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Flavor and stability of potato chips fried in canola, high oleic acid sunflower, sunflower, and cottonseed oils

Hung-Wei Lin

To the Graduate Council:

I am submitting herewith a thesis written by Hung-Wei Lin entitled "Flavor and stability of potato chips fried in canola, high oleic acid sunflower, sunflower, and cottonseed oils." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Sharon L. Melton, Major Professor

We have read this thesis and recommend its acceptance:

Marjorie Penfield, John Mount

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Carolyn Minkel

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Date 08-30-1993

FLAVOR AND STABILITY OF POTATO CHIPS FRIED IN CANOLA, HIGH OLEIC ACID SUNFLOWER, SUNFLOWER, AND COTTONSEED OILS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Hung-Wei Lin

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DEDICATION

This thesis is dedicated to my father,

Si-Chung Lin (1929-1989)

who has always been my inspiration

and my wife,

Yan Lin,

for her support, understanding and love throughout this endeavor.

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ABSTRACT

The objective of this study was to determine the effects of canola (CA), high oleic acid sunflower (HOSU), regular sunflower (SU), and cottonseed (CS) oils on the characteristics, flavor, and stability of potato chips. Oil degradation during frying was monitored also by peroxide value (PV), free fatty acid (FFA) levels, and fatty acid compositional changes. Chips were fried in the different oils and stored 0 wk (fresh) and under fluorescent light or in the dark at 23°C for 2 and 4 wk. Chips were analyzed for color, moisture and oil contents, PV of chip oil, concentrations of volatile components, flavor desirability, and acceptability.

The PV of each frying oil increased then decreased with increasing use. Free fatty acid content of frying oils increased with increasing use (4 hr frying) from 0.022 to 0.071% oleic acid. SU, CS, CA, and HOSU contained, respectively, 66.1, 57.4, 22.4, and 12.4% linoleic (C18:2) and 21.7, 16.4, 57.9, and 77.6% oleic (C18:1) acids. CS was most saturated containing 22.0% palmitic (C16:0). CA contained 9.7% linolenic acid (C18:3), and other oils, <1%. The percentages of C16:0, C18:0, and C18:1 increased with increasing oil use, but the levels of C18:2 and C18:3 decreased. Chips contained 1.26% moisture and 44.6% oil and

had a mean *L* value of 54.3, chroma of 27.2, and hue angle of 88.3 (yellow color). Oil from fresh chips had a mean PV of 4.4. Storage in dark did increased PV of oil in SU fried chips, but not in CA, HOSU or CS fried chips. Storage in light increased PV of oil in chips fried in all oils, but of SU fried chips the most. Twenty-four compounds were identified in chip volatiles, which included, 7 pyrazines, 3 alkanals, 4 alkenals, 3 alkadienals, 2-pentylfuran, 2-furaldehyde, benzaldehyde, 1-octen-3-ol, and phenyl-acetaldehyde. Concentrations of many aldehydes increased during storage in light but not in the dark. SU fried chips were most acceptable (like moderately to very much) of all chips. CA fried chips were less acceptable than CS fried chips but HOSU fried chips were just as acceptable as the CS fried chips. Storage in light or dark decreased flavor desirability in SU chips, and storage in light decreased flavor desirability in CS and CA chips but not in HOSU chips. SU and CS chips had higher levels of t,t-2,4-decadienal and CA chips higher levels of t,t-2,4-heptadienal. Increases in levels of hexanal, 2-furaldehyde and 2-nonenal in SU and CA chips during storage may have decreased flavor desirability while increasing concentrations of t,t-2,4-decadienal resulted in a less desirable flavor in the CA chips.

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CHAPTER I

INTRODUCTION

The level and type of fat in the diet of American consumers are considered unhealthy. Reports abound that link the intake of saturated fatty acids in the diet to the incidence of coronary heart disease (Peterkin, 1990; Sanders, 1990; Wardlaw and Snook, 1990). The 1988 Surgeon General's Report on Nutrition and Health urged Americans to reduce the consumption of fat, particularly of saturated fat (Morrison, 1990). Still, Americans love fatty foods. Currently, dietary fat provides 37% of Americans' total energy intake even though nutrition experts recommend that dietary fat provide no more than 30% of total energy intake and that saturated fat provide no more than 10% (Morrison, 1990; Sanders, 1990).

Consumption of a wide variety of snack and convenience foods, which may contain high amounts of fat, continues to increase in the United States (Smith et al., 1985). These foods contribute to the high dietary fat intake. In 1992, 38.4% of the total amount (5.2 billion pounds) of edible fats and oils consumed by Americans was used for baking and frying (USDA, 1992). Even if the levels of fat in these products are not reduced, substitution of unsaturated oils/fat for more saturated fat in these products could

result in a more healthy diet for Americans.

Deep-fried foods are overwhelmingly popular in the United States. In the mid 1980s, over 500 million pounds of oils/fats were used annually for frying potato chips (Stevenson et al., 1984). Oils/fats provide heat transfer during frying and contribute to the desirable color, flavor, and textural characteristics of the fried foods (Lisińska and Leszczyński, 1989; Stevenson et al., 1984; Varela, 1988). During the frying process, the oil/fat is exposed to moisture, heat, and oxygen, and undergoes hydrolysis, oxidation, and thermal reactions to form volatile and nonvolatile decomposition compounds which affect fried food quality (Boskou, 1988; Han, 1989; Stevenson et al., 1984). The formation rate and type of decomposition products formed depend on the frying fat, the foods being fried, the fryer design and the operating conditions of the fryer (Stevenson et al., 1984; Varela, 1988). Generally under the same conditions, the more unsaturated oils/fats are less stable during frying.

The flavor of fried foods is essentially dependent upon the type and concentration of the volatile decomposition compounds present (Deck et al., 1973; Han, 1989). According to Min and Schweizer (1983), thermal oxidation of the frying oil is responsible for the majority of the volatile compounds in potato chips. Also, the flavor

stability of snack foods such as chips, which contain ≥33% fat, depends greatly upon the degree of unsaturation of the fatty acids in the absorbed frying oil (Eskin et al., 1989). It is not surprising then that the type of oil used for production of snack foods affects their flavor likability and shelf life.

