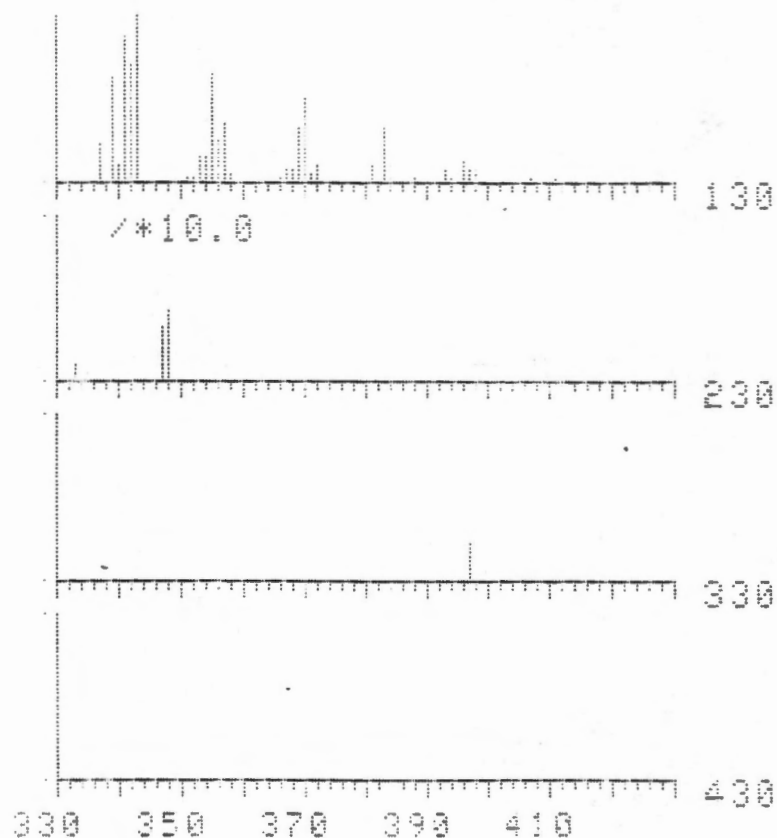


Figure D-5. Mass spectrum of unknown 5 (aldehyde).

FILENAME:SOY22D.24
COMMENT:BGS INPUT:SOY22D.01
(*100) (*100)
DATA R.T. PEAK BASE PEAK TOTAL
1 34.9 186 280(108) 1788
40 280(108) 1673

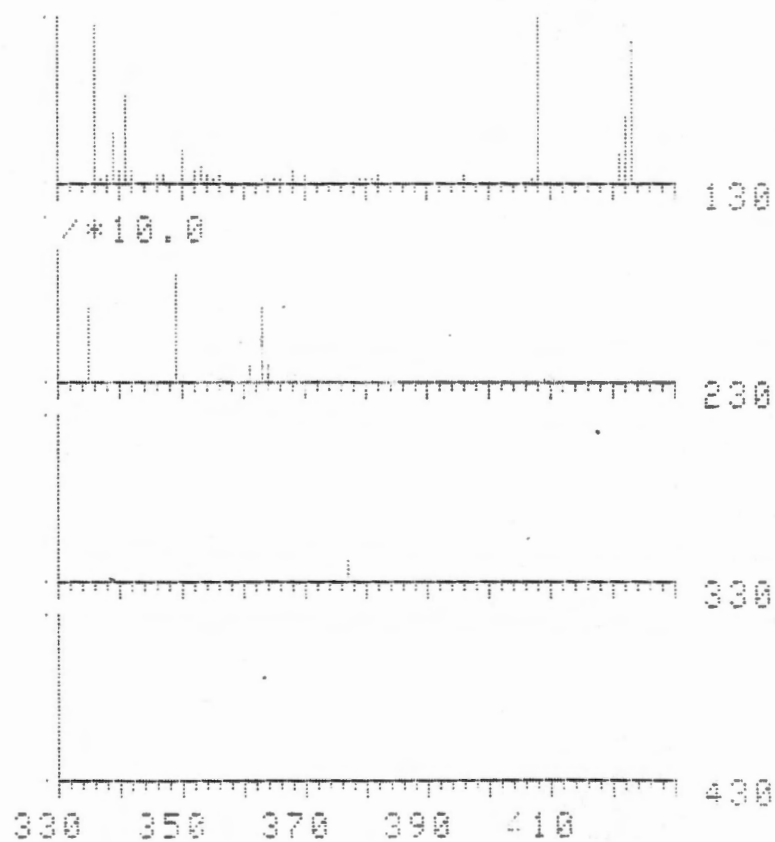


Figure D-6. Mass spectrum of unknown 6 (pyrazine).

