To the Graduate Council:

I am submitting herewith a dissertation written by Sajida S. Jafar entitled "Performance of Partially Hydrogenated Soybean Oil versus Palm Oil Olein during Laboratory Frying of Potatoes and the Effect of Oils on the Flavor and Acceptability of Potatoes." 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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PERFORMANCE OF PARTIALLY HYDROGENATED SOYBEAN OIL VERSUS PALM OIL OLEIN DURING LABORATORY FRYING OF POTATOES AND THE EFFECT OF OILS ON THE FLAVOR AND ACCEPTABILITY OF POTATOES

A Dissertation

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Degree

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Sajida S. Jafar

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DEDICATION

This work is dedicated to my parents as an expression of my neverending gratitude and love.

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ABSTRACT

The objectives of this experiment were to compare the frying performance of partially hydrogenated soybean oil versus palm olein during laboratory frying and to determine the effect of these frying oils on the flavor of fried potatoes. A replication consisted of 2 partially hydrogenated soybean oils (PHSO), A with an iodine value (IV) of 94 and B with an IV of 102, and palm olein (PO), with each oil used to fry potatoes every hour for 8 hours/day for 4 consecutive days. Two replications were completed. Oil samples were collected at the beginning of the frying and at the end of each day for analysis of dielectric constant by Food Oil Sensor (FOS); change in color (Hunter color values, "L", "a" and "b") and total change in color (ΔE), % total polar components (TPC) and % free fatty acids (FFA). The first batch of potatoes fried in each oil and the next to last batch of potatoes fried each day were evaluated for flavor desirability by a sensory panel (n=32). The second batch of potatoes fried on the 1st day and the last batch fried on the 4th day were analyzed for flavor volatiles by gas chromatography-mass spectroscopy (GCMS).

PO became darker, more yellow and redder than either PHSO A or B during 4 days of frying. With increasing frying time, the Hunter color "L" value decreased linearly, and the "a" value increased linearly, while the "b" value and ΔE increased quadratically. FOS did not differ significantly among the frying oils, but % TPC and FFA did. During frying, PO had a higher level of FFA than PHSO A or B, and PHSO A had a higher level than PHSO B. PO also had a higher level of TPC than either PHSO during frying, but there was no

difference in % TPC between PHSO A and PHSO B. FOS, % FFA and % TPC all increased with increasing time of frying.

As a whole, the sensory panel liked the flavor of potatoes fried in PO slightly less than that of potatoes fried in either PHSO. The panel particularly did not like the flavor of potatoes fried in fresh PO; however, with increasing frying time, they liked PO fried potatoes better. In contrast, the flavor score of potatoes fried in PHSO A decreased linearly with increasing frying time while that of potatoes fried in PHSO B did not change ($p<.05$). The sensory panel was composed of those (Panel A, n=15) who liked the flavor of potatoes fried in PO better than those fried in PHSO A while the rest of the panel (Panel B, n=17) liked the potatoes fried in any PHSO better than those fried in PO. The levels of 19 identified compounds and 8 unknown compounds (for which mass spectra were obtained) were measured in the volatiles of the fried potatoes. The levels of 11 volatiles: 2-methyl pyrazine; t-2-octenal; benzaldehyde; t,t-2,4-heptadienal, t,c,-2,4-decadienal; c,t-2,4-decadienal; t,t-2,4-decadienal and 3 unknowns were different among the oils ($p<.10$) and concentrations of 15 volatiles were less in potatoes fried at 4 days than those fried in fresh oil ($p<.10$). Flavor desirability scores from the entire panel or from Panel A were not significantly correlated with levels of any of the volatiles, but the flavor desirability scores of Panel B were significantly correlated with concentrations of t-2-octenal ($r = .61$), cyclohexenone-2-one ($r = .60$) and an unknown.

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CHAPTER I

INTRODUCTION

Deep-fat frying is one of the most common methods of cooking in the United States. The use of fats and oils in cooking has increased rapidly during the last few years due to the growing number of fast-food restaurants which produce deep fried food such as fish, chicken, and french fried potatoes. Food prepared by this method of cooking develops a unique flavor and color due to degradation of the frying fat which is absorbed by the food, the reactions among food components, and the reaction of the fats with constituents of the food at the high frying temperatures (1). During deep-fat frying, the fat or oil is exposed to high temperatures, moisture and oxygen for days at a time. Under these conditions, various chemical and physical changes occur in the frying medium and in the food being fried. These changes affect the life of the frying oil and the quality of the fried food, particularly the flavor. Frying oils during use develop high levels of free fatty acids and total polar components through hydrolysis and oxidation, resulting in an increase in the dielectric constant of the oil which can be measured using a Food Oil Sensor (2). The color of the oil also darkens mainly due to polymers formed by oxidation and from solubilization of the browned particles from the fried foods (2). Measurement of the free fatty acid content, the total polar components, the dielectric constant and the color of the frying oils are common methods for assessing the changes in an oil during frying use in industry (2). Probably the most common

method of measuring deterioration of a frying oil in restaurants is the change in the color of the oil. The frying oil finally reaches a point where it is no longer desirable for frying foods (3,4), and it has to be discarded or diluted with fresh oil.

A restaurant operator or industrial fryer is concerned about the cost and stability of an oil during frying and its effect on the fried food quality, particularly the flavor (5). The stability of the oil and its effect on the flavor of fried foods depend largely on the amount of unsaturated fatty acids present in the oil (2). Soybean oil, even when partially hydrogenated, to reduce the unsaturated fatty acids, produces fishy, painty odors when used for frying (6) and has been associated with less desirable flavor in fried foods (7). Yet, partially hydrogenated soybean oil (PHSO) generally costs less than other vegetable oils, and is considered more desirable for frying . Palm olein, an oil which contains a high content of saturated fatty acids, is widely used in countries other than the United States as a frying oil (8) and in some instances, when at a cost advantage, has replaced PHSO for frying of snack foods and industrial frying in the United States. However, little information is available concerning the flavor of foods fried in PHSO versus that fried in palm olein or on the stability of PHSO versus palm oil olein during frying. Also, both of these oils need further investigation as frying oils because of their low cost and availability. This investigation was undertaken to (1) determine the deterioration of partially hydrogenated soybean oil and palm olein during frying under controlled laboratory conditions and (2) to investigate flavor and acceptability of potatoes fried in these oils.

CHAPTER II

REVIEW OF THE LITERATURE

I. CHANGES IN OIL DURING FRYING

Deep-fat frying is a complex process because many factors are involved (3). The complexity of this process is illustrated in Figure 1. During deep-fat frying, the oils are exposed to high temperatures, moisture from the foods and oxygen from the atmosphere. Under these conditions, various chemical reactions, including hydrolysis, oxidation and polymerization, take place (4). As these chemical reactions proceed, both volatile and nonvolatile decomposition products form (9). The volatile compounds have been collected, fractionated and identified from different oils and from single fatty acids (10). Chang et al. (9) identified a total of 220 volatile decomposition products isolated during the frying cotton balls in corn oil. These volatile decomposition products form simultaneously with the nonvolatile decomposition products and are removed from the oils during frying by steam generated during the frying process (3). The nonvolatile decomposition products which consist of high molecular weight compounds are formed by thermal oxidation and polymerization of unsaturated fatty acids (11). These products accumulate in the frying oil and affect the quality of both the frying oil and the fried foods (12). The formation of the volatile and nonvolatile compounds in frying oils changes the physical and chemical characteristics of the oil.

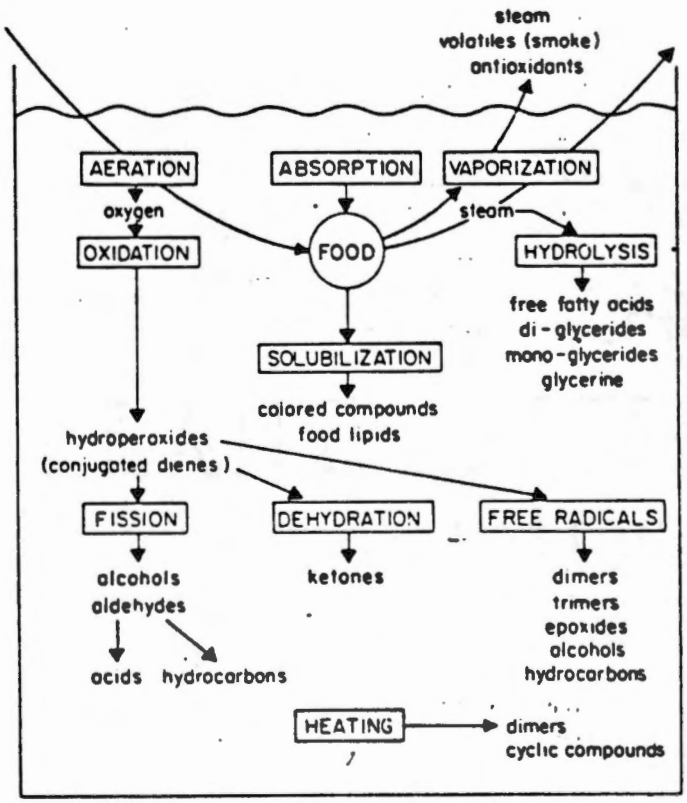


Figure 1. Processes and reactions occuring in frying oils during use according to Fritsch (3)

A. Chemical Reactions

1. Hydrolysis.

During frying, the temperature of frying and the moisture that is released from the fried food causes the hydrolysis of ester linkages with the formation of free fatty acids, mono- and diglycerides and glycerol (10). The free fatty acids are more susceptible to oxidative and thermal degradation than those still esterified with glycerol (13). Thus, higher levels of free fatty acids in an oil increase the possibilities of alteration of the oil characteristics during frying.

2. Thermal oxidation.

Both saturated and unsaturated fatty acids undergo thermal oxidative reactions. This process occurs via the formation of hydroperoxides which may decompose to form secondary products (10). According to Russel (14), oxidative decomposition is a major factor in the deterioration of frying oils. This process occurs under normal frying conditions as long as the oils are exposed to air.

a. Saturated fats. Saturated fatty acids and their esters are considered to be more stable than unsaturated ones (13). However, these fatty acids and esters when heated to temperatures higher than 150 C will undergo oxidative reactions and give the following products: carboxylic acids, 2-alkanones, n-alkanals, lactones, n-alkanes and 1-alkenes (10). A study on the thermal oxidation of a series of saturated triacylglycerols with even numbered C6 to C18 fatty acids was reported by Crnsar et al. (15) in which these compounds were heated in air for one hour at 180 or 250 C.

The volatile decomposition products were examined qualitatively and quantitatively. Their results showed that the oxidative pattern was similar for the same sample heated at the two temperatures, and that the volatiles consisted mainly of hydrocarbons, methyl ketones, alkanals and lactones. In their study, larger amounts of the decomposition products generally were formed at the higher temperature. They also showed that both fatty acid chain length and temperature of heating had a decided effect on the quantitative pattern of hydrocarbons formed. It is generally accepted that the principle mechanism in thermal oxidation of saturated fatty acids involves the formation of hydroperoxides and that oxygen attack occurs at all methylene groups in the fatty acids (16).

b. Unsaturated fats. Unsaturated fatty acids are much more susceptible to oxidation than saturated fatty acids (17). The principle mechanism involved in this process is via the formation of a hydroperoxide intermediate. Lomano and Nawar (18) studied the effect of heating temperature and time on the peroxide value of oils. In their study, they used three temperatures: 70 C at which the isomeric hydroperoxide intermediate could be characterized; 180 C, a typical frying temperature and 250 C, a temperature of severe heating. Their results showed that hydroperoxides were formed at all three temperatures. At the higher temperatures, however, the hydroperoxide decomposition occurred rapidly, resulting in a net peroxide value of 0 after heating at 250 C for 30 minutes. The relative quantities of the products of thermal oxidation were not only dependent upon the heating temperature but also on the length of time for which they were heated.

Unsaturated fatty acids, just like saturated fatty acids, produce several volatile products through thermal oxidation: saturated and unsaturated hydrocarbons, aldehydes and ketones, alcohols, lactones, hydroxy acids and aromatic compounds (9). The types and amounts of products formed during oxidation depend upon the level of unsaturation and temperature. The major volatiles isolated from oleate heated to 180 C for various lengths of time included heptane, octane, octanal, nononal, decanal, 2-decenal, undecenal and the corresponding alkyl heptanoate (10). The major volatiles isolated from ethyl linolenate heated for 5 hr at 250 C were pentane, hexanal, ethyl hexanoate, 2-heptenal, ethyl octanoate, t,c,-2,4-decadienal, t,t-2,4-decadienal, ethyl 8-oxo-octanoate, ethyl 9-oxo-octanoate, 2 pentyl furan and monoethyl octandioate (20). Heating ethyl linolenate at or above 180 for one hr or longer resulted in 9 major volatiles: ethyl furan, pentyl furan, ethyl heptanoate, ethyl octanoate, c,t-2,4-heptadienal, ethyl octenoate, t,t-2,4-heptadienal, ethyl 8-oxo-octanoate and ethyl-oxo-nonanoate. The major type of products found for each unsaturated fatty acid ester remained essentially the same when oxidized at various temperatures and for increasing lengths of time, but the concentrations of the volatiles changed. Oxidation of these unsaturated fatty acid esters at increasingly higher temperatures (70 to 220 C), however, caused major qualitative changes in the volatiles present in trace amounts (10).

The volatiles isolated from heated oils which are glyceride mixtures of these various fatty acids reflect the decomposition of their constituent fatty acids. Since most oils contain oleate and linoleate as their major

fatty acids, the volatile decomposition products isolated from these oils is similar to a mixture of oleate and linoleate (10)

Athough the volatiles produced during thermal oxidation of an oil are important to the flavor, they represent only a small portion of the total products produced (10). It is estimated that the volatile products formed during thermal oxidation account for only about 2% of the total products formed (10).

3. Polymerization.

Another chemical reaction that takes place during frying is polymerization. Polymerization of oils is the union of two or more molecules of fat to form a larger molecule. This union occurs at the double bond position of fatty acids, and thus, lowers the degree of unsaturation in oils. Two kinds of polymerization processes occur: the oxidative polymerization via free-radical mechanisms and the thermal polymerization which occurs in the absence of oxygen (10). Polymerization produces nonvolatile products which represent approximatly 98% of the product formed by thermal degradation. These nonvolatile products consist of oxidized monomers, dimers and polymers; nonpolar dimers and polymers and cyclic monomers, dimers and trimers (13).

B. Changes in Chemical Characteristics of Oils During Frying

Several chemical characteristics of an oil change when exposed to oxygen and moisture at the high temperature of frying; some of which are presented below.

1. Free fatty acid content.

The level of free fatty acids in an oil increases as the frying process proceeds. The formation of these acids is due to two important chemical reactions: hydrolysis and oxidation (10). Perkins (11) reported that free fatty acids are formed as a result of cleavage and oxidation of the double bonds in unsaturated fatty acids of oils. Nawar (10) reported that free fatty acids are also formed by hydrolysis of tricacylglycerols in the presence of heat and water.

2. Level of volatile compounds.

Nawar (10) reported that after the first 30 min of frying, the primary volatile oxidation products of fatty acids : saturated and unsaturated aldehydes, ketones, hydrocarbons, lactones, alcohols, acids and esters, can be measured by gas chromatography applied to the frying oil. The level of these volatiles, which depends upon the type of oil, the food and the heat treatment during frying, generally reaches a plateau value, a balance between their formation and evaporation or decomposition (10). Because of this plateau, the level of volatiles cannot be used as an indicator of the extent of deterioration or use of a frying oil.