Cottonseed oil has been the most popular frying oil for production of potato chips in the southeastern United States (Weiss, 1983). However, cottonseed oil contains fairly high levels of saturated fatty acids (>35%) compared with other vegetable oils such as sunflower and canola oils (Weiss, 1983). Researchers reported that the flavor of chips fried in sunflower oil or in partially hydrogenated canola oil was as stable and desirable as that of chips fried in the more saturated cottonseed oil (Melton et al., 1993; Robertson et al., 1972, 1978). Also, oil processors have recently recommended unhydrogenated canola oil, the least saturated of all commercial oils/fats, for potato chip production (Covington, 1992). Regular sunflower and high oleic sunflower oils also have been appearing with increasing frequency on the ingredient labels of fried snack foods. However, no research reports were found in which the flavor volatiles of chips fried in any of the sunflower oils were investigated in combination with stability and sensory evaluation studies or in which chips fried in unhydrogenated

canola oil had been studied at all. Such studies are needed for a fuller understanding of the relationship of frying oils to chip flavor and to see if unhydrogenated canola oil is suitable for the production of desirable chips. Therefore, the objectives of this experiment were (1) to evaluate characteristics and frying performance of unhydrogenated canola, high oleic sunflower, sunflower, and cottonseed oils during potato chip production, (2) to determine composition and color of potato chips fried in such oils, (3) to determine stability of such chips stored in dark and light, and (4) to investigate chemically and sensorially the flavor of fresh and stored potato chips fried in such oils.

CHAPTER II

REVIEW OF THE LITERATURE

1. NUTRITIONAL ASPECTS OF UNSATURATED FAT VS. SATURATED FAT

Many snack and fast foods, such as potato chips, corn chips, fried chicken, fried fish, are prepared by deep-fat frying. During the frying process, the food absorbs frying fat, which is subsequently ingested by consumers. Since consumption of snack and fast foods is increasing in the U.S.A., the composition of frying fat is of concern to nutritionists (Smith et al., 1985). Currently, many health promotion organizations urge all Americans, including young people, to modify the amount and type of fat they consume (Ellison et al., 1990; Witchi et al., 1990).

Most fat is in the triglyceride form, a chemical moiety made up of a glycerol skeleton to which fatty acids are attached via ester linkages. Depending upon the number of double bonds in their carbon chains, fatty acids are classified as saturated (no double bonds), monounsaturated (one double bond), and polyunsaturated (two or more double bonds) (Labuza, 1971; Morrison, 1990).

Epidemiological studies have shown that a progressive

fall in coronary heart disease (CHD) has occurred in the U.S.A. and Australia since 1967. This evidence is associated with reduction in consumption of animal fats and increase in polyunsaturated fat consumption (Hetzel et al., 1989). The epidemiological results have been supported by animal experiments in which a linoleic enriched vegetable fat diet resulted in a protective effect against CHD in rats and marmoset monkeys (Hetzel et al., 1989).

High plasma levels of certain lipoproteins, such as low density lipoprotein (LDL) and very low density lipoprotein (VLDL), increase the risk of CHD (Sanders, 1990). There is also a strong link between low levels of high density protein (HDL) and an increased risk for CHD (Sanders, 1990; Wardlaw and Snook, 1990).

Saturated fatty acids, including lauric acid (C12:0) to palmitic acid (C16:0), increase plasma cholesterol level and LDL concentration more than just a high dietary fat intake (Sanders, 1990). In contrast, dietary saturated fatty acids with 18 carbons (stearic acid, C18:0), do not affect cholesterol or lipoprotein levels (Sanders, 1990). Nutrition experts suggest that the level of saturated fat consumed should be below 10% of the daily total energy intake (Sanders, 1990). They do not differentiate among types of saturated fatty acids.

Both monounsaturated and polyunsaturated dietary fat

can lower serum LDL level in men, but, depending upon the dietary level, polyunsaturated fat may also lower serum HDL levels which is not advantageous to lowering the risk of CHD (Gillis, 1988; Sanders, 1990; Wardlaw and Snook, 1990). For example, a diet containing 28% of total energy intake as polyunsaturated fat lowered serum HDL-cholesterol concentrations, but when polyunsaturated fat provided 19% of the total dietary energy level, it had no significant effect on serum HDL cholesterol concentrations (Wardlaw and Snook, 1990). Neither was any report found where intake of polyunsaturated fat close to that of the average American (7% of total energy intake) lowered serum HDL cholesterol level.

The effect of dietary polyunsaturated fat on serum HDL levels also is dependent on the concentration ratios of polyunsaturated to saturated fat. If the ratio of polyunsaturated fat to saturated fat is less than 1.5, then no matter what the level of polyunsaturated fat is in the diet, it is not likely to lower serum HDL concentration (Wardlaw and Snook, 1990).

Replacing saturated fat with monounsaturated fat in the diet also can have a positive impact on lowering the risk of CHD. For example, Greece has one the lowest rate of CHD incidence among nations, but fat supplies 30 to 40% of total energy intake in the Greecian diet. Olive oil, which con-

tains substantial amounts of monounsaturated fatty acids (>75% C18:1), is the primary oil/fat used in Greece and helps to reduce the incidence of CHD (Sanders, 1990; Wardlaw and Snook, 1990).

Changing people's eating behavior is difficult and time consuming (Ellison et al., 1990), and diets containing less than 30% of total energy intake as fat become unpalatable (Sanders, 1990). However, substitution of unsaturated for saturated fat also may improve health (Ellison et al., 1990) and one way to accomplish this is to use more unsaturated fats. Stevenson et al. (1984) reported that over 500 million pounds of frying oil was used yearly in the production of potato chips. That represents nearly 10% of the total amount of fat consumed yearly (5.2 billion pounds) by American consumers (USDA, 1992). If potato chip frying oil, which is often cottonseed oil, was replaced by more unsaturated oils such as sunflower oil and canola oil, then progress in altering the composition of Americans' dietary fat could be made.

2. DEEP-FAT FRYING - GENERAL INFORMATION

Frying is one of the oldest and most popular cooking methods used in the world. Frying originated and developed in the olive-growing countries where olive oil contributed considerably to the development of the frying technique (Chang et al., 1978; Varela, 1988). The term deep-fat frying food, used to distinguish from sauteing and pan frying, refers to the food being totally immersed in a frying fat for cooking (Stevenson et al., 1984; Weiss, 1983).

Deep-fat fried foods are very popular in the U.S.A. where people consume large quantities of snack and convenience foods, such as potato chips, corn chips, cheese puff, fried chicken and fish, and french fries which are cooked by deep-fat frying (Smith et al., 1985; Stevenson et al., 1984). Currently, nearly 40% of the total amount of edible fats and oils consumed by Americans yearly (5.2 billion pounds) are from fried and baked foods (USDA, 1992). More than 500 million pounds (10% of total amount of fats and oils consumed) are used for frying potato chips annually (Stevenson et al., 1984).