FILENAME:SOY22D.26
COMMENT:BGS INPUT:SOY22D.01
(*100) (*100)
DATA R.T. PEAK BASE PEAK TOTAL
1 36.4 189 615(101) 3832
49 615(101) 3672

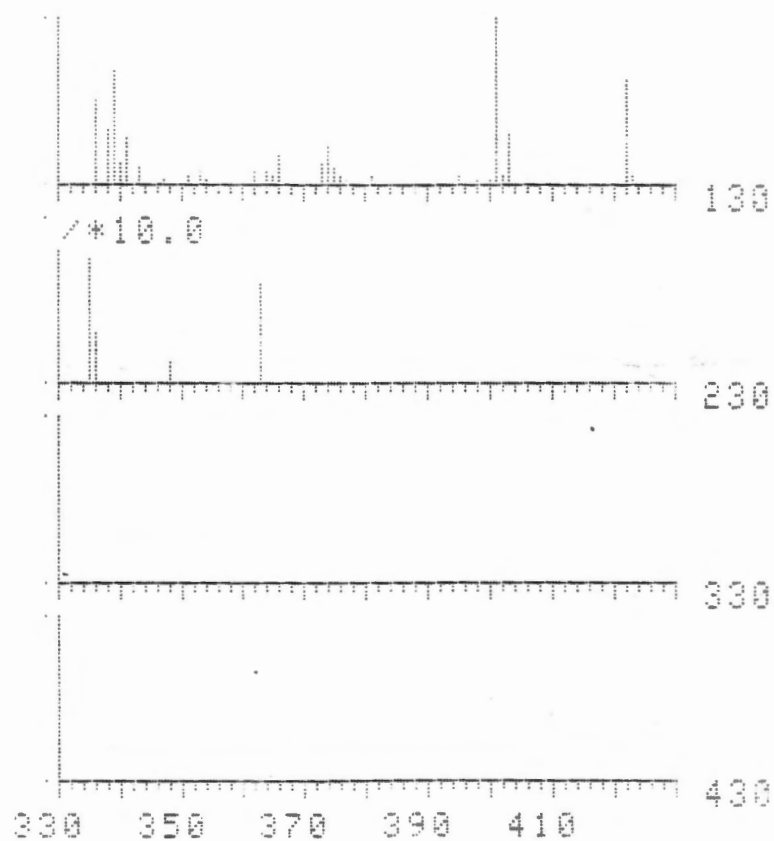


Figure D-7. Mass spectrum of unknown 7 (pyrazine).

```

FILENAME:M-2
COMMENT:BGS INPUT:M-2 .01
          (*100) (*100)
DATA  R.T. PEAK  BASE  PEAK  TOTAL
      1  39.6  165  405(  43)  3187
          47  405(  43)  3098

```

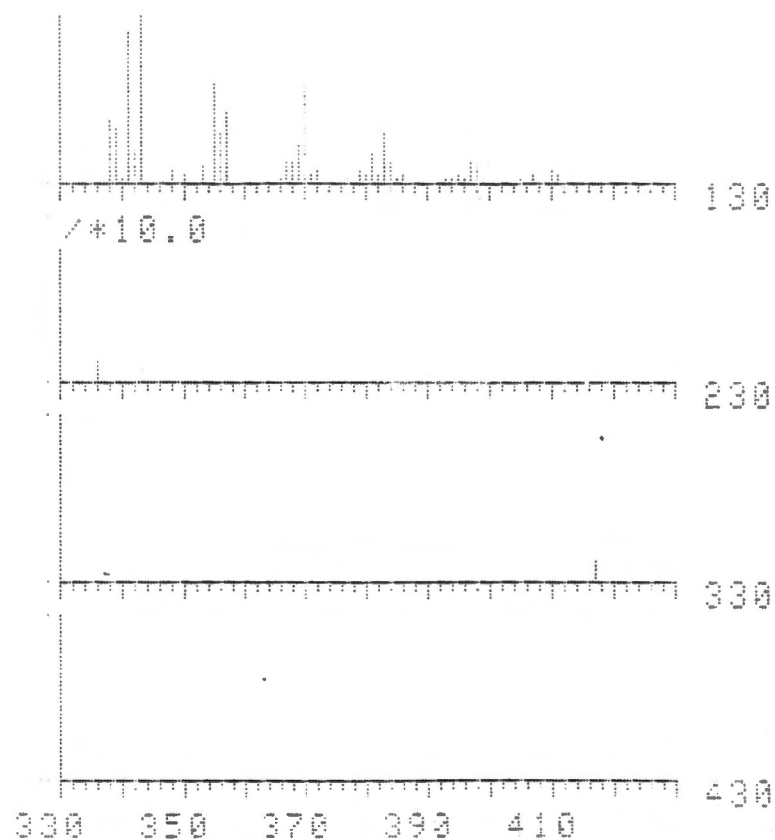


Figure D-8. Mass spectrum of unknown 8 (aldehyde).