3. Ultraviolet absorbance.

The absorbance at 232 and 270 nm of an oil is dependent upon the level of conjugated double bonds (dienes) and the level of alpha and beta unsaturated carbonyl compounds (13). During frying, the level of these dienes and carbonyl compounds increases in an oil because of oxidation (10), with accompanying increases in the absorbance at these wavelengths.

4. Polymer content.

Dimeric and polymeric acids and dimeric and polymeric glycerides are formed as a result of thermal and oxidative free radical combinations (10). Polymerization of these components in frying oils leads to a deposition of gums on various parts of the fryer (1). The level of these polymers in the oil generally increase with increasing use of a frying oil.

5. Level of polar compounds.

With increased use, a frying oil develops several types of polar compounds including free fatty acids, nonpolymeric polar compounds of moderate volatility (hydroxy- and epoxy acids), mono- and diglycerides, and cyclic monomers (10,13). These compounds also lead to an increase in the dielectric constant as previously described.

C. Changes in Physical Characteristics of Frying Oils

As a result of the chemical reactions that take place during the frying the physical characteristics of frying oils change.

1. Color.

During frying the color of the oil darkens. This color change has been attributed to the presence of unsaturated carbonyl compounds and to non-polar compounds of foodstuff solubilized in the fat (13). These unsaturated carbonyl compounds polymerize or enter into the nonenzymatic browning reaction resulting in the dark color (17).

2. Dielectric constant.

The ability of oils to transfer electrical energy increases during

frying due to the formation of polar compounds by hydrolysis and oxidation (13). These polar compounds include free fatty acids, mono- and diglycerides, carbonyl compounds, hydroxy- and epoxy fatty acids (10,13).

3. Viscosity and foaming ability.

During use, frying oils form polymers via oxidative and degradative reactions (20). As a result of these polymerization reactions, the density and viscosity of the oil increase which also increases the tendency of the oil to foam (13).

4. Smoke point.

The smoke point of an oil is that temperature at which an oil will emit a thin film of smoke (1). During frying the oil smokes because of evolution of volatile compounds. The smoke point decreases with increasing levels of volatile compounds from hydrolysis and oxidation reactions in the oil, particularly free fatty acids (23). The amount of smoke emitted from the fryer is dependent also upon the amount of volatile compounds present (13). Eventually, the smoke point will be lowered below the frying temperature if the oil is not diluted or replaced with new oil (1).

II. METHODS FOR MEASURING DETERIORATION OF FRYING OILS

Because the chemical reactions which occur during frying are very complex and various types of products are produced, there is no single reliable method used to measure the deterioration of an oil during frying. The frying operator faces the problem of deciding when to discard a frying oil. The decision requires good judgement and knowledge of the nature of

frying oils/fats, fried food and the frying operation.

For many years, the measurement of frying oil deterioration has been done by means of several physical and/or chemical measurements. These measurements are based on common methods, most of which have been standardized (22). These methods include the following.

A. Physical Measurements

1. Color measurement.

This method has been used in many studies to evaluate the deterioration of frying oil. Stevenson et al. (23) used the Hunter Color Difference Meter to measure the color change of soybean and canola oil during the frying of french fried potatoes.

2. Dielectric constant measurement.

The Food Oil Sensor reading (FOS) (24) is easily and quickly obtained and is based on the change in the dielectric constant of the frying oil (25,26). Smith et al. (27) evaluated the changes in the FOS reading of partially hydrogenatedd soybean oil during frying. They found a high correlation coefficient for the increase in the FOS reading related with % polar components (r=0.95) and with % free fatty acid (r=0.92). Paradis and Nawar (25) reported that the FOS reading is a simple method of measurement and represents the net balance between the polar and nonpolar components that develop in the oil during the frying process. Husain (28) used the FOS reading to measure the deterioration of palm olein and partially hydrogenated soybean oil during frying of potatoes and fish for 5

consecutive days. This researcher also found that FOS reading was highly correlated with other fast methods of measuring frying oil deterioration. In Husain's study, the FOS reading generally increased with increasing frying time but the amount of change for a given frying oil per unit time depended upon the type of food fried. Other researchers have reported that the amount of change in the FOS reading with frying time was also dependent upon the type of oil used (10).

B. Chemical Measurements

1 Free fatty acid measurement.

One of the most common measurements for frying oil deterioration is the determination of the % free fatty acids (29). The level of free fatty acids in frying oils before heating is important to the overall level developed during frying (3, 29). One of the criticisms of this method for measuring deterioration of a frying oil is that it cannot distiguish between free fatty acids formed by hydrolysis and those formed by oxidation, and that volatile free fatty acids are lost during frying (3,26). However, this measurement is used by many industrial frying operations as a quality control tool for their frying oil (30), and it has been found to be highly correlated with other methods for measuring deterioration (27,31). Husain (28) reported a correlation coefficient of 0.93 between % free fatty acids and level of total polar components in soybean oil and palm olein used to fry either potatoes or fish.

2. Petroleum ether insolubles.

This method, which is based on the premise that only unoxidized components in the frying oil are soluble in petroleum ether, is tedious (10). It is also inaccurate since some oxidized products in frying oils are soluble in petroleum ether. The German Society for Fat Research, however, used results of this method to define a "deteriorated" frying oil that should be discarded, and this definition has received international acceptance (10). A frying oil is "deteriorated" if the peteroleum ether insolubles (PEI) are >0.70% and the smoke point is less than 170 C, or if the PEI are >1.0% regardless of smoke point.

3. Total polar components.

Several investigators have shown across different frying oils that an oil containing 27% total polar components (TPC) is equivalent to a frying oil containing 1% PEI (3,10). The original method for determination of TPC involved determination of the weight of nonpolar components in frying oil after elution from a silica gel column with a petroleum ether-diethyl ether mixture. The % polar components were then calculated by difference.

The level of TPC in frying oils has been found to have high correlation with other measurements of frying oil deterioration by rapid methods (24, 26, 27, 30) and with hours of frying time (25). The silica gel column method for determination of % TPC is too time consuming to be used as a rapid measurement for frying oil deterioration; therefore, a more rapid method was developed (32). Levels of TPC determined by this rapid method are highly correlated with % TPC determined by the silica gel column method (r=0.99), and the rapid method has been used successfully to measure the %

TPC in restaurant and laboratory frying oils (33). The 27% level of TPC in frying oils is rapidly becoming an accepted standard for a "deteriorated" frying oil internationally (35), and TPC is an excellent measure for deterioration of the oils during frying.

III. STABILITY OF OILS DURING FRYING

The stability of oil during frying may be defined as its ability to keep a fresh taste and odor during storage and the frying process (10). The stability of a frying oil is dependent on many factors. The rate of physical and chemical changes in an oil during frying depend upon (a) the fatty acid composition, (b) the presence of additives, (c) the conditions of frying (temperature, exposure to oxygen, time of frying), (d) turn-over rate (amount of fresh fat added to the frying fat daily), (e) cleaning of fryer (f) filtration of the oil (g) type of foods fried and (h) fryer design (4). Factors c, d e, f, and h will be considered under a single topic of frying management practices and the other factors will be discussed separately.

A. Fatty Acid Composition

Fatty acid composition of frying oils plays an important role in the stability of oils during frying. The rate of oil degradation increases with degree of unsaturation (35). Oils like soybean oil and canola oil which are rich in linolenic acid are less stabile during frying than cottonseed oil and corn oil which are low in linolenic acid (10). Frankel et al. (36) reported

that during frying, hydrogenated soybean oil, which contained 2.4% linolenic acid, had significantly lower odor intensity scores than unhydrogenated soybean oil which contained 7 to 9% linolenic acid. Landers and Rathman (37) reported that partial hydrogenation of soybean oil increased it's stability to oxidation. This same conclusion was reached by Warner et al. (38) after studying the effects of hydrogenation on the room odor of soybean cooking oils. Evans et al. (39) reported that hydrogenated soybean oil had significantly better room odor scores than those for soybean salad oils. All of these reports show what has already been reported in this reveiw, saturated fat is more stabile to thermal oxidation than unsaturated fat.

B. Additives

1. Antioxidants.

Synthetic antioxidants when added to oils at ambient temperature retard oxidation (1), but at frying temperatures, they are less effective (40,41). Antioxidants volatilize during frying (41). Frankel et al. (36) found that the stability of soybean oil to thermal oxidation was improved by addition of tertiary butyl hydroxy quinone (TBHQ). Asap and Augustin (42) also found that addition of TBHQ improved the stability of palm oil during frying and improved the shelf-life of the fried potato crisps.

The use of naturally occurring antioxidants, tocopherols, to improve the quality of frying oils has been studied also. Conflicting results were reported in the literature concerning the stability of tocopherol at frying temperatures. Gordon and Magos (43) reported that tocopherol was

inactivated as an antioxidant by the high temperature of frying. On the other hand, Sakata et al. (8) showed that the stability of palm oil during frying was increased when tocopherol was added.

2. Silicone.

Silicone is commonly used to improve the quality and stability of frying oils (36, 37, 44, 45). It acts as an oxygen barrier for the oil by forming a protective film at the air-oil interface (46,47). Sakata et al. (8) in their study on the quality of fried foods in palm oil reported that silicone added to palm oil prevented foaming and oxidation during frying. Freeman et al (46) reported that the frying stability of sunflower oil was improved by adding methyl silicone.

C. Characteristics of Fried Food

The kind of food fried affects the thermal stability of frying oils. Food rich in lipids reduces the thermal stability of oils during frying due to the diffusion of fats from the food to the frying oil (1, 37). McGill (20) reported that food such as fish or chicken, when fried, reduced the stability of frying oil because the unsaturated fats diffuse from the food into the frying oils during cooking. Any barrier interferring with this diffusion such as battering of the food, can improve the stability of the frying oil (48).

D. Management Practices

Proper handling of oils during frying is necessary to have the

maximum thermal stability of the oils. Many factors must be controlled.

1. Temperature of oil and frying load.

The temperature of the frying oils should always be lower than 196 C since higher temperatures reduce the stability of the oil. In addition, when the oil is not being used for frying for fairly long periods of time, the temperature should be reduced 50 to 100 C to protect from oxidation (1). The amount of food fried at one time also influences the temperature of frying. An overloaded frying kettle requires a higher temperature of frying in order to cook the food, thus increasing the breakdown of the frying oil (29). To maintain maximum frying oil stability, it is necessary to fry the appropriate amount of food for which the frying kettle was designed and maintain the appropriate frying temperature.

2. Oil exposure to oxygen.

Aeration of oils results in faster deterioration by oxidation. Peers and Swaboda (49), who studied sunflower oil, as a frying oil reported that exposure of the oil to oxygen during frying resulted in faster deterioration than when it was protected from the air. During frying, the surface of the oil was covered by a blanket of steam which reduce its exposure to oxygen (1).

3. Oil rotation or turn-over rate.

Continuous heating of oils results in rapid deterioration; however, this level of deterioration can be controlled if fresh oil is added to the frying oil at regular intervals. In a restaurant that uses frying as a major method of cooking food, many fryers will be used. In these situations, frying oil is rotated from one fryer to the next fryer according to a

predetermined pattern, with oil being discarded weekly from specified fryers (5). In addition, if oil is judged to be deteriorated during the week in any of the fryers, it is common practice to replenish that fryer with oil from another fryer in that pattern of oil rotation. During frying, the fried food absorbs the oil; therefore, replenishment of the frying oil will be needed the most in fryers that fry the largest amount of food. Robertson (48) defined the turn over rate as the total amount of fat in the fryer to the rate at which fresh fat is added to the fryer. The higher the turn-over rate, the less deteriorated the frying oil. The proper turn over rate will keep the level of free fatty acids in the oil low and replace the silicone which is lost by oil absorption and degradation. Weiss (1) reported that a daily turn-over rate of 15 to 25% is desirable to maintain high quality frying oil.

4. Fryer capacity and design.

A fryer of the correct size, shape and design for the type and amount of food to be fried should be used in every frying operation to maintain high quality frying oil (29). A fryer with the smallest surface to volume ratio will improve the stability of frying oil because it reduces the exposure of the oil to air at high temperatures (29). Fryers that can increase oil temperature rapidly (quick-recovery fryers) also allow the oil temperature to be reduced during slow periods of business in a restaurant and then be returned quickly to frying temperatures when needed (1). This reduction in temperature increases the life of a frying oil. A well-designed fryer will also have fry baskets of such size that it will not be overloaded with food if they are half filled (1).

5. Cleaning.

Daily cleaning is important to maintain stability of frying oils. This involves removal of the plymerized fat or "gums" from the fryer (1). In normal practice in a restaurant, however, fryers are completely cleaned (boil-out) once a week (5). Boil-out of fryers is accomplished by boiling the equipment in a solution of alkaline cleaning compound, followed by a water rinse, a dilute acid (vinegar) rinse and a final water rinse (1).

6. Oil filtration.

Perhaps more important to the stability of a frying oil than daily cleaning, is daily filtration of the frying oil (1). Filtration of the frying oil removes particles of food which have accumulated during frying. If these particles of food are not removed, they burn. The burnt particles increase the deterioration rate of the frying oil. Filter-aids should also be used (1). Filtration with a filter aid reduces the content of free fatty acids and color bodies and can increase the frying life of an oil by 50 to 90% (50).

IV. CHANGES IN FOODS DURING FRYING

A. Water Loss and Fat Absorption

In deep-fat frying, fats or oils act as a heat transfer medium to cook the food quickly and efficiently. The frying oil also is absorbed by the fred food and affects the quality (1). In order to understand the chemistry of water loss and exchange for frying oil, it is necessary to describe the structure of fried food. According to Robertson (51), the fried food consists

of three zones: the outer, crust and inner zones (Figure 2).

The outer zone surface is the brown color resulting from the nonenzymatic browning or "Maillard" reaction. The crust zone is formed on the food by dehydration of the outer parts of foods during frying. This zone starts to form when the frying temperature reaches 100 C and some of the water contained in the food is evaporated. At this point frying oil starts to enter the food and occupy the space created by the water loss. The levels of oil and water in this area depend on the kind of fried food. For example, in fried potatoes. this zone contains approximately 10% oil and 3% water (13). The inner zone or "core" is a cooked moist area consisting of whatever food constituents are deep fried. The cooking in the inner zone is done by heat penetration, and the texture and flavor change here is due to the effect of heat on food itself, and not to the fat absorbed (51).

B. Flavor Formation

The flavor of food is an important quality for the consumers and of deep concern to the producers. As a result of water evaporation from the fried food and the penetration of oil into the food, the frying oil reacts with protein and carbohydrate components of the food forming a flavor which is especially attractive to consumers (1). Chang et al. (52) reported that the flavor of deep-fat fried foods is partly due to the volatile decomposition products which are formed during deep-fat frying from the frying shortening, the food and the interaction between the two.