The use of frying as a heating technique is comparable to other thermal processing methods. However, frying may result in a decrease in preparation time and notable

increase in palatability when compared to other specific cooking methods (Varela, 1988).

All fried foods have an inner zone and an outer zone after being subjected to frying. The inner zone is a moist and cooked interior from which moisture is partly lost during frying. In fact, hot frying fat acts on the interior zone for only a short period of time, which is why deep-fat frying at high temperatures (>180°C) does not cause any more damage than other culinary processes. Steam, formed by frying, can prevent oil penetration into the inner zone, but not the outer zone. The outer zone is a crispy exterior skin, shell, or crust, which is one of the most palatable characteristics of a fried food and is produced by dehydration of the outer portion of the food. During the frying process, frying fat penetrates into the outer zone and partly replaces the void in the food created by dehydration. The outer zone surface has a desirable golden brown appearance as a result of browning or the Maillard reaction (Robertson, 1967; Stevenson et al., 1984; Varela, 1988; Weiss, 1983).

During deep-fat frying, the frying fat is either continuously or repeatedly used at high temperature in the presence of air, moisture, and the chemical components of the foods being fried. Hydrolytic, thermal, and oxidative decompositions of the frying fat occur under these

conditions. Such decomposition reactions cause formation of volatile decomposition products (VDP) and nonvolatile decomposition products (NVDP) (Chang et al., 1978; Handel and Guerrieri, 1990; Weiss, 1983).

Most of the VDP are removed from the frying oil by steam generated during frying. For example, according to Handel and Guerrieri (1990), free fatty acids were removed faster than they were generated during frying. However, the VDP retained in the fried food contributes to its flavor (Pokorny, 1989), and many VDP are formed from the fat during frying. Chang et al. (1978) identified 211 VDP produced by corn oil, hydrogenated cottonseed oil, trilinolein, and triolein under simulated commercial frying conditions.

Formation of NVDP in oil during frying is largely due to thermal oxidation and polymerization of unsaturated fatty acid present in frying oil during frying. The NVDP remain in frying oil and promote further degradation. The formation and accumulation of NVDP are responsible for physical and chemical changes in frying fat. The physical changes include increases in viscosity, darkness of color, and foaming and decreases in smoke, fire, and flash points (Weiss, 1983). Beside the increase in polymer content, other chemical changes include increases in the concentration of total polar components and hydroxyl content and decreases in level of unsaturated fatty acids. In

general, the chemical and physical changes lead to darkening, smoking, foaming, and increased viscosity in the frying fat. (Mancini-Filho et al., 1986; Perkins, 1967; Stevenson et al., 1984).

The performance and life of a frying fat is affected by many factors: (1) the conditions under which the frying process is done including time used for frying, frying temperature, fryer material and design, and daily turn over rate of the fat, (2) the types of frying fats including their chemical and physical properties, additives and contaminants, and (3) the food itself including any coating or battering, its physical structure (size and form), its thermal stability, interchange of food lipids and frying fat, and solubilization of color pigments (Robertson, 1967; Varela, 1988; Weiss, 1983). Addition of silicone (dimethylpolysiloxane) to frying fat can protect the oil from thermal oxidation by forming a monolayer on the surface of the fat and protecting it from exposure to oxygen (Handel and Guerrieri, 1990). Although antioxidants, such as tertiary butylhydroquionone (TBHQ) and butylated hydroxyanisole (BHA), become less effective when subjected to frying temperature, the combination use of antioxidants and silicone in frying oil has a synergistic effect in extending quality of frying oil (Boskou, 1988). Addition of bleaching clay and charcoal to frying oil combined with

daily filtration of the frying fat also removes decomposition products and improves the quality of frying oil during the early stages of its fry life (Mancini-Filho et al., 1986).

3. OXIDATION AND THERMAL DECOMPOSITION OF FAT

During deep-fat frying, the frying fat is subjected to elevated temperature, air, and moisture; therefore, hydrolytic, thermal, and oxidative decomposition of frying fat may occur. Fat oxidation that occurs at frying temperatures (>170°C) results in different concentrations and types of volatile products than oxidation at ambient temperatures (Frankel, 1980; Pokorny, 1989). A limited degree of lipid oxidation is desirable during deep-fat frying to provide desirable flavor components, but it can proceed to the point that the frying fat is deteriorated or the flavor becomes unacceptable. Oxidation at ambient temperature commonly results in rancid flavor (Gray, 1978; Handel and Guerrieri, 1990; Paquette et al., 1985; Stevenson et al., 1984). According to Frankel (1980), however, oxidation of the unsaturated fat is what produces desirable odor and flavor associated with deep-fat frying.

Lipid Oxidation

In general, lipid oxidation is proceeded either by self-catalytic free radical mechanism (autoxidation) or by photosensitized oxidation (Frankel, 1991). Autoxidation is the primary reason for deterioration of lipid containing foods (Gray, 1978; Nawar, 1985), and is the reaction of unsaturated fats with molecular oxygen. Photosensitized oxidation is initiated by a singlet oxygen mechanism and catalyzed by chromophobic components in the oils, such as natural dyes and pigments (Nawar, 1985; Neumann et al., 1991). The rate of lipid oxidation is roughly proportional to the degree of unsaturation of the fatty acid composition of the lipid. Thus, linolenic acid with three double bonds is more susceptible to oxidation than oleic acid with only one double bond (Gray, 1978; Stevenson et al., 1984).

In most cases, the oxidation of fatty acids proceeds through the following free-radical chain mechanism, that can be describe as initiation, propagation, and termination steps, to from hydroperoxides (Gray, 1978; Melton, 1983).