FILENAME:M-2
COMMENT:BGS INPUT:M-2 .01
(*100) (*100)
DATA R.T. PEAK BASE PEAK TOTAL
1 43.7 219 66(39) 386
66 66(39) 350

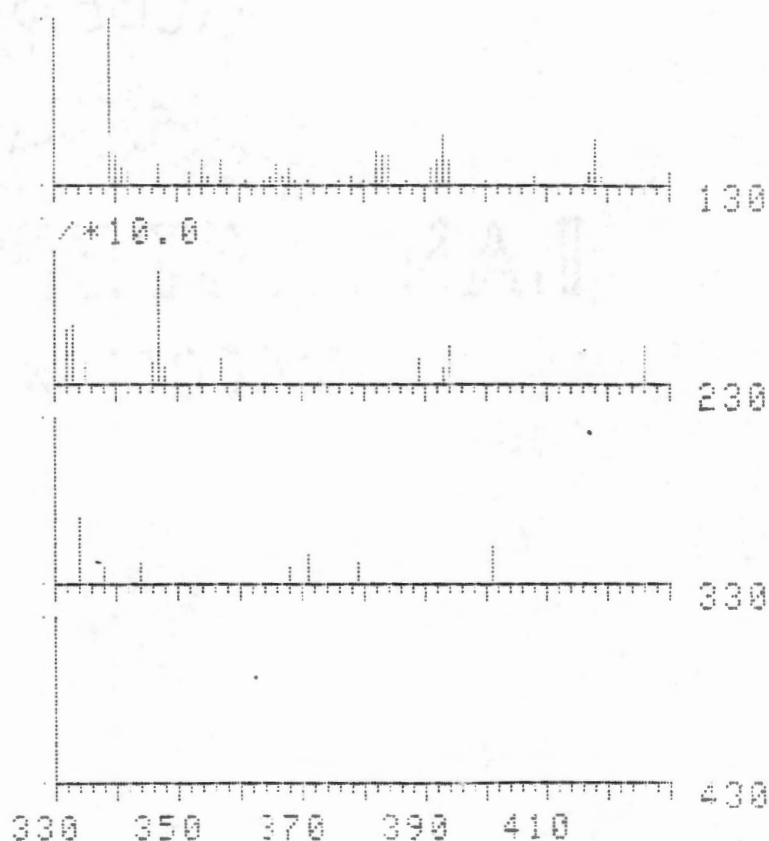


Figure D-9. Mass spectrum of unknown 9.

```

FILENAME:M-2
COMMENT:BGS INPUT:M-2 .01
          38
          (*100)
DATA  R.T.  PEAK  BASE  PEAK  TOTAL
      1  45.0  152  179(  41)  1665
          67  179(  41)  1618