Maga and Sizer (53) studied the the effect of temperature and frying

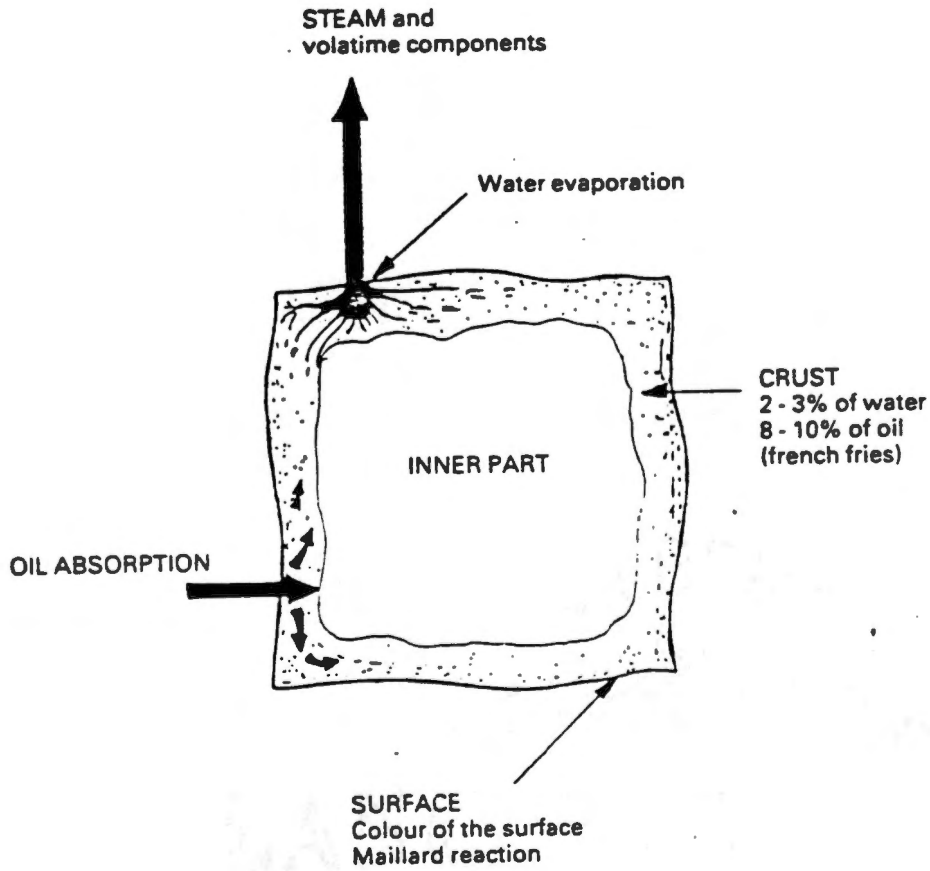


Figure 2. Zones of fried food according to Butierrazet et. al (13)

time on the flavor of potato chips. Their results showed the frying temperature had a greater effect than the time of frying. Robertson and Morrison (54) determined the effect of three frying oils, sunflower, cottonseed and palm oil, on the flavor score of potato chips . They reported that oils did not affect the flavor score of the chips significantly. In another study, Robertson et al. (55) fried potato chips in a partially hydrogenated sunflower oil and a cottonseed-corn oil mixture and then evaluated the flavor by a sensory panel. Again, there was no significant difference found in the flavor of chips between the two frying oils.

C. Fat Composition of the Fried Food

Many studies reported in the literature have been concerned with the lipid changes that occur in food during frying. Thompson and Aust (56), in a study in which potatoes were fried in partially hydrogenated soybean oil, determined the lipid changes in the heated oil and in the fried potatoes over a frying period of many hours, during which the frying oil was replenished three times. Their results showed that the level of polyunsaturated fatty acids decreased in both oil and fried potatoes with increasing frying time and that the amount of food fried had a greater influence on changing the lipid composition of the frying oil and fried food than hours of frying. Stevenson et al. (23) showed that fat extracted from french fried potatoes was identical in composition to that of the frying fat.

V. THE FLAVOR OF FRENCH FRIED POTATOES

Flavor is the sensation produced by a food taken in the mouth, perceived mainly by the sences of taste and smell, and also by the pain, tactile and temperatures found in the mouth (21). Flavor is also defined as all the volatile chemical compounds in a food product that cause that sensation (21). The flavor of fried potatoes is produced mainly during frying by lipid oxidation and nonenzymetic browning reactions (17) and is dependent largely on the flavor of the frying oil (10). Only two studies have been conducted on the flavor of fried potatoes. Vallese (57) identified the flavor volatiles of french fried potatoes from McDonalds. In that study, the flavor volatiles of the potatoes were fractionated into 8 fractions by gas chromatography and each single fraction further separated by a second gas chromatographic procedure. Vallese (57) reported 85 compounds in the flavor volatiles of potatoes with pyrazines and unsaturated carbonyl compounds being the most common types of compounds. Carlin (58) also investigated the flavor of McDonald's french fried potatoes. In this latter study, the volatile flavor compounds from the potatoes were divided into two groups. The first group of compounds contained pyrazines, furans, pyridines, thiazoles, oxazoles and sulfides, all compounds formed by nonenzymetic browning reactions. The second group of compounds contained aldehydes, ketones, acids, alcohols, esters, and lactones which are formed from the interaction of frying fats and potatoes or from the frying fat alone. The first group of compounds was reported to be formed from constituents in the potato itself and was considered responsible for the potato flavor in

the french fries. The second group of compounds gave rise to the fried food flavor in the potatoes. Overall, oxazoles and thiazoles were postulated to be the most significant compounds contributing to the total flavor of french fried potatoes.

CHAPTER III

MATERIALS AND METHODS

I. EXPERIMENTAL PROCEDURES

A. Materials

Three kinds of frying oils, palm oil olein and two partially hydrogenated soybean oils (see manufacturer's specifications, Table 1) were obtained from a fat/oil processor in Tennessee. Prior to the beginning of the experiment, the entire lot of each oil was mixed thoroughly to ensure homogeneity and stored in sealed plastic containers until it was used. Frozen parfried potatoes were obtained from a wholesale company in Knoxville, TN. The potatoes were 0.95 cm straight cuts which had been partially fried. The parfried potatoes were stored at -18 C until fried.

B. Experimental Design

A single replication in this experiment consisted of the 3 frying oils used simultaneously for discontinuous frying of potatoes for 8 hrs per day for 4 consecutive days, during which samples of each oil were obtained for physical and chemical analyses at the end of each day of frying, and potatoes fried in each oil at the beginning of the first day and near the end of each day were evaluated for flavor acceptability. Two replications were

Table 1. Frying oil specifications.

Specification	Palm Olein	Soybean Oil "A"	Soybean Oil "B"
Color, Lovibond, Red max.	3.5	1.0	1.0
Free fatty acid, % max.	0.05	0.05	0.05
Iodine values		94.00	102.00
AOM stability, hrs, min.	50.00	40.00	35.00
Solid fat index,			
10.0 C^0		3.00	
21.1 C^0		0.03	2.50
26.7 C^0	2.0		1.00

[a]Specifications obtained from the manufacturer.

completed. A different lot of parfried potatoes was used for each replication, but a single homogeneous lot of each oil was used for both replications.

In addition to the analysis of oil samples and sensory evaluation of potatoes fried in the three different oils, the flavor volatiles of the second batch of potatoes fried in each oil on the first day and from the last batch of potatoes fried in each oil on the 4th day of frying were analyzed.

C. Frying Procedure

At the beginning of the first day of frying a 200 g sample of each oil was obtained and 2620 g of each of the 3 oils were put in separate household fryers (Dazey Chef's pot size 4 liter) and heated to 190 C. One hr after the heat was turned on for each fryer, 400 g of frozen parfried potatoes were fried for 5 min in each fryer, after which they were removed from the oil, and excess oil from the potatoes drained back into the fryer. The oil temperature in each fryer, which dropped slightly during the frying of the potatoes, was returned to and maintained at 190 C until the next batch of potatoes was fried. In each fryer, a 400 g batch of parfried potatoes was fried every hour for 8 hrs per day for 4 consecutive days. At the end of each day, the oil was cooled to 91 C and filtered through pure cotton in an Econoline filter cone to remove food debris. A 200 g sample of each oil was taken from the filtered oil for chemical and physical analyses, and the remaining oil was supplemented with fresh oil to a weight of 2620 g which was returned to a cleaned fryer for subsequent frying the next day.

D. Analysis of Oil Samples.

All oil samples were kept in sealed glass bottles under a nitrogen atmosphere at -18 C until analyzed. The oil samples were analyzed for color, free fatty acid (FFA) content, Food Oil Sensor (FOS) reading, and level of total polar components (TPC). Only fresh oil samples were analyzed for fatty acid composition.

The color of each oil sample was measured in the transmission mode of a Color-Eye Model D-1. After The X, Y and Z values were set to 100% using the fresh oil sample as the standard according to the method of Stevenson et al. (4), the X, Y and Z values of each used frying oil sample were measured. The Hunter Color "L", "a" and "b" values and total color change, ΔE, were calculated from the X, Y and Z values (21).

The FOS readings which are based on changes in the dielectric constant were measured using the Food Oil Sensor, Model NSI-20. The Food Oil Sensor was set to 0 using as a standard the fresh oil sample that was the same as the used oil samples to be measured according to the method of Fritsch et al. (26).

The FFA content of each oil sample was determined by an AOCS method (22) as the percentage of oleic acid in the sample. Total polar components of each oil sample were measured using the rapid method of Melton and Sykes (32). The fatty acid composition of each fresh oil was determined by an AOCS (22) method. Methyl esters of the fatty acids (FAME) were analyzed on the Shimadzu model 6 AM GC equipped with a FID, a

Shimadzu model E1A integrator, and a 30 m x 0.25 mm i.d. SP2330 fused silica capilliary column. Analysis of the FAME was performed during a temperature programmed run from 150 to 220 C at 2 C/min with injector and detector temperatures at 250 C.

E. Sensory Evaluation

The first batch of potatoes fried in each oil on the first frying day and the next to last batch of potatoes fried each day were used for sensory analysis. The potatoes were kept warm under heat lamps until evaluated by a 32-member untrained panel. Samples of potatoes (2 pieces) fried in each of the three frying oils were coded with randomized numbers, and were served one at a time in random order to a single panelist. Samples served under a white light were evaluated for flavor on a 7-point hedonic scale (see Appendix A) where 7 = extremely desirable flavor, 6 = very desirable flavor, 5 = moderately desirable flavor, 4 = slightly desirable flavor, 3 = slightly undesirable flavor, 2 = very undesirable flavor, and 1 = extremely undesirable flavor (59).

The panel was divided into two types of panels: A and B, based upon their scores for the flavor and acceptability of foods fried in soybean oil versus those fried in palm olein.

F. Flavor Volatile Extraction

The potato samples collected for volatile analysis were stored in sealed heavy polyethylene freezer bags under nitrogen at -30 C until analyzed. The volatiles were isolated from 150 g of potatoes in the following manner. The potatoes were blended for 5 min on a high speed in an Osterizer blender with 700 ml of 60-70 C HPLC grade water to which 1 ml of methanol solution containing 1 mg of methyl palmitate was added as an internal standard. The aqueous potato slurry was poured into 1000 ml round bottom flask with a side tube for nitrogen delivery to the center of the flask, and the flask was connected to a simultaneous distillation extraction (SDE) apparatus. Nitrogen was bubbled through the slurry to prevent oxidation of the sample during extraction. The slurry flask was placed in a 125-130 C oil bath, and a 125 ml Erlenmeyer flask containing 45 ml of HPLC grade methylene chloride was connected to the SDE apparatus for extraction of the volatiles (60). The volatiles were extracted for 2.5 hr after which the slurry flask was removed from the hot oil bath. After the apparatus cooled for 30 min, the methylene chloride extract containing the volatiles was collected. One ml of a methylene chloride solution containing 0.1 mg of pyragallol was added to the volatile extract, and it was cooled to 0 C before concentration to 1.0 ml volume by solvent evaporation into a trap cooled by liquid nitrogen in a low flow of nitrogen under vacuum (61). At the end of each sample extraction, the apparatus was steam cleaned for 2 hrs using the same conditions as described for volatile extraction except 700 ml of HPLC grade water was placed in the round bottom flask instead of a potato slurry.

All glass ware that was used in the volatile extraction was cleaned using the procedure given in Table 2. A blank using 700 ml HPLC grade water was run after extraction of 3 potato samples to determine possible artefacts.

G. Qualitative and Quantitative Analysis of The Volatiles

Volatiles in each sample were qualitatively analyzed on a Shimadzu Model 9AM gas chromatograph containing a 30 m by 0.25 mm i.d. fused silica SP2330 capilliary column (Supelco, Inc.) directly interfaced with a Shimadzu QP 1000 mass spectrometer (GCMS analysis). The volatiles were quantitatively analyzed on a Shimadzu Model 6AM gas chromatograph containing a like column attached to a flame ionization detector (GC-FID). Conditions for GCMS and GC-FID are given in Table 3.

A tentative identification of a volatile was made by matching its mass spectrum with that of a known compound via a computer search of a library of mass spectra. Positive identification included matching the retention time (RT) and the mass spectrum of an unknown volatile compound with the respective RT and mass spectrum of a known compound analyzed under exactly the same conditions as the sample volatile.

For each sample, a volatile peak was identified as being the same compound on the GCMS and GC-FID chromatograms, when its relative retention time (to methyl palmitate) was the same on both chromatograms. The concentration of each volatile was determined in mg equivalents of methyl palmitate/150 g potatoes by dividing the volatile peak area by the

Table 2. Cleaning procedure for glassware used in volatile extraction.

Procedure	Solution
Wash	Soap and warm water
Rinse	Distilled water
Rinse	Acetone
Rinse	HPLC grade water
Rinse	4% Glacial acetic acid
Rinse	HPLC grade water

Table 3. Conditions for GCMS and GC-FID analysis of fried potato volatiles.

GC variable	Type of analysis	
	GCMS[a]	GC-FID[b]
Injector temperature, C	210	230
Detector time, C	250	230
Column initial temperature, C	25	65
Initial hold time (min)	2.5	0
Temperature rate increase degree C/min	2	2
Column final temperature, C	220	220
Final hold time (min)	30	30
Carrier gas	helium	helium

[a]Ion source was 250 C with an energy of 70 eV, and samples were run in splitless mode using a Grob splitter.

[b]Samples were run using a 30:1 split.

peak area for methyl palmitate from the GC-FID analysis. The relative response ratio of each volatile to methyl palmitate was assumed to be 1.00.

II. STATISTICAL ANALYSIS

All Hunter color values, FFA content, FOS reading, and TPC level, were analyzed as a function of frying oils (Soybean A, Soybean B and palm oil olein), time of frying oil use (0, 1, 2, 3 and 4 days), their interaction and replication. Concentration of volatile compounds were analyzed as a function of the same independent variables except time only had 2 values, 0 and 4 days. Significantly different ($P<.05$) means among the oils were separated by the Student-Newman-Kuhls (SNK) test (62). Significantly different means among times were separated by orthogonal polynomials, and equations were obtained using the general linear model (GLM) program in SAS (62). A graph of each equation was constructed to show these significant differences across 0 to 4 days. When significant interactions ($p<.10$) were found, the variables were analyzed as a function of time for each oil, and equations were obtained by GLM showing the significant time effect ($p<.05$) for each oil.

Flavor scores of each fried potato sample were averaged for the total panel of 32 members, for panel A, a 15 member panel, and for panel B, a 17 member panel. The average flavor score for each panel was analyzed statistically as a function of oil, time of frying and their interaction. Significantly different means ($p<.05$) among oils or times were identified by the Student Neuman Kuhls (SNK) test. When significant interactions ($p<.10$)

were found, the scores were analyzed as a function of time for each oil by orthogonal polynomials as described previously.

The concentration of each potato volatile was also analyzed statistically as a function of oils, time of frying (0 and 4-days) and their interaction. Significantly different means among oils or among times ($p<.10$) were identified as described for the flavor score with significant interactions treated in same manner also except orthogonal polynomials were not used to separate means among time since 2 times were evaluated. Correlation coefficients were obtained between the flavor desirability score from each type of sensory panel and the concentration of each flavor volatile.

CHAPTER IV

RESULTS AND DISCUSSIONS

I. PHYSICAL AND CHEMICAL ANALYSIS OF USED FRYING OIL

A. Color

Sums of squares for the effects of frying oil and time of frying oil used on the change in Hunter color values and total color change, ΔE, of the frying are presented in Table 4. Both "a" and "b" values and ΔE were significantly affected by the type of frying oils and time of oil use, but not by their interaction. Replication was significant for "a" and "b" values and ΔE. The Hunter "L" value was significantly affected by time but not by the interaction, oil x time, or oil type ($P<.05$).