Initiation: $RH + O_2 \rightarrow R\cdot + \cdot OH$

Propagation: $R\cdot + O_2 \rightarrow ROO\cdot$

$ROO\cdot + RH \rightarrow ROOH + R\cdot$

Termination: $R\cdot + R\cdot \rightarrow RR$

$R\cdot + ROO\cdot \rightarrow ROOR$

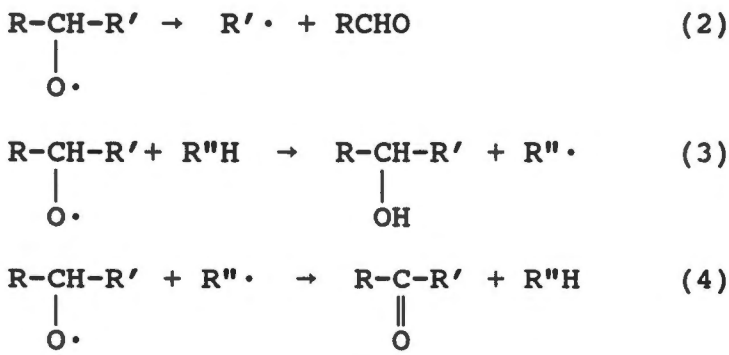
$ROO\cdot + ROO\cdot \rightarrow ROOR + O_2$

For autoxidation, free radicals may be produced under the presence of initiators, such as heat, metals, irradiation or light. These free radicals can further propagate to form peroxyl radicals and hydroxyperoxides under the presence of O_2.

For photosensitized oxidation, oxygen can be excited into a singlet state by energy transfer mechanism from a photosensitizer (such as chlorophyll and ß-carotene) that has been exposed to light. Then singlet oxygen reacts with unsaturated fatty acids to form radicals. The reaction rate between unsaturated and singlet oxygen fat is 1500 times faster than with normal oxygen to form hydroperoxides (Frankel, 1991; Neumann et al., 1991; Paquette et al., 1985).

Breakdown of the hydroperoxides may produce a wide variety of volatile and nonvolatile products. Hydroperoxides breakdown may undergo the following mechanism.

$$R\text{-}CH(OOH)\text{-}R' \rightarrow R\text{-}\underset{\underset{O\cdot}{|}}{CH}\text{-}R' + \cdot OH \qquad (1)$$



(2)

(3)

(4)

The first step is a homolytic scission at the oxygen-oxygen bond to yield the alkoxy and hydroxy free radicals (1). The second step is carbon-carbon bond cleavage which can occur on either side of the alkoxy group (2). In general, this reaction may result in the formation of aldehyde (volatile or nonvolatile) and a new radical. The volatile aldehydes are known to play an important role in the oxidized flavor of fats. The alkoxy radical can also abstract a hydrogen atom from the other molecule, which results in the formation of an alcohol and a new free radical (3). The free radicals formed from reaction (2) and (3) can further proceed propagation of chain reaction. However, interaction of two free radicals may yield non-radical products and terminate the chain reaction. Consequently, this termination reaction leads to the formation of ketones (4) (Nawar, 1985; Paquette et al., 1985).

According to Nawar (1985), aldehydes formed from lipid oxidation may not be stable and can further undergo a

variety of further reactions. For example, saturated aldehydes can be easily oxidized to form corresponding acids and can also participate in polymerization and condensation reaction.

Hydrolysis

Hydrolysis occurs during deep-fat frying when the frying fat is subjected to elevated temperatures and moisture is escaping from the food. Hydrolysis results in the liberation of free fatty acids, mono- and di-glycerides, and glycerine in the frying oil (Fritsch, 1981; Nawar, 1985; Stevenson et al., 1984).

High levels of free fatty acids in frying oil result in decreased smoke point, increased foaming, and reduction in the quality of fried food (Jacobson, 1991). In addition, free fatty acids are more susceptible to oxidation than fatty acids esterified to glycerol (Nawar, 1985).

The moisture introduced from the food has a positive effect on prevention of oil oxidation during frying. The steam, generated during frying, forms a film on the surface of the frying fat and prevents contact with air. It also helps strip the VDP and remove odors from frying fat (Handel and Guerrieri, 1990; Stevenson et al., 1984).

Handel and Guerrieri (1990) covered the frying vessel in order to retard evaporation and found that free fatty

acid value (AV) increased rapidly in the frying fat. Accordingly, AV of frying fat containing added 5% free fatty acids decreased because more free fatty acids evaporated than were formed. When AV of frying oil was adjusted to 2%, the production of free fatty acids equilibrated with evaporation. Also, addition of free fatty acids to a frying fat did not cause a catalytic increase in production of polar compounds, which can be interpreted that the added free fatty acids did not increase the fat hydrolysis rate.

In general, the products of hydrolysis reaction have no adverse effect on either quality or nutritional value of a fried food. Rather, the adverse effects are caused by lipid oxidation (Fritsch, 1981).

Thermal Decomposition

Under the condition of deep-fat frying, where the frying temperature is usually kept at a temperature between 175° and 200°C (Handel and Guerrieri, 1990), thermal oxidative reactions of saturated and unsaturated fats may occur (Nawar, 1985).

When frying fat is heated in air at temperatures higher than 150°C, even saturated fats may undergo oxidation and result in formation of complex decomposition compounds, among which a homologous series of carboxylic acids, 2-alkanones, n-alkanals, lactones, n-alkanes, and 1-alkenes

are major decomposition compounds. At frying temperatures, the oxidative decomposition reaction of unsaturated fats proceeds very rapidly. The mechanism and products of thermal oxidative reactions of unsaturated fats are the same as those of their autoxidation reactions (Nawar, 1985).

4. POTATO CHIPS

The name, potato chips, refers to thin potato slices deep-fat fried in oil or fat. The manufacture of potato chips can be traced back to the 1940s, after the technique of potato peeling, slicing, and frying had been introduced into the food industry (Lisińska and Leszczyński, 1989).

Production of high quality potato chips from raw potato tubers by deep-fat frying results in large changes in the chemical composition and physical and sensory characteristics of the potato. According to Talburt (1987), fresh potato tubers contain on the average: 77.5% water, 2% protein, 0.1% fat, 1% ash, and 19.4% carbohydrate. In general, potato chips consist of 40% fat, 5.5% protein, 50% carbohydrate, 3% ash, and 1.5% water (Lisińska and Leszczyński, 1989; Smith, 1987). Sugar and amino acids in the potato engage in the Maillard browning reaction to form the characteristic yellow-brown color of potato chips (Leszkowiat et al., 1990). Concentrations of other

microconstituents in the potatoes, such as vitamins, also may be decreased by thermal degradation, and because of the increase of fat level in the potato during frying, the caloric level in the potatoes increases also (Lisińska and Leszczyński, 1989). These physical and chemical changes in potatoes that occur during frying are responsible for the desirable sensory characteristics of potato chips.