```

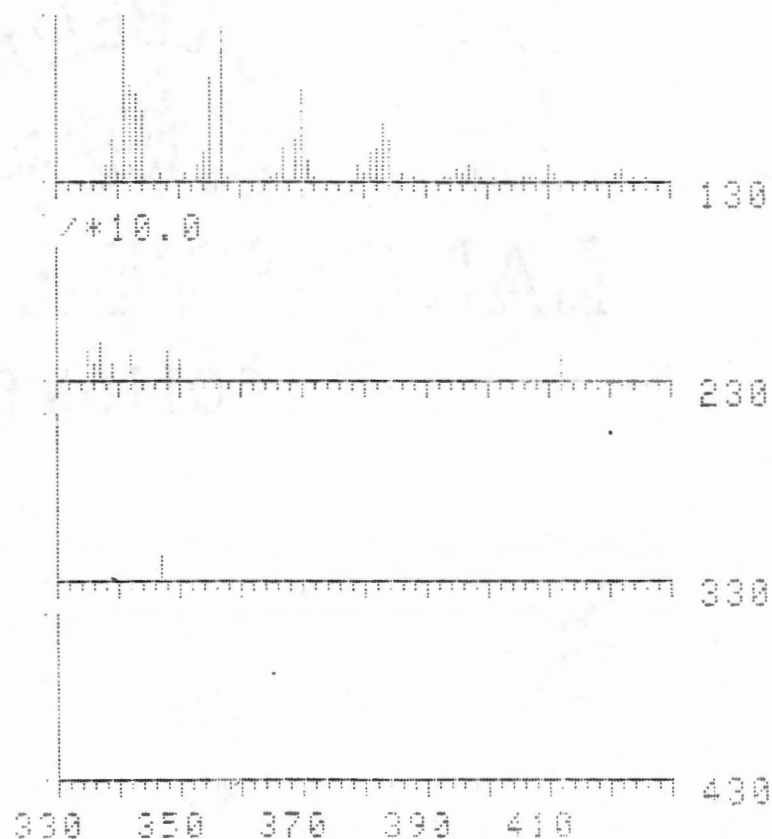


Figure D-10. Mass spectrum of unknown 10 (aldehyde).

```

FILENAME:M-3
COMMENT:BGS INPUT:M-3 .01
          (*100) (*100)
DATA  R.T.  PEAK  BASE  PEAK  TOTAL
      1  47.8  105  200( 162)  1364
          65  200( 162)  1307

```

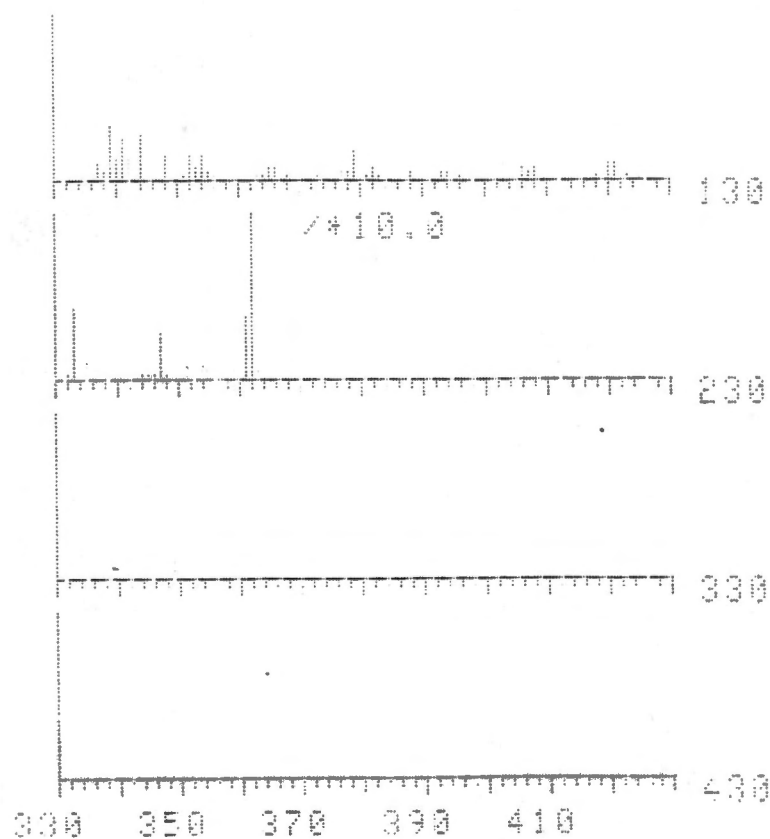


Figure D-11. Mass spectrum of unknown 11.