The Hunter color values and ΔE averaged across time of use for three oils are shown in Table 5. Palm oil olein had greater positive "a" and "b" values and ΔE than did soybean oil B but not soybean oil A ($P<.05$). The "a" value and ΔE of soybean oil A were not significantly different from that of soybean oil B, but the "b" value of soybean oil A was greater than that of soybean oil B. Generally, these results show that during frying, palm oil olein (PO) when compared to partially hydrogenated soybean oil (PHSO) became darker, more yellow and redder. This is in agreement with other researchers (63, 64) who reported, that upon heating, palm oil color darkens more quickly than other oils. This rapid color darkening is the result of

Table 4. Sums of squares from the analysis of variance of color of frying oils as a function of oil type and time of frying oil use.

Source	Degrees of freedom	Hunter color values L	a	b	ΔE
Oil (O)	2	49.84	23.02*	87.64*	109.21*
Time (T)	4	1088.19*	625.80*	3376.23*	5138.06*
Time	1	1085.17*	620.39*	3288.96*	5072.86*
$Time^2$	1	.31	.83	83.12*	56.83*
$Time^3$	1	.43	4 34	3.53	7.08
$Time^4$	1	2.281	0.24	0 61	1.28
O x T	8	25.03	10.76	29.65	31.46
Rep	1	39.74	19.15*	71.65*	127.94*
Error	14	146.88	28.13	57.64	103.41
Total	29	1349.68	706.86	3622.81	5510.09

*Significant at the P< 05 level.

Table 5. Hunter color values and change in color, ΔE, averaged across time of frying oil use for each type of frying oil.

Color	Frying oil		
	Palm olein	Soybean oil A	Soybean oil B
Hunter color			
"L" value	89.7	92.8	91.8
"a" value	7.9[a]	7.0[ab]	5.8[b]
"b" value	18.6[a]	18.0[a]	14.7[b]
ΔE	22.7[a]	20.6[ab]	18.0[b]

[ab]Means (n=10) in a row bearing unlike superscript letters are significantly different at the P<.05 level.

formation of high molecular weight compounds rather than the carotenoids (64), and Tan et al. (63) reported that phenolic compounds were responsible for this color darkening in heated palm oil. Tan et al. (63) also reported that these phenolic compounds might be from the tannins found in palm fruit which are pressed out with the crude palm oil and not removed completely by subsequent processing. Upon heating, these compounds polymerize to form the dark color. The color of the oil during frying is one of the most often used quality tests by fast-food restaurants today (65). When the oil reaches a given color such that the frying operator cannot see the bottom of the fry basket inserted in the fryer, it is either diluted with fresh frying oil or discarded. The greater color change of palm oil olein with heating could cause the palm olein to be discarded prematurely by such restaurants and might be a problem if palm oil were used widely as a frying oil in the United States.

The Hunter color "L", "a" and "b" values and ΔE are shown as a function of time of frying oil use in Figures 3, 4, 5, and 6 , respectively. The "L" value of the oils decreased linearly and the "a" value increased linearly across time as shown in Figures 3 and 4, respectively. The "b" value and ΔE increased quadratically across time as shown in Figures 5 and 6, respectively. During the frying process, the color of all frying oils changes from a light color to a dark brown. These changes are due to a combination effect of oxidation and polymerization of fatty acids and increase in level of soluble brown melanoidine pigments from the fried foods and other factors (63). These color changes are the reason for the decrease in the "L" values and increase in "a" and "b" values and ΔE across time of frying oil use.

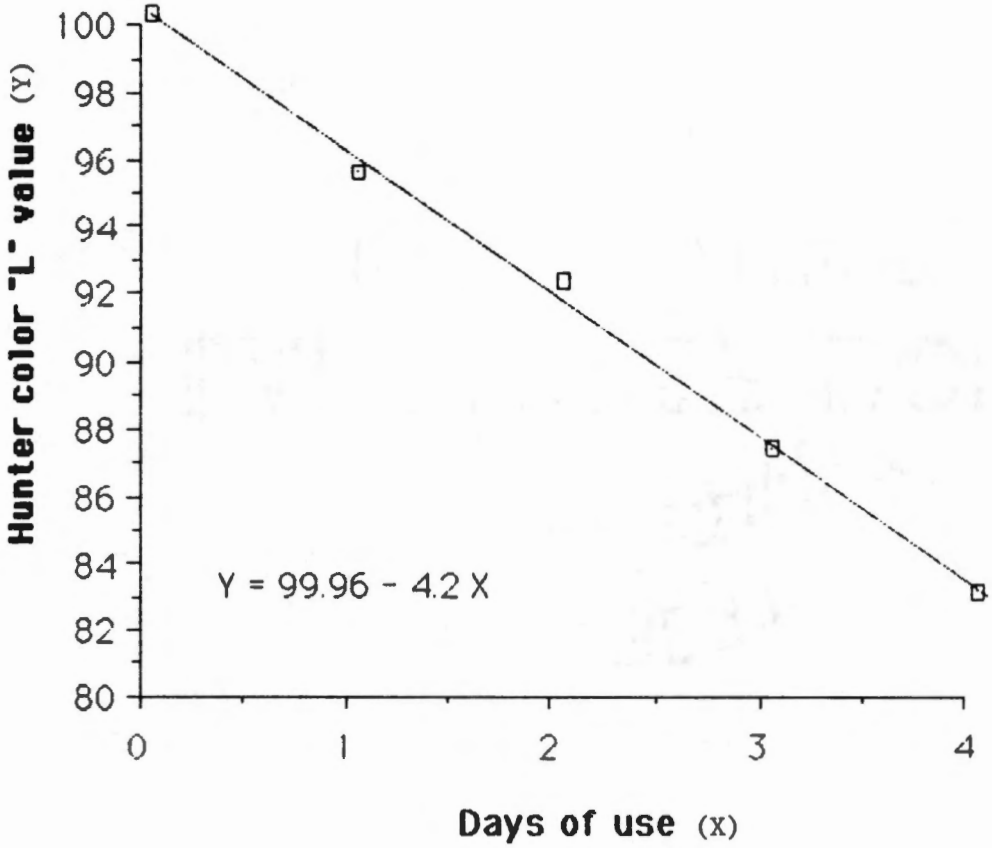


Figure 3. Mean (n=6) Hunter color "L" value of frying oil as a function of days of frying oil use.

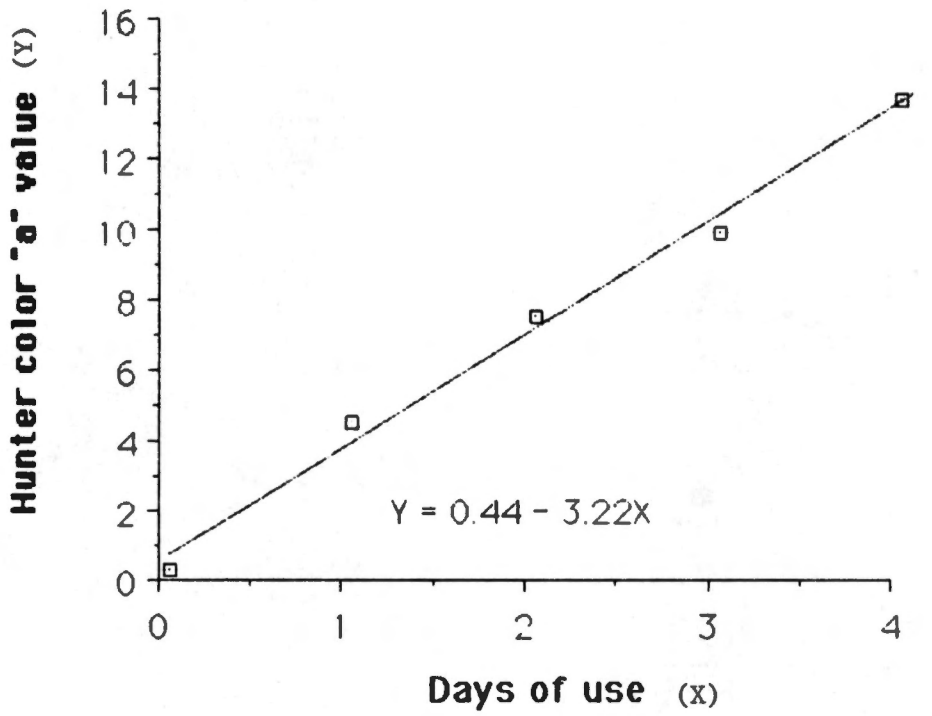


Figure 4. Mean (n=6) Hunter color "a" value of frying oil as a function of days of frying oil use.

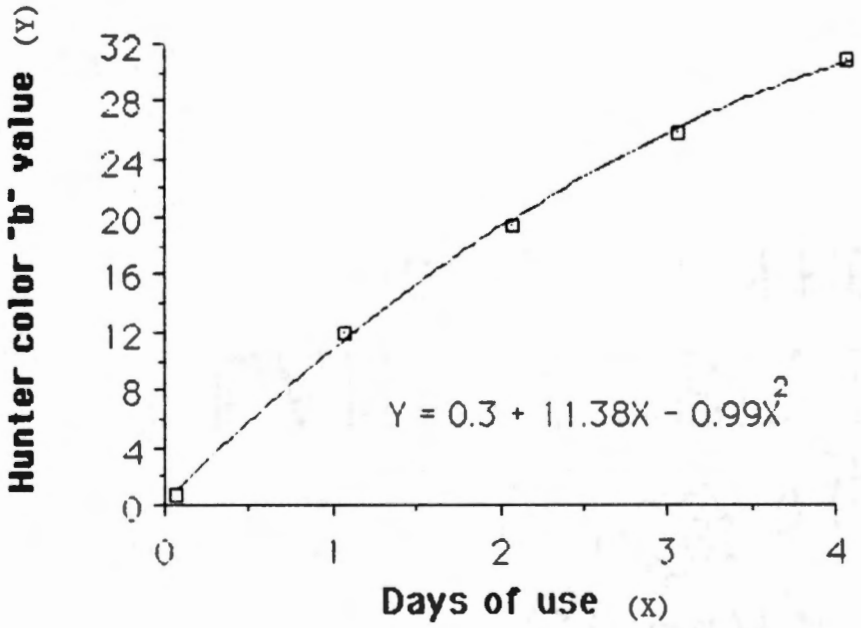


Figure 5. Mean (n=6) Hunter color "b" values in frying oil as a function of days of frying oil use.

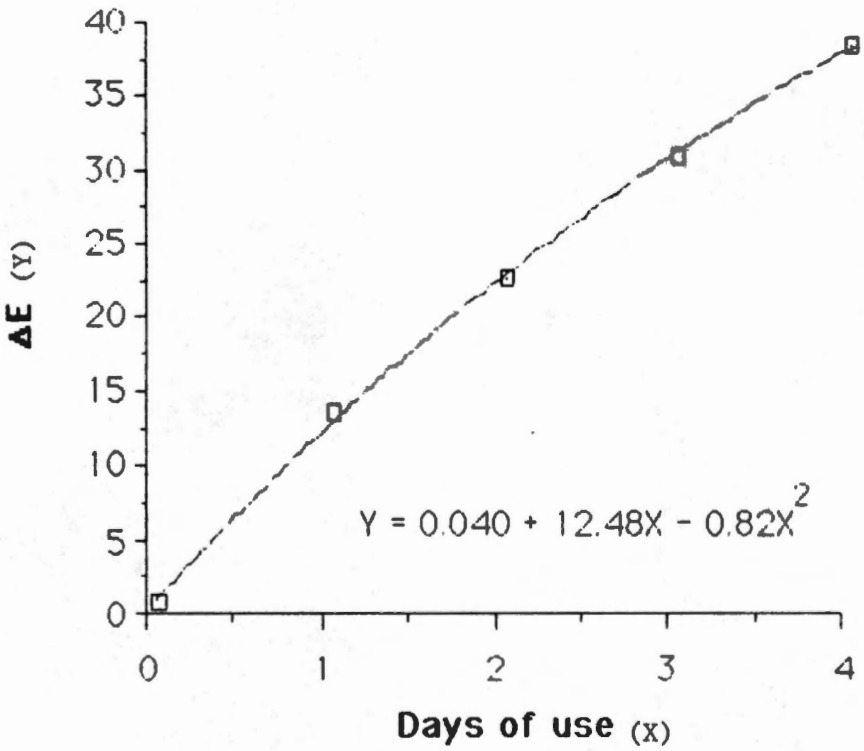


Figure 6. Mean (n=6) color change (ΔE) of frying oil as a function of days of frying oil use.

B. Food Oil Sensor Reading

The analysis of variance for the effects of the type of oil and time of frying oil use on the Food Oil Sensor (FOS) reading is presented in Table 6. The FOS reading which is based on the dielectric constant of the oil was not affected by the type of frying oil, but it was affected significantly by time ($p<.05$). Mean values of the FOS reading averaged across time for each oil are presented in Table 7. The mean FOS values averaged across oil are plotted as a function of days of oil use in Figure 7. There was a significant cubic relationship (Table 6) between the FOS reading and the time as shown in Figure 7. Generally, the FOS reading increased during the 4 days of frying oil use. This increase in FOS value can be explained by the fact that many chemical reactions take place during the process of frying. These include hydrolysis, oxidation and polymerization (66). As a result of these reactions, the percentage polar components increases in the oils with accompanying increases in the dielectric constant or FOS reading of the oil with increased time of use. Paradis and Nawar (25) reported that oxidation products were primarily responsible for the change in the FOS reading and that the level of total polar components had the highest correlation with FOS reading of all measurements for frying oil deterioration during frying in their study. The FOS reading or dielectric constant is most useful when the frying time is the only variable (27). Wu and Nawar (67) reported that FOS readings are influenced by several factors, and caution must be taken when this method is used to evaluate the quality of frying oil.

Table 6. Sums of squares from analysis of variance of physical and chemical characteristics of frying oils as a function of type of oil and time of use of frying oil

Source	Degrees of freedom	FOS[a] reading	Free fatty acids,%	TPC[b], %
Oil (O)	2	0.0156	0.4288*	103.24*
Time (T)	4	10.6407*	6.3857*	386.90*
Time	1	10.2259*		383.04*
Time^2	1	0.3207*		3.86
Time^3	1	0.0928*		0.00
Time^4	1	0.0013		0.00
O x T	4	0.0725	0.166*	12.04
Soybean A				
Time	1		2.064*	
Time^2	1		0.116*	
Time^3	1		0.004	
Time^4	1		0.004	
Palm olein				
Time	1		2.926*	
Time^2	1		0.026	
Time^3	1		0.001	
Time^4	1		0.000	
Soybean B				
Time	1		1.368*	
Time^2	1		0.040*	
Time^3	1		0.002	
Time^4	1		0.001	
Rep	1	0.0701	0.0001	1.24
Error	14	0.1855	0.0971	38.78
Total	29	10.9843	7.0780	542.21

[a]Food oil sensor reading
[b]Total polar components

*Significant at the P<.05 level.

Table 7. Food Oil Sensor readings and contents of free fatty acids and total polar components averaged across time of frying oil use for each type of frying oil.

	Frying oil		
Characteristic	Palm olein	Soybean oil A	Soybean oil B
Food Oil Sensor (FOS) reading	1.0	1.0	1.0
Free fatty acid content, % FFA	0.74[a]	0.55[b]	0.45[c]
Total polar component content, % TPC	10.79[a]	7.07[b]	6.67[b]

[abc]Means (n=10) in a row bearing unlike superscripts are significantly different at the $P < .05$ level.