Color of Potato Chips

During frying, color development in the food product proceeds by the following three mechanisms: (1) carmelization, (2) reaction of aldehydes, and (3) the Maillard reaction. In carmelization sugars dehydrate and react to form dark colored pigments; the high temperatures during the frying process accelerate carmelization. During frying, the fat undergoes thermal oxidative degradation to form ketones, alcohols, and aldehydes. One such aldehyde, malonaldehyde, reacts with amino acids and produces a brown colored complex. During the Maillard reaction, amino acids react with reducing sugars to form a dark-colored complex.

However, the Maillard reaction is believed to be mainly responsible for color development in potato chips (Coffin et al., 1987: Leszkowiat et al., 1990). Leszkowiat et al. (1990) fried filter paper disks soaked in a solution containing a similar chemical composition of water soluble

components as that found in potato tubers. An increase in glycine concentration in the solution increased the color absorption of the fried disks slightly. These latter researchers explained that this observation may be due to reaction of malonaldehyde and similar aldehydes with the extra glycine. In contrast, an increase in sucrose concentration in the filter paper disks increased color absorption (became darker) of the fried disk greatly. Leszkowiat et al. (1990) explained that since sucrose can decompose into fructose and glucose at frying temperatures, these reducing sugars can react with amino acids to form the brown color complex. This observation may indicate that the Maillard reaction accounts for the major color development in potato chips.

Since the concentration of amino acids (35-40 μmol/gm) of potato tubers is 3-4 times more than that of sugars (10-15 μmol/gm) (Lisińska and Leszczyński, 1989), any excess amount of sugar in fresh potatoes can directly contribute to the color formation in the potato chips (Leszkowiat et al., 1990). Starch in the potato tubers can be converted to sucrose, glucose, and fructose during exposure or storage at low nonfreezing temperatures (Coffin et al., 1987; Parkin and Schwobe, 1990). Although sucrose can be converted back to starch during reconditioning of potato tubers at room temperature after cold storage, monosaccharides, such as

glucose and fructose, can not be converted back to starch. Consequently, the monosaccharides accumulate during cold storage and form a dark brown color during frying increasing the color absorption of the potato chips (Parkin and Schwobe, 1990).

Many other factors also may affect the color of potato chips during production: the fat in which they are fried, the thickness of the potato slice, blanching conditions and frying conditions. According to Robertson et al. (1978), color of potato chips fried in palm oil was lighter than those fried in soybean and cottonseed oils. However, Han (1989) found that color of chips fried in the cottonseed oil had a higher Hunter *L* value or were lighter in color than those fried in the soybean and palm olein oils. According to Smith (1987), thicker potato slices result in a lighter color (decreased color absorption) in the chips. Increased blanching times leaches sugars out of the potato resulting in lighter, more desirably colored chips; however, increasing blanching water temperature has only a small effect on chip color (Smith, 1987). Also, higher frying temperatures and longer frying times result in darker colored chips, a detrimental effect. According to Parkin and Schwobe (1990), a commercial standard for potato chip color is an Agtron red value of 50 which is equivalent to a Hunter *L* value $\geq$ 40.

Texture of Potato Chips

The texture of potato chips is related to their moisture content (Gamble and Rice, 1988). The potato chips may be stale (have a leathery texture) if the moisture of potato chips exceeds 2%. Storage conditions also affect potato chip texture. Vickers (1987) equilibrated potato chips with Aw=0.11 and Aw=0.44 buffer solutions and studied texture by sensory evaluation and acoustical measurement. This researcher concluded that potato chips equilibrated with Aw=0.44 buffer solutions were less crispy, as determined by both sensory and acoustical evaluation, than those equilibrated with Aw=0.11 buffer solutions.

Moisture content of potato chips is affected also by temperature and time used for frying and the thickness of potato slices (Gamble and Rice, 1988). Longer fry times and higher frying temperatures result in production of drier chips, but it takes higher fry temperatures and longer times to decrease moisture content of thicker potato slices to a desirable level.

Chip texture is also affected by the dry matter content of potato tubers. If the dry matter of potato tubers is more than 25%, the resulting chips may be hard instead of crispy (Lisińska and Leszczyński, 1989).

Oil Content and Yield of Potato Chips

Another very important factor determining quality of potato chips is the oil content which is determined by the amount of oil absorbed during frying. If too much oil is absorbed, the cost of chip production is too costly to the manufacturer. If not enough oil is absorbed, chips of unacceptable quality are produced and yield is decreased (Lisińska and Leszczyński, 1989; Smith, 1987). Oil absorption during frying is influenced by the specific gravity of potato tubers, thickness of potato slices, drying of potato slice before frying, temperature, and time used for frying (Gamble and Rice, 1988; Lisińska and Leszczyński, 1989; Smith, 1987).

Specific gravity of potato tubers is correlated to their dry matter and has been used as an index of potato quality for more than 100 years (Potter et al., 1964). Lulai and Orr (1979) investigated the effect of specific gravity on chip yield and oil content using Norchip potatoes with specific gravities from 1.060 to 1.110. They observed that the yield of the chips increased and oil content of the chips decreased linearly with increasing specific gravity.

Gamble and Rice (1988) studied how oil content of potato chips was affected by thickness of potato slices. They found that both the yield and the oil content of the chips decreased as the thickness of potato slices increased.

The oil absorbed by potato chips during frying is directly related to the surface area available for moisture loss and oil uptake. The greater the surface area, the greater the moisture loss and the higher the oil uptake.

Gamble et al. (1987) fried 1.5 mm thick potato slices at different temperatures (145°, 165°, and 185°C) and for different periods of time to study the effect on moisture loss and oil uptake by the chips. Their study showed that the chip yield decreased with increased frying temperature; however, the oil content of the chips was not directly related to frying temperature. The yield of potato chips decreased with increasing frying time up to 5 min after which the yield stayed constant at 33%.

Drying potato slices before frying lowers the oil content of chips. First of all, drying results in lowering the moisture content thus increase specific gravity of potato slices (Smith, 1987). Secondly, drying reduces the surface moisture of potato slices so that the frying time can be also reduced (Linsińska and Leszczyński, 1989). Therefore, drying results in reduction of oil content in chips.

Flavor and Odor of Potato Chips

The flavor and odor of potato chips are dependent chiefly upon the volatiles present in the chips but are also influenced by other factors: the nonvolatile decomposition products present, the aroma inherent in the raw potatoes, the oils/fats used for frying, and added flavor material (Lisińska and Leszczyński, 1989; Smith, 1987). The volatiles are formed via reaction of amino acids with sugars during frying of chips (Deck et al., 1973; Leszkowiat et al, 1990; Smith, 1987), and during frying and storage, by oxidation and degradation of frying fat present in the chips at 35-44% (Frankel, 1991; Hawrysh, 1990).