FILENAME:M-3 .41
COMMENT:BGS INPUT:M-3 .01
DATA R.T. PEAK BASE PEAK TOTAL
1 50.4 177 164(121) 1598
68 164(121) 1552

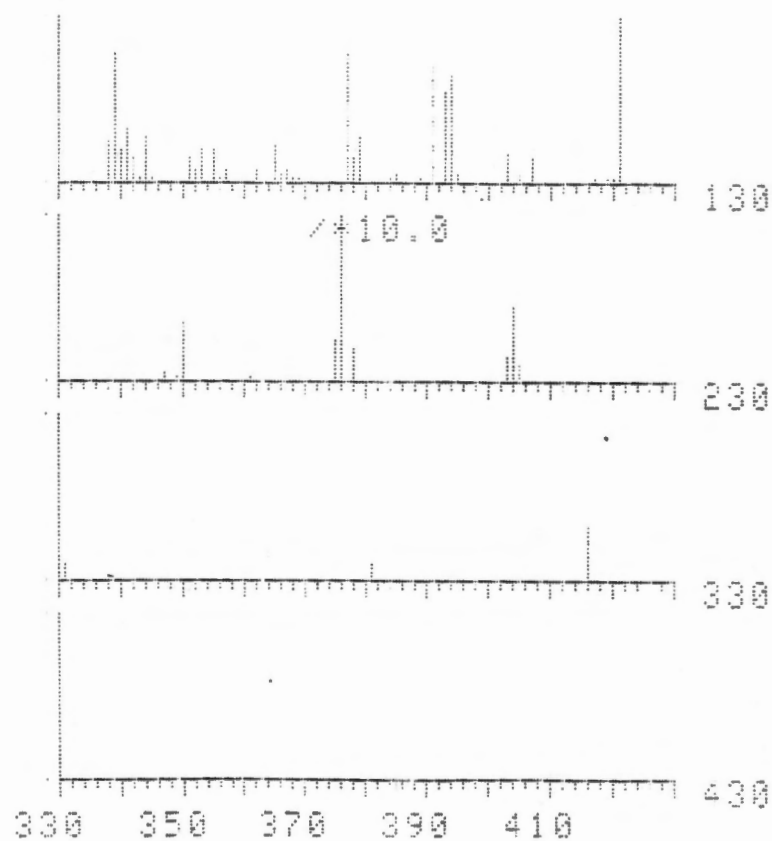


Figure D-12. Mass spectrum of unknown 12.

```

FILENAME:M-2
COMMENT:BGS INPUT:M-2 .01
(*100) (*100)
DATA R.T. PEAK BASE PEAK TOTAL
1 53.0 191 111( 94) 647
50 111( 94) 599

```

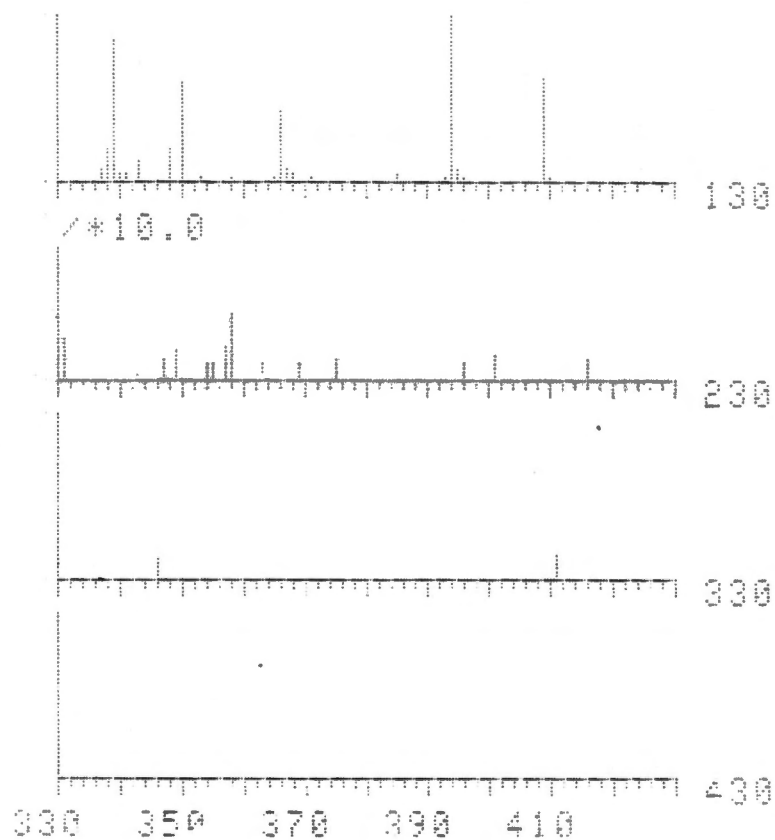


Figure D-13. Mass spectrum of unknown 13.

VITA

Myung Joo Han was born in Pusan, Korea, on February 20, 1959, to Ryen Worle Lee and Gook Hyun Han. In 1977, she graduated from Kyung-Hee High School in Seoul, Korea. In 1978, she entered the Kyung-Hee University. In 1982, she received the Bachelor of Science degree with a major in Food Science and Nutrition from the Kyung-Hee University in Seoul, Korea. In September 1983, she entered the graduate program in the department of Food Technology and Science at the University of Tennessee, Knoxville. She received the Master of Science degree with a major in Food Technology and Science in March 22, 1985. She received the Doctor of Philosophy degree in Food Technology and Science in May 1989. She married Dong Hyun Kim on December 26, 1987.