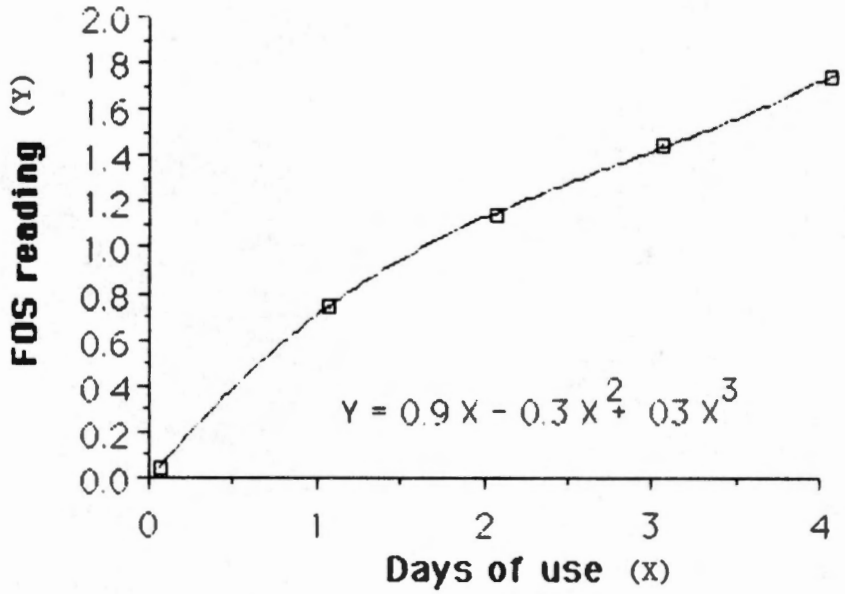


Figure 7. Mean (n=6) Food Oil Sensor (FOS) reading of frying oils as a function of days of frying oil use.

Fritsch et al. (26) reported a linear relationship between the FOS readings of hydrogenated vegetable shortening and hydrogenated animal-vegetable shortening with the frying time. In the present study, a cubic relationship was found between FOS value of the frying oil and time of oil use, but the FOS reading generally increased with increasing time. The frying fats in the study of Fritsch et al. (26) were not replenished with fresh fat during use; however, in the present study the frying oils were replenished with fresh oil at the end of each day. Husain (28) generally found an increase in dielectric constant of palm olein and soybean oil with increasing frying time; however, replenishment of the used oil with fresh oil caused a decrease in the FOS reading. In another study, Wu and Nawar (67) also found that the FOS reading decreased after replenishment of the used oil with fresh oil.

In general, the FOS reading is easy to obtain and within limits can be a good measure for deterioration of frying oils. While it has been reported that it is most useful as measuring the deterioration of a single oil during frying (67), no significant differences were found among the frying oils of the present study for the FOS reading.

C. Free Fatty Acid Content

The analysis of variance for the effects of type of oil and time of frying on the percentage free fatty acid of frying oils is presented in Table 6. There was a significant difference in the free fatty acid content due to type of oil, time and their interaction ($p<.05$). The mean percentages of FFA

averaged across time of use for each oil are presented in Table 7. Across frying, palm oil olein developed a higher level of free fatty acid than soybean A or B. Soybean oil A had a higher level of FFA than soybean oil B. The average percentage free fatty acid for each frying oil as a function of time of oil use is presented in Figure 8. For each oil, the % FFA generally increased across time of frying oil use. There was a quadratic relationship between % FFA of palm oil olein and soybean oil B and days of frying, and a linear relationship between % FFA of soybean oil A and days of frying (see Figure 8).

Several studies have been reported in which the % FFA has been shown to increase with frying time (17, 26, 28, 68, 69, 70). Reasons for higher levels of FFA forming in palm olein than in soybean oil are not known. However, Husain (28) also found that palm olein developed higher levels of FFA than soybean oil during laboratory frying of potatoes and fish. Stevenson et al. (23) reported a linear relationship between % FFA and frying time during the performance of soybean oil and canola oil. Bracco et al. (68) who fried potato slices in either palm oil liquid fraction or peanut oil also found a linear relationship between % FFA and time of frying.

D. Total Polar Components

Levels of total polar components (TPC) were significantly affected by type of oil used and time of frying but not by their interaction (see Table 6). The mean values for TPC averaged across frying time for each oil are presented in Table 7. Palm oil olein had the highest % TPC (10.80) of all 3

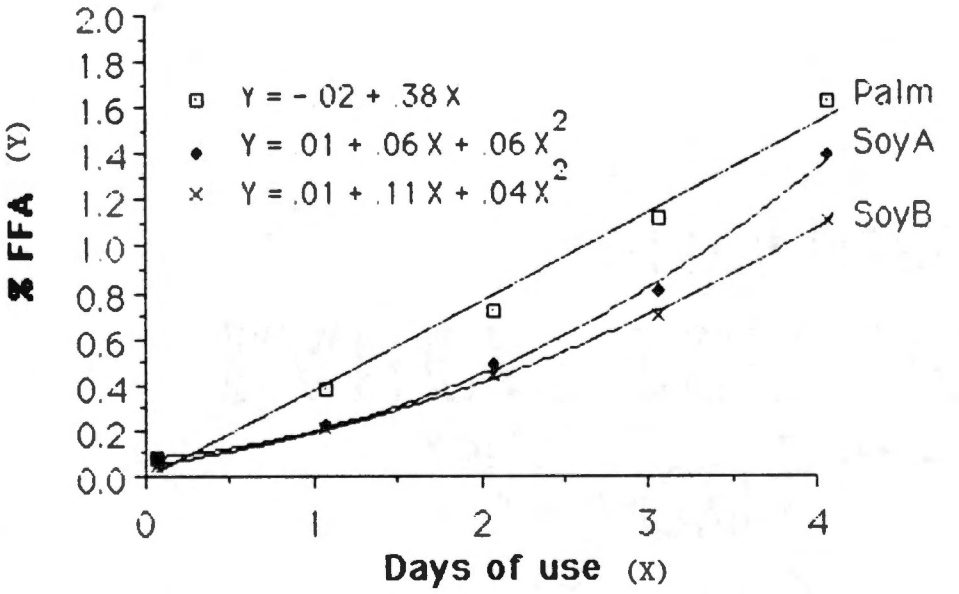


Figure 8. Mean (n=2) percentage free fatty acids (% FFA) in each frying oil as a function of days of use.

oils. No significant differences were found between soybean oil A and B in their % TPC. There was a linear relationship between % TPC and days of frying oil use as shown in Figure 9. By the fourth day of frying oil use, however, % TPC of the oils had only increased to 12.8. This level of TPC is too low for the frying oil to be discarded. The level of TPC at which point the oil is considered deteriorated and should be discarded is 27% (12). The results of the present study agree with several researchers in the level of TPC developed in laboratory frying for 4 days (4, 26, 28, 67). In the study by Husain (28), however, the % TPC exceeded the cut-off level by the third day of laboratory frying. The higher level of TPC in palm olein compared with the soybean oils is to be expected in view of the higher % of FFA in palm olein (Table 7).

E. Fatty Acid Composition Of Frying Oils

The fatty acid composition of the fresh frying oils is given in Table 8. Of the three oils, soybean oil A had the highest level of 18:1 (oleic) acid, soybean oil B had the highest level of 18:2 (linoleic) acid, and palm olein had the highest level of 16:0 (palmitic) acid. Soybean oils contained higher levels of fatty acid isomers: 18:1 isomers (a) and (b) and 18:2 isomers (a) and (b), than palm olein. The higher levels of isomers found in the soybean oils are because they were partially hydrogenated and the isomers form during that process (21). The fatty acid composition (Table 8) shows that the most unsaturated of the frying oils is soybean oil B and the most saturated is palm olein. These results are in agreement with the iodine

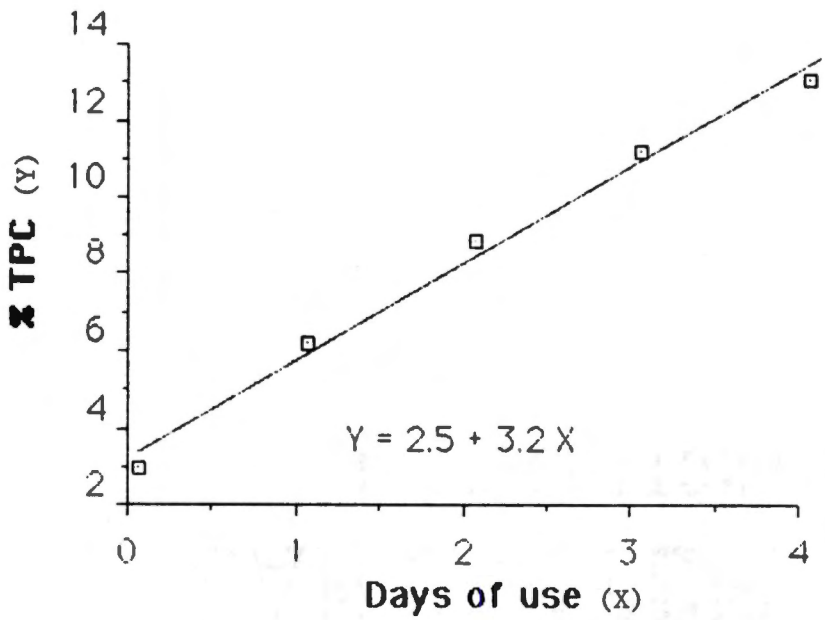


Figure 9. Mean (n=6) percentage of total polar components (TPC) in frying oil as a function of days of frying oil use.

Table 8. Mean percentage of fatty acid composition of fresh oils.

Fatty acid composition	Frying oils		
	Soybean oil B	Soybean oil A	Palm olein
	----------%----------		
10:0			0.02
11:0			0.05
12:0	0.02	0.04	0.28
13:0			0 02
14:0	0.10	0.08	1 10
15:0		0.02	0.04
16:0	10.70	9.38	41.10
16:1	0.08	0.08	0.21
17:0	0.09	0.09	0 10
17:1	0.05	0 06	0.06
18:0	3.90	3.80	3.57
18:1	55.70	60.52	42 70
18:1 11	0.95	5.22	
18:112		1.06	
18:211		2.13	
18:2	26.30	14.69	9.58
18:212		0.74	
20:0	0.35	0.49	0.47
18:3	0.73	0.25	0.26
20:1	0.71	0.60	0.21
20:2	0.34	0.74	0.17
20:3			0.06

values of soybean oils given in Table1 (p.26) showing that soybean oil B (iodine value = 102) is more unsaturated than soybean oil A (iodine value = 94).

II. SENSORY EVALUATION

A. Total Panel

The analysis of variance for the flavor desirability score from the total sensory panel for potatoes fried in each oil and at different frying time is presented in Table 9. The flavor score was affected significantly by type of oil and had a significant oil x time interaction ($p<.05$). When the sums of squares for time and oil x time were partitioned in linear (time), quadratic ($time^2$), cubic ($time^3$) and quartic ($time^4$) effects for each frying oil, a significant linear time effect on the flavor score was found for potatoes fried in soybean oil A and a significant cubic time effect on the flavor score of potatoes fried in palm olein was found. The flavor score from the total panel for potatoes fried in soybean oil B was not significantly affected by time.

The mean flavor desirability scores from the total panel for potatoes fried in different oil is shown in Table 10, and the flavor score of the total panel for potatoes fried in each oil is shown as a function of time of frying oil use (frying time) in Figure 10. The total panel liked the flavor of potatoes fried in palm olein slightly less ($p<.05$) than that of potatoes fried in either soybean oil. They scored the flavor of potatoes fried in either

Table 9. Sums of squares[a] from the analysis of variance of sensory scores of potatoes as a function of frying oil type and time of frying oil use.

Source	Degrees of freedom	Total[b] panel	Panel A[b]	Panel B[b]
Oils (O)	2	.311*	1.609*	4.204*
Time (T)	4	235	.387	.955
O x T	8	1.070*	412	1.407
Soybean oil A				
Time	1	.208*		
Time^2	1	008		
Time^3	1	.001		
Time^4	1	019		
Palm olein				
Time	1	486*		
Time^2	1	157		
Time^3	1	262*		
Time^4	1	118		
Soybean B				
Time	1	.024		
Time^2	1	000		
Time^3	1	000		
Time^4	1	.118		
Error	14	.541	2.051	2.994
Total	29	2.483	4.907	9.699

[a]Sums of squares followed by an * are significant at the $p<.05$ level.

[b]Total panel consisted of 32 members; Panel A had 15 panelists who liked palm olein less than soybean oil A and Panel B had 17 panelists who liked soybean oil A more than palm olein.

Table 10. Mean flavor desirability score of potatoes fried in different oil averaged across time of frying oil use.

	Frying oils		
Panel type	Soybean oil A	Soybean oil B	Palm olein
	Mean score[a]		
Total[b]	4.3[c]	4.2[c]	4.0[d]
Panel A[b]	4.1[d]	4.3[cd]	4.6[c]
Panel B[b]	4.4[c]	4.2[c]	3.6[d]

[a]7-point scale where 3=slightly undesirable, 4=slightly desirable and 5=moderately desirable flavor.

[b]Total panel had 32 members, Panel A, 15 members and Panel B, 17 members.

[cd]Means (n = 10) in a row bearing unlike superscripts are significantly different at the P<.05 level.

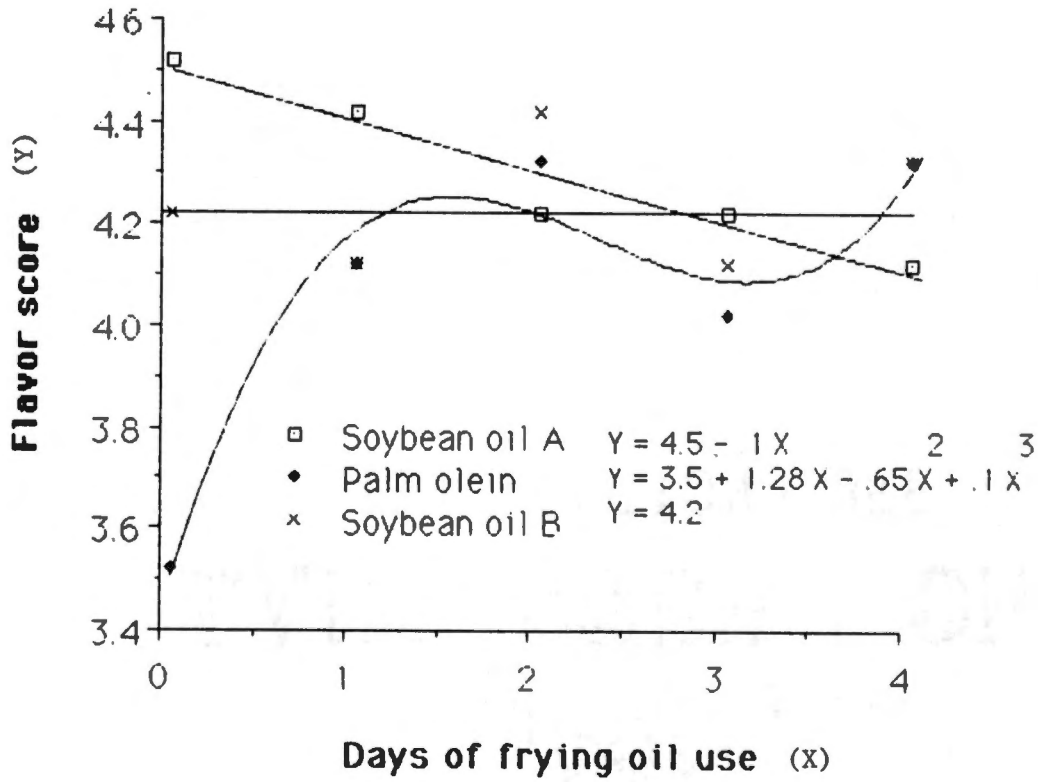


Figure 10. Mean (n=2) flavor score from total sensory panel for potatoes fried in different oils as a function of days of oil use. Sensory scale was 7-points where 3=slightly undesirable, 4=slightly desirable and 5=moderately desirable.

soybean oil just above slightly desirable (4.0), and the flavor of potatoes fried in palm olein exactly at slightly desirable. For the total panel, potatoes fried in soybean oil A decreased linearly in flavor desirability from 4.5 to 4.2 from 0 to 4 days of frying time. To the sensory panel as a whole, potatoes fried in palm olein had the lowest flavor desirability score (3.5) when fried in the fresh oil (0-day). This flavor score increased to 4.1 by the end of the first day of frying in the oil and did not really change appreciably after that time (Figure 10). The straight horizontal line at 4.2 in Figure 10 represents the average flavor score of the total panel for potatoes fried in soybean oil B.