Several volatiles have been identified in both fresh and stored potato chips. Mookherjee et al. (1965) identified 18 monocarbonyl compounds from fresh potato chips and 19 in stale potato chips. Buttery and Ling (1972) identified 46 compounds in a nonbasic fraction of steam volatile oil from potato chips. Deck et al. (1973) identified 53 compounds from potato chips and fractionated them into 9 groups, which included 8 nitrogen compounds, 2 sulfur compounds, 14 hydrocarbons, 13 aldehydes, 2 ketones, 1 alcohol, 1 phenol, 3 esters, 1 ether, and 8 acids.

Evidence for chip flavor volatile formation via reactions of amino acids and sugars was provided by Smith (1987). According to Smith (1987), the odor produced by

frying filter paper disks dipped in a solution containing amino acids and sugars at concentrations similar to those present in raw potatoes, was remarkably similar to that in fresh potato chips. In contrast, chips made from potato slices leached with hot water or alcohol, which removed soluble sugars and amino acids, did not possess characteristic potato chip flavor and odor. Smith (1987) concluded that the Maillard browning reaction provided volatiles important to desirable flavor of potato chips.

Pyrazines formed via the Maillard browning reaction are also common volatiles present in potato chips (Buttery et al., 1970). Two of these compounds, 2,5-dimethylpyrazine and 2-ethylpyrazine, have been described as having strong potato or roasted potato flavor (Deck et al., 1973). Also present in potato chips, 2-ethyl-3,6-dimethylpyrazine, with a trace amount of 2,5-dimethylpyrazine, has a characteristic earthy potato flavor (Deck et al., 1973).

Other volatile compounds arising from thermal degradation of amino acids in raw potatoes are also present in chips. One such compound is dimethyl disulfide, a low-boiling sulfur compound with a cabbage-like aroma at a high concentration and an onion-like aroma at a low concentration. Dimethyl disulfide may be produced by the degradation of methional, a decomposition product of methionine, or directly during degradation of methionine

(Arroyo and Lillard, 1970). Phenylacetaldehyde, which is one of the most abundant volatiles present in potato chips and which has a very strong, pleasant flavor, is produced from phenylalanine during frying (Arroyo and Lillard, 1970; Deck et al., 1973).

Furfuraldehyde which is formed via dehydration of sugars (Heath and Reineccius, 1986) also has been found in potato chips (Melton et al., 1993). It has a sweet, baked food aroma (Deck et al., 1973), and therefore, may contribute to the pleasant flavor and odor of potato chips.

Other volatile compounds, which may be derived from more than one source or formed via unknown pathways, are also present in potato chips. These include the aromatic volatiles, such as ethyl benzene, butyl benzene, 1,2,4-trimethylbenzene, and 1-ethyl-3,5-dimethylbenzene, which have rather unpleasant and kerosene-like objectionable odors (Deck et al., 1973). Other such compounds include diphenyl ether, which has a camphorous odor and is the only ether identified in potato chips (Deck et al., 1973), and benzyl thiobenzoate, which has a rather unpleasant, sulfur-like odor (Arroyo and Lillard, 1970; Deck et al., 1973). Two other compounds identified as volatiles in potato chips include ethyl acetate which is thought to be an artifact formed from ethyl ether used for extraction of the volatiles and 2,6-di-tert-butyl-4-hydroxytoluene (TBHQ), a common

antioxidant added to frying fat (Deck et al., 1973).

The oil content which is 35-44% of potato chips (Smith et al., 1985) also undergoes oxidation and degradation during frying to produce volatile components which affect flavor (Frankel, 1991; Smith, 1987; Stevenson et al., 1984). The thermal oxidation of the different unsaturated fatty acids in the chip oil results in different volatiles (Frankel, 1991; Hawrysh, 1990; Mookherjee et al., 1965; Smith, 1987). Oxidation of oleic acid (C18:1) yields heptanal, octanal, and nonanal. Hexanal, pentanal, cis-2-octenal, trans-2-nonenal, 1-octen-3-ol, 1-octen-3-one, and 2,4-decadienal (all geometrical isomers) are produced by oxidation of linoleic acid (C18:2). The volatile compounds, 2,4-heptadienal, trans,cis-2,6-nonadienal, 1-cis-5-octadien-3-one, trans,cis-3,5-octadien-2-one, and cis-3-hexanal originate mainly from oxidation of linolenic acid (C18:3). Another compound formed via thermal oxidation of frying fat is ethanol (Deck et al., 1973). Of all these volatiles, trans,trans-2,4-decadienal is believed to be most responsible for deep-fat fried flavor (Pokorny, 1989).

Oxidation of the oil in potato chips with subsequent formation of volatiles also occurs during storage. According to Min and Schweizer (1983), gas chromatographic (GC) analysis of the head space of potato chips stored in bottles showed that the potato chips consumed oxygen and

generated carbon dioxide during storage. Propane, butane, and pentane, which are sensitive to photooxidation, also increased in concentration in potato chip head space. The peroxide value of the potato chips increased proportionally to the decrease in oxygen level indicating that oxygen was involved in oxidation of potato chips. Min and Schweizer (1983) also found that concentrations of volatile compounds increased as peroxide value of potato chips decreased. They reported that this indicated that the volatile compounds were formed by decomposition of peroxides, the primary oxidation product of lipids.

Other investigators have related rancidity scores from sensory evaluation with the concentration of specific chip volatiles formed by oxidation during storage. Warner et al. (1974) stored potato chips at 60°C and determined that pentane concentration increased in the chip headspace as storage time increased. These latter researchers also found a linear correlation between the rancidity scores from a trained panel and pentane concentration in the chip headspace.

Oxidation of fatty acids, which occurs during storage of potato chips, can produce similar volatile products as thermal oxidation. For example, 2-propanal, which is derived from lipid oxidation and has a sharp pungent flavor, increases greatly in concentration during storage of potato

chips at room temperature (Dornseifer and Powers, 1963). Levels of hexanal and pentanal, two compounds already listed as products of C18:2 oxidation, increase in stale potato chips (Deck et al., 1973; Dornseifer and Powers, 1963; Mookherjee et al., 1965). Acetone, which can only originate from oxidation of linolenic acid, increases greatly during storage of potato chips at room temperature (Mookherjee et al., 1965). Also, the two compounds, 2-pentanone and 2-propanone, which are derived from lipid oxidation, both increase in concentration in chips during storage (Mookherjee et al., 1965).

The concentrations of other compounds produced by thermal oxidation of fatty acids during frying are also affected during potato chip storage. The compound, trans, trans-2,4-decadienal, having the characteristic deep-fat fried flavor, decreases greatly in concentration upon storage of potato chips (Han, 1989). The disappearance of 2,4-decadienal may be due to polymerization or autoxidative decomposition to other carbonyl compounds (Mookherjee et al., 1965). Upon exposure to air at room temperature, 2,4-decadienal develops first stale then rancid odors. Other aldehydes, such as trans-2-octenal, trans-2-nonenal, trans-2-decenal, and trans-2-undecenal, which are present in potato chips as a result of thermal oxidation of lipids, also decrease during storage of potato chips (Han, 1989).

The levels of two other compounds, ethanal and 2,3-butanedione, which have pleasant aromas and are thermal oxidation products of lipids, also decrease in concentration during chip storage (Deck et al., 1973; Dornseifer and Power, 1963; Mookherjee et al., 1965).

5. VEGETABLE OILS USED FOR FRYING POTATO CHIPS

The performance of cooking oils used for deep-fat frying depends up on the oil being used, the surface to oil volume ratio, the availability of air, the nature of the fried food, frying temperatures, and the equipment used for frying. The oil/fat used for deep-fat frying is not only a heat transfer medium but also becomes an ingredient of the fried food (Boskou, 1988; Weiss, 1983).

The frying fat contributes a flavor to potato chips which is a characteristic of that fat (Weiss, 1983). Therefore, it is important to investigate the effect of different oils/fats on potato chip quality since a large amount (500 million pounds) of frying oil is used annually for potato chip production (Stevenson et al., 1984). Cottonseed and sunflower oils are among the oils currently used for commercial production of potato chips (Weiss, 1983). Sensory characteristics and stability of potato chips fried in hydrogenated sunflower oil (Robertson and

Morrison, 1977) and in hydrogenated canola oil (Melton et al., 1993) have also been investigated. However, no reports exist of the flavor volatiles present in fresh and stored chips fried in regular or high oleic sunflower oil or of the characteristics of potato chips fried in unhydrogenated canola oil.

Cottonseed oil is frequently used to produce potato chips with a shiny, bright color; the chips also have very desirable flavor (Weiss, 1983). Cottonseed oil currently ranks fifth in the world production and consumption of major oils (Haumann et al., 1988; Weiss, 1983).

Sunflower oil is also satisfactory for frying potato chips, but it is more costly than other vegetable oils (Haumann et al., 1988). The high concentration of linoleic acid and desirable flavor and odor of heated sunflower oil make it highly acceptable for food use (Campbell, 1983). In quantity, sunflower oil is the fourth ranked edible oil traded in the world oil and fat market, following soybean, palm, and rapeseed (including canola) oils (Haumann et al., 1988).

High oleic sunflower oil, which is a new variety developed by two Russian scientists, was grown commercially for the first time in the United States in 1984. It is currently grown in North and South America, Europe, Asia, and Australia (Purdy, 1986; White, 1992).

After the introduction of low erucic acid and low glucosinolate varieties of rapeseed, the production of low erucic acid rapeseed oil (LEAR or canola oil) expanded in North America and Europe. This increased production has raised rapeseed oil from the eighth ranked oil in world production 25 years ago to the third ranked today (Haumann et al., 1988). Canola oil refers to rapeseed oil that contains less than 2% of erucic acid and is extracted from rapeseeds containing less than 30 μmol/g of one or any combination of the four known aliphatic glucosinolates including gluconapin, progoitrin, glucobrassicanapin, and napoleiferin, in its defatted meal (Haumann et al., 1988; Shahidi, 1990).

Cottonseed Oil

Cottonseed oil was the first edible oil produced in the United States, and its production dominated the world edible oil production until World War II. In general, cottonseeds yield about 16% crude oil, 45% meal, 9% linters, and 26 % hull (Cherry, 1983).

According to White (1992), the ranges in content of fatty acids in cottonseed oil are as follows: myristic acid (C14:0), 0.8-1.1%; palmitic acid (C16:0), 23.0-23.9%; stearic acid (C18:0), 2.7-4.2%; C18:1, 11.9-22.8%; C18:2, 47.5-58.1%; arachidic acid (C20:0), 0.3-0.7%; and docosanoic

acid (C22:0), 0.3-1.4%. Although the degree of unsaturated fatty acids of cottonseed oil may be related to its growing climate, the total unsaturated fatty acids vary only slightly, from 71.1% in the driest climate to 73.3% in the wettest climate (White, 1992). In addition to the previously listed fatty acids, cottonseed oil also contains small quantities of cyclopropenoid fatty acids (CPFA), sterulic and malvalic acids, in amounts ranging between 0.1 and 0.3 %. The CPFA have been shown to cause several toxic effects in animal tests. Another toxic compound existing in cottonseed oil is gossypol, a complex phenolic compound, which gives a strong red to brown color to crude cottonseed oil. However, gossypol and CPFA, are completely removed during production of refined cottonseed oil.

Not too many years ago, cottonseed oil was the predominant and preferred oil for production of snack foods in the U.S.A. because of its desirable flavor (Miller, 1988). Usually, potato chips fried in cottonseed oil are used as standards in comparison with those fried in other oils (Fuller et al., 1971; Han, 1989; Robertson et al., 1978). According to Weiss (1983), cottonseed oil has a nut-like flavor which is very desirable to consumers in potato chips and other fried foods. Like other oils, the flavor of deodorized cottonseed oil reverts. But unlike other oils, this reversion flavor is desirable (Weiss, 1983). Also, the

intensity of reversion flavor of cottonseed oil is strong enough to mask the less desirable reversion flavors of other oils when blended with cottonseed oil (Weiss, 1983).

However, the quality improvements in soybean oil have decreased the use of cottonseed oil in the United States (Miller, 1988), and U.S. farmers have turned to growing soybeans instead of cotton. The highest production of cottonseed oil occurred in 1953 at just over 2 billion pounds; the lowest production occurred in 1983 at 777 million pounds (Haumann et al., 1988). The availability of cottonseed oil is dependent upon the market for cotton lint, which has have been declining for years. If current production trends continue to decrease, cottonseed oil will become a specialty item of declining importance and high cost (Han, 1989; Miller, 1988).