B. Panel A

The analysis of variance for the flavor scores of panel A which consisted of 15 people who liked the flavor of potatoes fried in palm olein better than the flavor of potatoes fried in soybean oil A is given in Table 9. The flavor score of panel A was significantly affected by type of frying oil only ($p<.05$). As shown in Table 10, this group of people liked the flavor of potatoes fried in palm olein slightly to moderately (4.6) which was significantly more than they liked the flavor of potatoes fried in soybean oil A (4.1). However, panel A did not score the flavor of potatoes fried in soybean oil B significantly different from that of potatoes fried in soybean oil A or palm olein.

C. Panel B

The analysis of variance for the flavor scores for panel B is also shown in Table 9. The flavor score for panel B was significantly affected by type of frying oil only ($p<.05$). This panel of 17 people liked the flavor of potatoes fried in soybean oil A or B more than the flavor of potatoes fried in palm olein. They scored the flavor of potatoes fried in palm olein (3.6) between slightly undesirable and slightly desirable and the flavor of potatoes fried in either soybean oil between slightly and moderatly desirable (Table 10).

Little research has been reported concerning the effect of palm olein versus soybean oil on the flavor of fried foods. It has been suggested that the flavor of foods fried in fresh palm olein really was not desirable, but that the flavor improved with increasing time that the palm olein was used for frying (71). The results of the present study support this suggestion. This finding suggests that any commercial frying operation using palm olein as a frying oil should heat it for a few hours before frying food to avoid this problem. Weiss (1) reported that potato chippers found that consumers noticed a difference in chips fried in palm oil versus those fried in other oils but that this difference did not seem to affect the overall acceptability of the chip. The results of the present study show that this report is an oversimplification of consumers tastes and preferences. Fifty three percent of the people serving on the total panel or Panel B really did not like the flavor of potatoes fried in palm olein compared with those fried in the soybean oil, while the rest of the panel or Panel A liked the flavor of

potatoes fried in palm olein a little better than those fried in soybean oil A. More research is needed to determine if this small sampling is representative of the consumers in the United States.

III. VOLATILE COMPOUNDS IN FRIED POTATOES

The analysis of variance for the effects of oil, time of frying and their interaction on the flavor volatiles isolated from fried potatoes is given in Appendix (Table B-1). Mass spectra for unknowns, A, B, C, D, E, F, G, ad H are presented in appendix C. The average level of volatiles in potatoes fried in each oil are given in Table 11. At the $p<.10$ level, potatoes fried in either soybean oil had higher levels of 2-methyl pyrazine, and unknown A than potatoes fried in palm olein; potatoes fried in soybean oil B had a higher level of benzaldehyde and t,c-2,4-decadienal than potatoes fried in soybean oil A or palm oil olein. The following differences were found at the $p<.05$ level. Potatoes fried in soybean oil B had higher levels of unknown E (aldehyde), and c,t-2,4-decadienal than potatoes fried in soybean oil A. Potatoes fried in soybean oil B also had higher levels of t-2-octenal, c,t-2,4-decadienal, t,t-2,4-decadienal and unknown G than potatoes fried in soybean oil A or palm oil olein. Potatoes fried in soybean oil A and B had significantly more t,t-2,4-decadienal than potatoes fried in palm olein. Potatoes fried in palm olein had less unknown B than those fried in soybean oils.

The effect of time of frying on the concentration of volatiles in fried potatoes is given in Table 12. In general, levels of volatiles were higher in

Table 11. Average (n=4) concentration (mg equivalents methyl palmitate/ 150 g potatoes) of flavor volatiles in potatoes fried in different oils averaged across time.

Compounds	Retention time (min)	Soybean oil (A)	Soybean oil (B)	Palm olein
		concentration		
2-methyl pyrazine	14.1	.28^{X}	.34^{X}	.08^{Y}
2,5-dimethyl pyrazine	17.4	1.50	2.31	.86
Unknown A	18.0	.29^{X}	.22^{X}	.04^{Y}
2,6 dimethyl pyrazine	19.1	.11	.07	.07
3-ethyl-2-methyl pyrazine	21.4	.22	.34	.69
2,3,5 trimethyl pyrazine	22.1	.26	.22	.07
nononal	23.1	.20	.35	.23
2-ethyl-5,6-dimethyl pyrazine	23.6	.22	.20	.07
2,6-dimethyl-3-ethyl pyrazine^{t}	23.9	.01	.03	02
Unknown B	24.4	.10^{a}	.11^{a}	04^{b}
Unknown C	26.0	.09	.09	.06
t-2-octenal	26.5	.24^{b}	.42^{a}	.14^{b}
Unknown D	27.1	.05	.05	.03
cyclohexene-2-one	28.2	29	40	.19
1-octanol^{t}	29.5	14	20	12
benzaldehyde^{t}	30.0	.08^{Y}	.15^{X}	08^{Y}
t,t-2,4-heptadienal	30.9	.03^{ab}	.08^{a}	.02^{b}
Unknown E (aldehyde)	31.9	.13^{b}	.27^{a}	17^{ab}
t-2-hexen-1-ol^{t}	33.2	.38	.41	.27
Unknown F (aldehyde)	39.8	.66	.51	.66
phenylacetaldehyde	40.6	1.36	1.51	.91
t,c-2,4-decadienal	46.0	.02^{Y}	.04^{X}	.02^{Y}
c,t-2,4-decadienal	47.1	.19^{b}	.34^{a}	.15^{b}
t,t-2,4-decadienal	49.0	1.10^{b}	1.81^{a}	.80^{c}
Unkown G	51.3	.06^{b}	.13^{a}	07^{b}
Unknown H	52.5	.03	.01	.02
1,2-dibenzene dicarboxylic acid^{t}	74.4	.14	.08	10

Table 11. (Continued).

[abc]Means in arow followed by a different superscript letter are different at the P<.05 level.

[t]Tentative identification.

[xy]Mean in a row followed by different superscripts letter are different at the P<.10 level.

Table 12. Average (n=6) concentration (mg equivalents methyl palmitate/ 150 g potatoes) of flavor volatiles in potatoes fried in different oils at different times.

Compounds	Time	
	1	2
	---------concentration----------	
2-methyl pyrazine	.35[x]	.13[y]
2,5-dimethyl pyrazine	1.84[x]	1.27[y]
Unknown A	.26[x]	.10[y]
2,6 dimethyl pyrazine	.13[x]	.04[y]
3-ethyl-2-methyl pyrazine	.41	.42
2,3,5 trimethyl pyrazine	.26[x]	10[y]
nononal	.24	.29
2-ethyl-5,6-dimethyl pyrazine	.25[x]	.07[y]
2,6-dimethyl-3-ethyl pyrazine[t]	.03	01
Unknown B	.12[a]	.04[b]
Unknown C	.13[x]	.03[y]
t-2-octenal	.26	.27
Unknown D	.07[a]	.02[b]
cyclohexene-2-one	.28	.30
1-octanol[t]	.19[x]	.12[y]
benzaldehyde[t]	.12[x]	.09[y]
t,t-2,4-heptadienal	.04	.04
Unknown E, aldehyde	.20	.18
t-2-hexen-1-ol[t]	.39	.31
Unknown F, aldehyde	57	.64
phenylacetaldehyde	1.58	.93
t,c-2,4-decadienal	.04[a]	.02[b]
c,t-2,4-decadienal	.26[a]	.20[b]
t,t-2,4-decadienal	1.43[a]	1.04[b]
Unkown G	.10[a]	.07[b]
Unknown H	.01[a]	.03[b]
1,2-dibenzene dicarboxylic acid[t]	.07[a]	.14[b]

Table 12. (Continued).

[abc]Means in arow followed by a different superscript letter are different at the P<.05 level.

[t]Tentative identification.

[xy]Mean in a row followed by different superscripts letter are different at the P<.10 level.

potatoes fried on the first day of frying than on the fourth day. At the $p<.10$ level, potatoes fried on the first day contained higher concentrations of 2-methyl pyrazine, 2,5-dimethyl pyrazine, unknown B, 2,6-dimethyl pyrazine, 2,3,5-trimethyl pyrazine, 2-ethyl-5,6-dimethyl pyrazine, unknown C, 1-octanol and benzaldehyde than potatoes fried on the 4th day of frying. At the $p<.05$ level, potatoes fried on the first day contained higher levels of unknown B, unknown D, t,c-2,4-decadienal; c,t-2,4-decadienal, t,t-2,4-decadienal; and unknown E and lower levels of unknown H and 1,2-dibenzene dicarboxylic acid.

Many differences found between the concentrations of volatiles, particularly the alkyl aldehydes, in the potatoes fried in the different oils were caused by the differnces in the fatty acid composition among the frying oils. Aldehydes are secondary oxidation products of unsaturated fatty acids, and specific aldehydes are initially produced by oxidation of 18:1, 18:2 or 18:3 fatty acids (20). Higher levels of t-2-octenal, and the 2,4-decadienal in the potatoes fried in the soybean oils compared with that of potatoes fried in palm olein (Table 11) reflect the differences in the levels of linoleic acid among the frying oils. The concentrations of these aldehydes in the fried potatoes were in the following order: soybean oil B > soybean oil A > palm olein which is the same order of linoleic acid (18:2) concentration in the frying oils (Table 8, p 54). The aldehyde, t,t-2,4-heptadienal, is a secondary oxidation product of linolenic acid (18:3), and its concentration was the greatest in the potatoes fried in soybean oil B which contained the highest level of 18:3 among the three frying oils (Table 8).

The compound, t,t-2,4-decadienal, has been reported to have a deep-fat fried odor (31) and is formed during the deep-fat frying process (72). This aldehyde has been identified in the flavor isolate of potato chips (73), and it is the second most abundant volatile isolated from the fried potatoes of the present study (Table 11).

Aldehydes, in addition to being formed by oxidation of fatty acids, may also be formed by the Strecker degradation, a non enzymetic browning reaction (17). Phenylacetaldehyde is formed from the amino acid, phenylalanine, in the potatoes during frying by such a reaction. It was one of the three most abundant volatiles isolated from the fried potatoes which is in agreement with the results of Deck et al. (74) who reported that phenylacetaldehyde was present in large amounts in the volatiles of potato chips. In fact, all aldehydes found in the present study, with the exception of nononal and isomers of decadienal, were identified in the potato chip volatiles.

Seven pyrazines were identified in the present study and one unknown was tentatively identified as a pyrazine (Table 11, p 62). More than 40 pyrazines have been identified in foods. They are heterocyclic nitrogenous compounds which are responsible for the flavor of roasted and browned foods. They are formed in the food by the Millard or nonenzymetic browning (NEB) reactions and by pyrolysis of amino acids. The flavor of the individual compound in this group depends on the nature and the position of the side chain molecules on the ring. The nature of the side chain molecule is largely dependent upon the carbonyl compounds which after Strecker degradation becomes an amino ketone which can condense to form pyrazines (17). These

dicarbonyl compounds are formed by degradation of sugars and amino acids during NEB reactions, but also may be derived from oxidizing fatty acids in the lipids (17). Therefore, significant differences found in specific pyrazine concentrations between the potatoes fried in different oils may also be related to the differences in fatty acid composition among the frying oils.

Pyrazines have been isolated from potato products by many investigators (58, 74, 75). The first volatile nitrogenous compound isolated from potatoes was 2,5-dimethyl pyrazine (76). This compound was the most abundant volatile in the fried potatoes of the present study (Table 11). Other pyrazine compounds found in the present study: 2,6-dimethyl pyrazine and 2,3,5-trimethyl pyrazine, were isolated from fried potato chips by Deck et al. (74) who reported 4 additional pyrazines in potato chips volatiles that were not isolated from fried potatoes in the present study.

In general, the levels of volatiles were less in potatoes fried at 4 days of frying oil use than at 0-day, and this may reflect a decreased level of these volatiles in frying oils after 4 days heating and frying. Nawar (2) reported that in any heated frying oil, the concentration of volatiles generally reaches a plateau as a result of simultaneous evaporation or decomposition. However, he reported lower levels of several aldehydes and hydrocarbons in corn oil heated continuously for 70 hr compared with corn oil heated at the same temperature for 1 hr (2). He also reported that the level of volatiles present in any frying oil was dependent on a continous or intermittent heating. Frying oils/fats used in commercial frying operations contained lower levels of volatile compounds than frying oils heated

continously in the laboratory (2). The levels of volatiles in an oil, however, cannot be used as an indicator of the extent to which a commercial frying oil has been used because of the dynamic state in which the volatiles exist. These volatiles are constantly being produced, evaporated, degraded and absorbed during frying.

The correlation coefficient of flavor desirability score of potatoes from each type of sensory panel with concentration of each volatile in the potatoes is given in Table 13. Since the flavor desirability increased with increasing magnitude of the flavor score, any positive correlation indicates a contribution to increasing flavor desirability and a negative correlation, a contribution to flavor undesirability. No significant correlation coefficients existed between flavor desirability score of Panel A with the volatile compounds isolated from the fried potato.

In contrast with the results of Panel A, the flavor desirability score of fried potatoes from Panel B was positively correlated with unknown A, t-2-octenal and, cyclohexene-2-one. No significant correlation coefficient was found between flavor desirability score of total Panel with volatile compounds isolated from fried potatoes.

Table 13. Correlation coefficients (n=12[a]) for the flavor score of fried potatoes with levels of volatile compounds isolated from the potatoes for sensory panels A and B and the total sensory panel[b]

Volatile compounds	Panel A	Panel B	Total Panel
2-methyl pyrazine	-.17	.48	.38
2,5-dimethyl pyrazine	-.26	.46	.32
Unknown A	-.32	.66*	.52
2,6 dimethyl pyrazine	.21	-.30	.03
3-ethyl-2-methyl pyrazine	-.10	-.04	-.11
2,3,5 trimethyl pyrazine	-.18	.54	.44
nononal	-.30	.30	.13
2-ethyl-5,6-dimethyl pyrazine	-.12	.44	.38
Unknown B	.02	.22	.25
Unknown C	.01	.40	.43
t-2-octenal	-.19	.61*	.52
Unknown D	.25	.28	.09
cyclohexene-2-one	-.33	.60*	.39
1-octanol[t]	-.36	.27	.02
benzaldehyde[t]	-.08	.27	.23
t,t-2,4-heptadienal	-.15	.34	.26
Unknown E (aldehyde)	-.27	-.10	-.29
t-2-hexen-1-ol[t]	-.15	.24	.45
Unknown F (aldehyde)	-.12	.22	.09
phenylacetaldehyde	-.42	.43	.17
t,c-2,4-decadienal	-.12	-.01	-.10
c,t-2,4-decadienal	-.34	.28	.07
t,t-2,4-decadienal	-.30	.34	.16
Unknown G	-.19	-.01	-.13
Unknown H	-.43	.19	-.09
1,2-dibenzene dicarboxylic acid[t]	-.08	.11	-.19

Table 13. (Continued)

[a]Coefficients followed by * are significant at the $p<.05$ level

[b]Panel A (n=15) liked the flavor of potatoes fried in soybean oil A less than that of potatoes fried in palm olein; Panel B (n=17) liked the flavor of potatoes fried in palm olein less than that of potatoes fried in soybean oil A; Total Panel had 32 members.

[t]Tentative identification.

CHAPTER V

SUMMARY

Frozen parfried potatoes were fried in each of two partially hydrogenated soybean oils, A with an iodine value of 94 and B with an iodine value of 102, and in palm olein, discontinuously (one 400-g batch every hour) for 8 hours a day for 4 consecutive days, and this was one replication. Two replications were run. Frying in all three oils was conducted simultaneously. Potatoes that were fried in each oil at 0, 1-, 2-, 3-, and 4-days of frying oil use were evaluated by an inexperienced 32-member panel for flavor desirability (7-point scale where 1= very undesirable and 7 = extremely desirable). Oil samples were collected prior to the start of frying and at the end of each day of frying. Fried potato samples were also taken from the second hour frying of the first day and at the end of the fourth day for volatile analysis by GCMS. The frying oil samples were analyzed for color, free fatty acid (FFA) content, total polar components (TPC), and by the Food Oil Sensor (FOS).

During the 4-days of frying time, palm olein developed a redder, more yellow color than either soybean oils and this caused the greatest color change during frying in the palm olein of the three oils. Palm olein also developed a higher content of free fatty acids and total polar components across 4 days frying than either of the soybean oils. Compared with soybean oil B, the less unsaturated soybean oil A also had a higher level of free fatty

acids formed across frying time. Across frying time of 0 to 4 days the following changes were found in the frying oils. The Hunter color "L" value decreased; the color values "a" and "b" increased; the color change, ΔE, increased; and the FOS reading and levels of FFA and TPC increased.

The inexperienced sensory panel (n=32) scored the flavor desirability of potatoes fried in palm olein lower than those fried in either soybean oil. The panel as a whole scored the flavor of potatoes fried in fresh palm olein (0-day) at 3.6. With subsequent heating and frying in the palm olein, however, the flavor of potatoes fried in palm olein became more desirable ($p<.05$). However, part of the panel (n = 15) liked the flavor of potatoes fried in palm olein (4.6) better than those fried in soybean oil A (4.1) while the rest (n = 17) reversed this finding by liking the flavor of potatoes fried in soybean oil A (4.4) or B (4.2) better than those fried in palm olein (3.5).

Nineteen identified compounds and seven unknown compounds that were characterized by their retention time by GCMS analyses and mass spectra were analyzed in the volatiles of the fried potatoes. The concentration of 11 volatiles: 2-methyl pyrazine; t-2-octenal; benzaldehyde; t,t-2,4-heptadienal; t,c,-2,4-decadienal; c,t,-2,4-decadienal; t,t-2,4-decadienal; 1,2-dibenzene dicarboxylic acid and 3 unknowns were significantly different among oils ($p<.10$ or lower). These differences generally could be explained by the differences in the fatty acid composition among the three oils. In addition, potatoes fried in oils that had been used for 4 days contained lower levels of 2-methyl pyrazine; 2,5-dimethyl pyrazine; 2,6-dimethyl pyrazine; 2,3,5-trimethyl pyrazine; 2-ethyl-5,6-dimethyl pyrazine; 1-octanol; benzaldehyde, t,t-2,4-decadienal and its

isomers; and 5 unknown compounds, and higher levels of 1,2-dibenzene carboxylic acid and a single unknown than potatoes fried at the beginning of the frying time ($p<.10$ or lower).

Flavor desirability scores of fried potatoes from a 15-member sensory panel who liked the flavor of potato fried in palm olein better than the flavor of potatoes fried in soybean oil were not significantly correlated with any of the volatiles isolated from the potatoes. In contrast to these results, the flavor desirability score of a 17-member panel who liked the flavor of potatoes fried in soybean oil better than those fried in palm olein was positively correlated with t-2-octenal, cyclohexen-2-one and an unknown ($p<.05$). The average flavor score of entire panel ($n=32$) also was not significantly correlated with any of the volatiles.

LITERATURE CITED

LITERATURE CITED

1. Weiss, T.J. "Food Oils and Their Uses", AVI Publishing Co., Westport, CT. pp. 157-180 (1983).

2. Nawar W. W., "Food Chemistry", ed. Owen R. Fennema, Marcel Dekker Co., Inc. New York (1985).

3. Fritsch, C. W., JAOCS, 58:272(1981).

4. Stevenson, S. G., M. Vaisey-Genser and N. A. M. Eskin, JAOCS, 61:1102 (1984).

5. Garnett, B., Personal comunication, Hungry Fisherman, Greenville, SC. (1987).

6. Weiss, T. J. "Food Oils and Their Uses", p. 35, AVI Publishing Co , Westport, CT, pp. 35 (1983).

7. Min, D. B. and T. M. Smouse, "Flavor Chemistry of Fats and Oils" AOCS Champaign, IL, (1985).

8. Sakata, M., Y. Takahashi, and M. Sonehara, JAOCS, 62: 449 (1985).

9. Chang, S. S., R. J. Peterson, and C. Ho, JAOCS, 55: 718 (1983).

10. Nawar, W. W. "Flavor Chemistry of Lipids" Ed. D. B. Min and T. H. Smouse, American Oil Chemist's Society. Champaign, IL. Chapter 2 (1985).

11. Perkins, E. G., Food Technol. 21:611 (1967).

12 Billek, G., G. Guhr, and J. Waibel, JAOCS, 55:728 (1978).

13. Butierraz, A., Q. Gonzalez and M. C. Dobarganes, "Frying of Foods. Principles, Changes, New Approaches". Ed. G. Varela, A. E. Bender, and I. D. Mortar, Ellis Norwood L td. Chichester, England, Chapter 10 (1988).

14. Russel, J.B., Nutr. and Food Sci., 87:13 (1984).

15. Crnjar, E. D., A. Witchwoot, and W. W. Nawar, J. Agric. Food Chem. 29:39 (1981).

16. Selke, E., W. K. Rohwedder and H.J. Dutton, JAOCS, 52:232 (1975).

17. Heath, H. B. and G. Reineccius, "Flavor and Chemistry and Technology" AVI Publishing Co. West Port, CT. (1986).

18. Lomanno, S. S., and W. W. Nawar, J. Food Science. 47:744 (1981).

19. Henderson, S K. and W. W.Nawar, JAOCS, 47:409 (1980).

20. McGill, E. A., Baker Dig. 6:38 (1980).

21. DeMan, J. M. "Principles of Food Chemistry", AVI Publishing Co., Inc. Westport, CT. pp. 202 (1980).

22 AOCS, "Official and Tentative Methods of the American Oil Chemists' Society", 3rd Ed. AOCS, Champaign, IL. (1984).

23. Stevenson, S. G., L. Jeffery, M. Vaisey-Genser, B. Fyfe., F. W. Houger, and N. A. M. Eskin., Can. Inst. Food Sci. Technol J., 17:187 (1987).

24. Graziano, V. J., Food Technolo, 33: 50 (1979).

25. Paradis, A. J., and W. W. Nawar, J. Food Sci. 46: 449 (1981).

26. Fritsch, C. W., D. C. Egberg, and J. S. Magnuson, JAOCS, 56: 746 (1979).

27. Smith, L. M., A. J. Clifford, C. L. Hamblin and R. K. Creveling, JAOCS, 63:1017 (1986).

28. Hussain, N. A. TITLE M. S. Thesis Knoxville, TN (1986).

29. Baeuerlen R., H. Brody, and Erickson, Bakers Digest, 4 (1968)

30. Heubschman, L., Personal Communication, Powell Valley Foods Caryville, TN, (1988).

31. Mookherjee, B. D., R. E. Deck, . and S. S.Chang, J. Agr. Food Chem., 13:131 (1965).

32. Melton, S. L. and D. Sykes, JAOCS, 64:664 (1987).

33. Melton, S. L. and D. Sykes, JAOCS, 65:521 (1988).

34. Robern H., and L. Gray, Can. Inst. Food Sci. Technol, 14:150 (1981).

35. Gray, J. I., JAOCS, 55: 539 (1978).

36. Frankel, E. N., K. Warnor and K. J. Moulton Sr., JAOCS, 62: 1354-1358 (1985).

37. Landers, R. E. and Rathmann., JAOCS, 58.255 (1981).

38. Warner, K., T. L. Mounts, and W. F. Kwolek, JAOCS, 62: 1483-1486 (1985).

39. Evans, C. D., K., G. R. Warner and J. C. Cowan, JAOCS, 49: 578 (1972).

40. Peled, M., T. Gutfinger and A. Letan, J. Sci. Food Agric., 26: 1655 (1975).

41. Augustin, M. A. and S. K. Berry, JAOCS, 60: 1520-1523 (1983).

42. Asap, T. and M. A. Augustin., JAOCS, 37: 1045-1051 (1986).

43. Gordon, M. H. and P. Magos, J. Food Chem., 10: 141-147 (1984).

44. Rhee, J. S., J. Food Sci. Technol., 10: 250-257 (1978).

45. Tangel,F. P., J. G. Leeder, and S. S. Chang, J. Food Sci., 42: 1110-1113 (1977).

46 Freeman, I. P., F. B. Padley, and W. L. Shepard, JAOCS, 50: 101-103 (1973).

47. Ohta, S. and H. Kusaka, JAOCS, 56: 202A (1979).

48. Robertson, C.J., Can. Ins. Food Sci. Technolo. J. 1:A66 (1966).

49. Peers, K. E. and P. A. T. Swoboda, J. Sci. Food Agric., 33: 389 (1982).

50. Jacobson, G. A., Food Technol., 21: 147 (1967).

51. Robertson, C. J., Food Technol., 21:34 (1967).

52. Chang S. S., R. J.Peterson and C. T. Ho. IN LIPIDS AS A SOURCE OF FLAVOR.

53. Mega, J. A. and C. E. Sizer "Pyrazines in Foods." In Critical Reviews in Food Technology 4:39 (1973).

54. Robertson, J. A., W. H. Morrison, B. G. Lyon, and R. L. Shaw, J. Food Science, 43:420 (1978).

55. Robertson, J. A., W. H. Morrison, D. Burdick, and R. Shaw, Am. potato J., 49:444 (1972).

56 Thompson, L. U. and Rea Aust. Can. Inst. Food Sci. Technol J, 16:246 (1983).

57. Vallese, F. M. "Identification of the volatile flavor costituents of french fried potatoes". Thesis, Rugers University, New Brunswick, NJ. (1987).

58. Carlin J.T., Q. Z. Jin, T. C. Huang, C. T. Ho, and S. S. Chang, J. Agric. Food Chem., 34:621 (1986).

59. Penfield< M. P., Personal Communication, University of Tennessee, Knoxville, TN (1987).

60. Au-Yeung, C. Y. and A. J. MacLeod, J. Agric. Food Chem., 29: 502 (1981).

61 MacLeod, A. J. and S. Jane Cave, J. Sci. Food Agric., 26: 351-360 (1975).

62. SAS "Users Guide. Statistics" , Ed. SAS Institute, Inc. Cary, NC. (1985).

63. Tan, Y.A, S.H. Ong, K.G. Berger, H.H. Oon and B.L. Poh, JAOCS, 62: 999 (1985).

64. Fraser, M.S. and G. Frankl, JAOCS, 58:926 (1981).

65. Lantze, C.W., and G.T. Carlin, Oil an Soap, 15: 38 (1983).

66. Sims, R. J. and H. D. Stahl, The Bakers Digest, October : (1970).

67. Wu, P. F. and W. W. Nawar, JAOCS, 63: 1363 (1986).

68. Bracco, U., A. Dieffenbacher and L. Kolarovic, JAOCS, 58: 6 (1981).

69. Handel, A.P., F. L. Hamouz, A. N. Dumper and M. E. Knickrehm, J Food Service Sys. 3(1): 49 (1984).

70. Meltzer, J.B., E.N. Frankel, T.R. Bessler and E.G. Perkins, JAOCS, 7: 779 (1981).

71. Corington, R. 1988. Personal Communication Kraft Edible Foods, Memphis, TN.

72. Guadagni, D.C., R. G. Buttery and J. G. Turnbaugh, J. Sci. Food Agric., 23:1435 (1972).

73. Krishnamurthy, R.G. and S. S. Chang, J. Amer. Oil Chem. Soc., 44:136 (1967).

74. Deck, R E, J. Pokorny and S. S. Chang, J. Food Sci., 38:345 (1973).

75. Deck, R.E., and S. S. Chang, Chem. Ind. (London) 1343 (1965).

76. Barr, H. K., Proc. Plant Sci. Symp. Camden, NJ, pp83-97 (1966).

APPENDICES

APPENDIX A

Name: _____ Date: _____

Please taste the sample of french fries and describe the flavor of the sample below. Rinse your mouth with water before tasting the next sample.

Sample _____

Extremely desirable flavor _____

Very desirable flavor _____

Moderately desirable flavor _____

Slightly desirable flavor _____

Slightly undesirable flavor _____

Very undesirable flavor _____

Extremely undesirable flavor _____

Please describe reasons for an undesirable flavor rating:

Figure- A-1. French fries score cards

APPENDIX B

ANALYSIS OF VARIANCE FOR FLAVOR VOLATILES

Sums of squares for concentrations of volatiles in potatoes fried in different oils at 0-day and 4-day frying period.

Source	Degrees of freedom	2-methyl pyrazine	2,5-dimethyl pyrazine	Unknown (A)	2,6-dimethyl pyrazine
Oil (O)	2	.1385	4.258	.1380*	.0055
Time (T)	1	.1435*	.984	.0718*	.0277*
O x T	2	.1134	.748	.0790	.0026
Rep	1	.1339	.628	.0066	.0001
Error	5	.1754	5.157	.0731	.0239
Total	11	.7046	11.776	.3684	.0598

		3-ethyl-2 methyl pyrazine	2,3,5-trimethyl pyrazine	nononal
Oil (O)	2	.4733	.0853	.0527
Time (T)	1	.0006	.0702*	.0051
O x T	2	.3159	0497	0023
Rep	1	1590	.0735*	0032
Error	5	1.2825	.0771	1892
Total	11	2.2313	.3557	.2524

		2-ethyl-5,6 dimethyl pyrazine	Unknown (B)	Unknown (C)
Oil (O)	2	.0535	.0124*	.0029
Time (T)	1	.0973*	.0179**	.0296*
O x T	2	.0356	.0174**	0037
Rep	1	.0832	0031*	.0045
Error	5	.1096	.0035	.0323
Total	11	.3794	0543	0731

B Table 1. (Continued).

Source	Degrees of freedom	t-2-octenal	Unknown (D)	Cyclohexen-2-one	1-octanol
Oil (O)	2	.1701**	.0010	.0937	.0151
Time (T)	1	.0009	.0073*	.0012	.0137*
O x T	2	.0171	.0018	.0079	.0002
Rep	1	.0062	.0013	.0059	.0001
Error	5	.0383	.0072	.1127	.0162
Total	11	.2327	.0186	.2214	.0453

		Benzal-dehyde	t,t-2,4-heptadienal	Unknown (E)	t-2-hexen-1-ol
Oil (O)	2	.0099**	.0085*	.0429**	.0021
Time (T)	1	.0036*	.0000	.0016	.0016
O x T	2	.0023	.0007	.0287*	.0008
Rep	1	0011	.0004	.0090	.0032*
Error	5	.0044	.0033	.0154	.0030
Total	11	.0213	.0129	.0977	.0107

		Unknown (F)	Phenyl-acetaldehyde	t,c-2,4-decadienal	c,t-2,4-decadienal
Oil (O)	2	.00005	.7809	.00108*	.0827**
Time (T)	1	.00001	1.2806	.00168**	.0135*
O x T	2	.00042	.2235	00104*	.0030
Rep	1	.00015	.3330	.00005	.0001
Error	5	.00422	1.7973	.00053	.0074
Total	11	.00484	4.4153	.00438	.1067

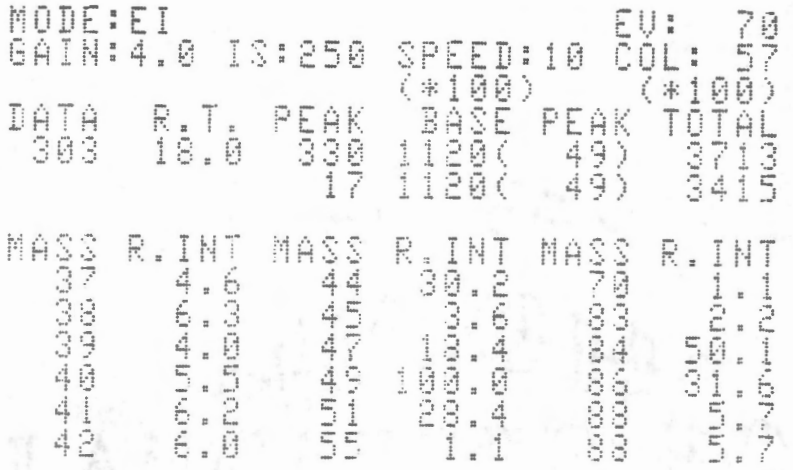
Source	Degrees of freedom	t,t-2,4-decadienal	Unknown (G)	Unknown (H)	1,2-dibenzen dicarboxylic acid
Oil (O)	2	2.1832**	.0116**	.00068	.00716
Time (T)	1	.4566**	.0037**	.00121**	.01939*
O x T	2	.0509	.0009	.00156*	.01246
Rep	1	.0005	.0002	.00012	.00046
Error	5	.0670	.0011	.00085	00096
Total	11	2.7583	.0176	.00442	04905

*Significant at p<.10.

**Significant at p<.05.

APPENDIX C

MASS SPECTRA DATA



```
MODE:EI                                          EV:   70
GAIN:4.0  IS:250  SPEED:10                       COL:  57
                  (*100)                          (*100)
DATA    R.T.   PEAK    BASE   PEAK    TOTAL
 303    18.0    330   1120(   49)     3713
                 17   1120(   49)     3415

MASS  R.INT  MASS  R.INT  MASS  R.INT
  37    4.6    44   30.2    70    1.1
  38    6.3    45    3.6    83    2.2
  39    4.0    47   13.4    84    1.4
  40    5.5    49  100.0    86    1.6
  41    6.2    51   28.4    88    5.7
  42    6.0    55    1.1    93    5.7
```

Figure C-1. Mass Spectrum Table Of Unknown A

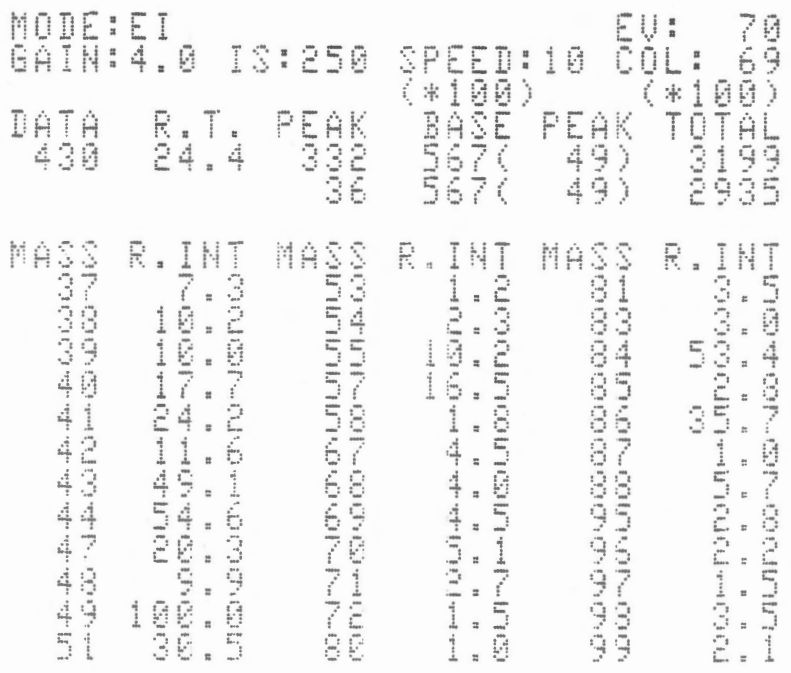


Figure C-2 Mass Spectrum Table Of
Unknown B

MODE:EI
GAIN:4.0 IS:250 SPEED:10 EV: 70
(*100) COL: 72
(*100)

DATA	R.T.	PEAK	BASE	PEAK	TOTAL
465	26.0	324	493(49)		2502
		31	493(49)		2292

MASS	R. INT	MASS	R. INT	MASS	R. INT
38	11.6	52	2.1	80	3.9
39	13.7	53	3.1	81	1.4
40	14.8	54	2.2	82	1.9
41	16.4	55	4.6	83	1.1
42	9.0	56	3.3	84	1.1
43	6.1	57	2.5	85	1.1
44	46.4	58	2.5	86	1.1
45	21.9	59	2.1	87	3.3
46	10.8	60	2.1	88	1.9
47	100.0	61	2.1	89	4.1
48	31.2	62	2.9	90	4.9

Figure C-3. Mass Spectrum Table Of Unknown C

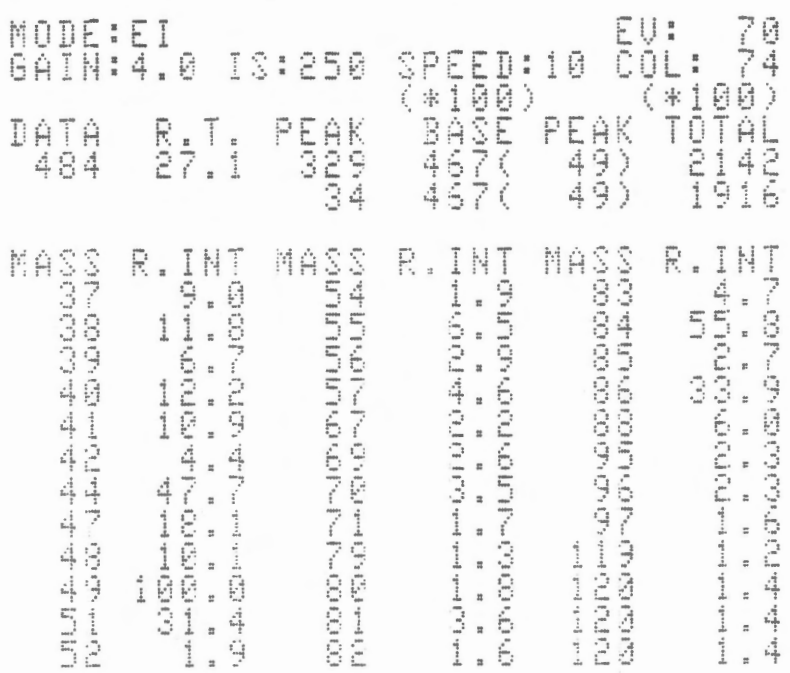
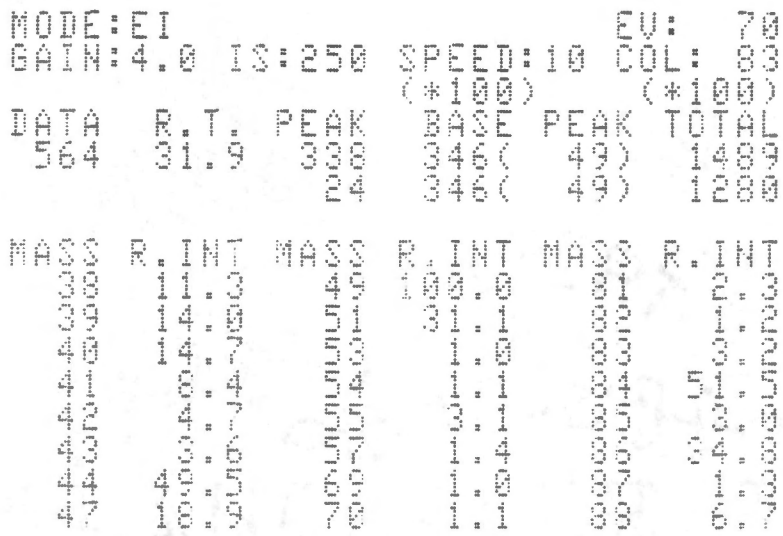


Figure C-4. Mass Spectrum Table Of Unknown D



```
MODE:EI                                          EV:   70
GAIN:4.0  IS:250  SPEED:10  COL:  83
                  (*100)      (*100)
DATA    R.T.  PEAK   BASE  PEAK  TOTAL
 564    31.9   338   346(   49)   1489
               24    346(   49)   1280

MASS  R.INT  MASS  R.INT  MASS  R.INT
  38   11.3    49  100.0    81    2.3
  39   14.0    51    3.1    82    1.2
  40   14.7    53    1.0    83    2.2
  41    6.4    54    1.1    84    1.5
  42    4.6    55    3.1    85    3.8
  43    6.5    57    1.4    86    3.8
  44   19.5    69    1.0    87    1.3
  47   18.9    70    1.1    88    6.7
```

Figure C-5. Mass Spectrum Table Of Unknown E

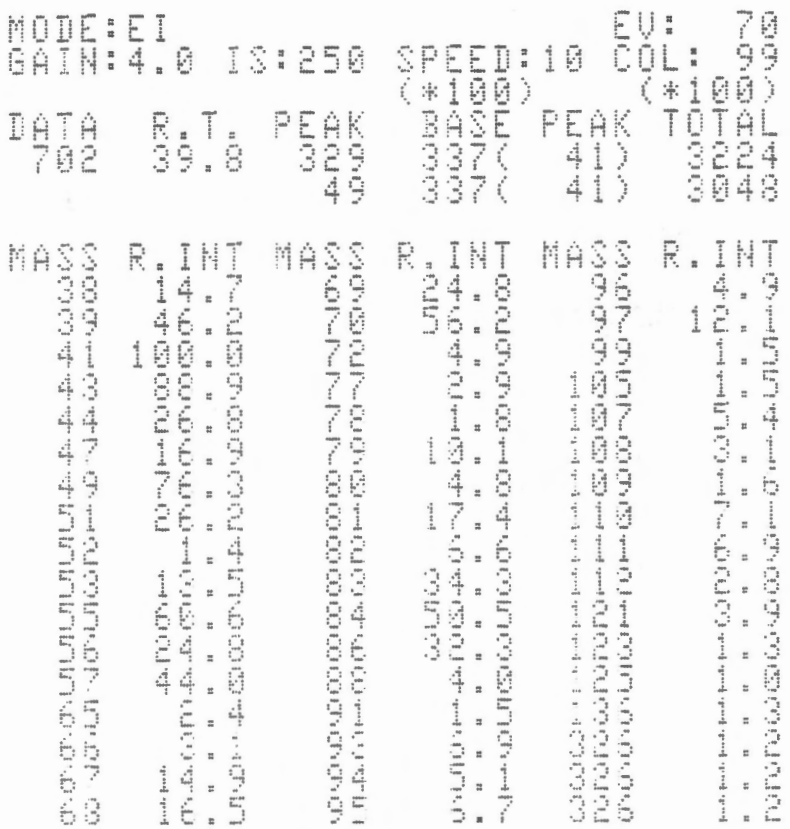


Figure C-6. Mass Spectrum Table Of Unknown F

MODE:EI EV: 70
GAIN:4.0 IS:250 SPEED:10 COL:122
(*100) (*100)

DATA	R.T.	PEAK	BASE	PEAK	TOTAL
882	51.3	320	688(219)		3313
		66	688(219)		2991

MASS	R.INT	MASS	R.INT	MASS	R.INT
37	4.9	78	2.6	133	2.5
38	5.8	80	1.1	135	1.1
39	1.1	81	2.0	141	1.1
40	1.2	82	1.6	143	1.1
41	1.2	83	1.3	145	1.1
42	7.7	84	7.4	146	1.1
43	7.2	85	2.3	147	1.1
44	6.1	86	1.0	155	1.1
47	1.2	91	1.9	159	1.1
49	2.2	95	1.0	161	1.1
51	1.0	97	1.7	163	1.1
53	1.0	98	1.1	171	1.1
55	7.0	99	3.7	175	1.1
57	19.4	107	1.4	189	1.5

Figure C-7. Mass Spectrum Table Of Unknown G

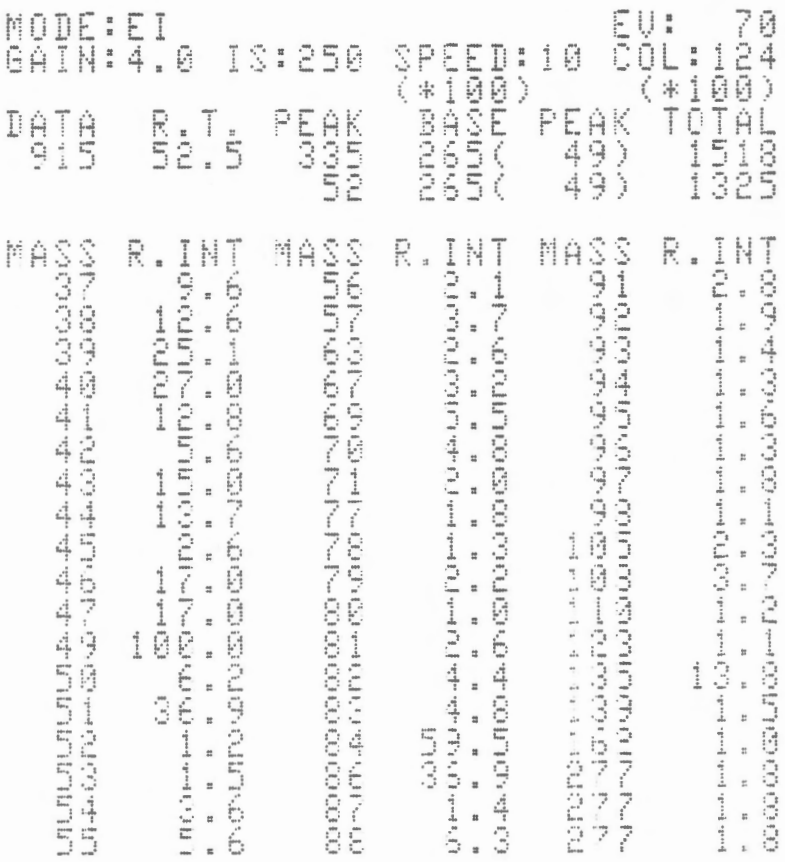


Figure C-8. Mass Spectrum Table Of Unknown H

VITA

Sajida S. Jafar Al-Beji was born on July 1, 1951, in Baghdad, Iraq, to Sadik Jafar Al-Beji and Hamdia Dakil. She received her high school diploma from Al-Markazia High School in Baghdad, Iraq in June, 1970. In September 1970, she entered the University of Baghdad (College of Science) in Baghdad, Iraq, and in June, 1974, she received a Bachelor of Science degree in Chemistry/Biochemistry. In September, 1974, she served with the University of Baghdad, College of Veterinary Medicine, Department of Physiology and Biochemistry. In June, 1979, she received a scholarship from the Government of Iraq to study in the United States.

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