Sunflower Oil

Sunflower oil is obtained from the seed of the plant *Heliantbus annus*, which is native to North America. Sunflower seeds were taken to Europe and Russia in 17th century, and since then, sunflower oil has been predominately used in European countries. At one time, the USSR was the world's largest producer of sunflower oil. However, the United States has become the world's largest exporter of sunflower seed as well as sunflower oil

(Campbell, 1983; Purdy, 1986).

Two types of sunflower seeds are produced: high oil and low oil seeds. High oil sunflower seeds, which contain 40% oil, are grown for oil production, while low oil sunflower seeds (containing about 30% of oil) are grown for confectionery, snack, and birdfeed markets (White, 1992).

Crude sunflower oil is light to dark amber in color. Refined oil is very light or pale yellow and has a relatively low level of natural antioxidants (Campbell, 1983; Robertson et al., 1972). The fatty acid composition of sunflower oil, especially the C18:2/C18:1 ratio, is affected by the climate in which the seeds are grown. This ratio is most affected by the growing temperature. The warmer the climate during maturation of the seeds, the higher the level of C18:1 and the lower the C18:2 level (Campbell, 1983). Concentration ranges of C18:2 and C18:1 acids in Northern sunflower oil, produced above the 39th latitude in the United States, range from 44 to 68% for C18:2 and 19 to 47% for C18:1. Nagao and Yamazaki (1983) grew four varieties of sunflower under seven different environmental conditions (planting locations and date) and observed that fatty acid compositions differed considerably among the sunflower oils. Fatty acid concentration ranges in the oils were as follows: palmitic acid, 4.2-6.2%; stearic acid, 2.4-6.0%; oleic acid, 13.6-49.9% and linoleic

acid, 43.8-75.4%. They concluded that the percentage of linoleic acid was negatively correlated with growing temperature and oleic acid content was positively related. However, the combined percentage of oleic acid and linoleic acid was consistent across growing conditions and was not affected by the environmental climate.

Two Russian scientists, Soldatov and Kharachenko, treated normal planting sunflower seed (Peredovik) with the mutagen, dimethyl sulfate, and derived progenies (Perevenets) which were high in oleic contents and stable to different climatic growing conditions (Purdy, 1986). Fick (1983), in the United States, selected the dominant genes from the Perevenet variety and incorporated them into hybrids suitable for commercial production. In 1984, high oleic sunflower seed was grown commercially in the United States for the first time in California, North Dakota, and Texas (Purdy, 1986). Purdy (1986) collected the high oleic seeds grown in these three areas and analyzed their chemical compositions. This researcher observed very little difference in levels of either oleic or linoleic acid among the oils obtained from the three growing areas. In the oils, palmitic acid ranged from 2.7 to 4.2%, stearic acid from 4.2-5.0%, oleic acid from 80.5 to 86.0%, and linoleic acid from 4.0 to 8.3%.

Several investigators have investigated the flavor

and/or stability of chips fried in sunflower oil versus other oils. In many studies, partially hydrogenated sunflower oil was used because of the instability of the unhydrogenated sunflower oil (White, 1992).

Robertson et al. (1972) compared flavor of potato chips fried in partially hydrogenated sunflower (37% C18:2, IV=107.5) with that of chips fried in a blend of 70% cottonseed and 30% corn oil. They found no significant difference in sensory flavor scores between the chips fried in fresh oils or oils heated 20 hr or between the fresh chips and chips stored up to 10 wk.

Robertson et al. (1978) investigated the stability of potato chips fried in southern sunflower (C18:2 50.3%, IV=122), cottonseed, and palm oils. They found that the fresh chips fried in cottonseed oil had a better flavor than those fried in sunflower and palm oils. However, they found no significant differences among the oils in the flavor scores of potato chips stored up to 10 wk.

Morrison et al. (1973) used the active oxygen method (AOM) to compare the oxidative stability of commercial shortening, partially hydrogenated northern sunflower oil, unhydrogenated southern sunflower oil, and unhydrogenated northern sunflower oils used for deep-fat frying. They reported that the initial AOM for these oils were 50.5, 29.2, 26.0, and 13.2, respectively. In the potato chip,

southern sunflower oil (C18:2 52.2%, IV=121) was expected to have a stability intermediate between the unhydrogenated, northern (C18:2 69.5%, IV=135) and partially hydrogenated (C18:2 37%, IV=109) northern sunflower oils. However, the rate of oxidation (measured by the slope of the log of AOM values vs. the time used for deep-fat frying) of commercial shortening was about the same as that of southern sunflower oil which was 3 times more than that of partially hydrogenated northern and northern sunflower oils. They noted that the rate of oxidation of southern sunflower was not expected, but hydrogenation of southern sunflower oil may increase its oxidative stability.

Huang et al. (1981) compared stability of northern sunflower (C18:2 70.5%, IV=136) and corn (C18:2 61%, IV=127) oils under different treatments. They found that sunflower oil had a less strong flavor intensity score and a higher preference score than corn oil. Sunflower oil developed peroxides more rapidly than corn oil, but the higher peroxide value of sunflower oil did not affect its superior sensory scores. Also, starch chunks fried in corn oil were more stable to oxidation than those fried in sunflower oil when subjected to the Schaal Oven Test (16 days of accelerated storage at 65°C).

Warner et al. (1989) analyzed flavor and oxidative stability of soybean, sunflower, and low erucic acid

rapeseed (LEAR) oils by sensory evaluation and chemical tests. Flavor scores of oils processed with and without addition of citric acid were not significantly different among soybean, sunflower, and LEAR oils. When aged at 60°C in the dark, sunflower oil developed significantly more volatile compounds than soybean and LEAR oils. Warner et al. (1989) reported that all freshly deodorized oils tasted nutty and buttery, but that each of the three oils developed distinct flavor characteristics during early stages of oxidation before development of rancid and painty flavors. The flavor of aged soybean oil was described as grassy and beany, while that of LEAR had characteristics described as cabbage, sulfur, and grassy. The odor of aged sunflower oil was described as pine, cedar, weedy, and acrid. In the later stages of oxidation, all oils were described as rancid; in addition, high linolenic acid containing soybean and LEAR oils also were described painty. LEAR also had a fishy flavor. Light exposed sunflower oil was described as stale or sour.

Purdy (1985) used the AOM method to compare oxidative stability of high oleic sunflower oils derived from different cultivars with that of northern sunflower oil. This researcher reported that the AOM values increased from 11 to 100 hr as the linoleic acid content decreased from 69% to 1%. The increase in the AOM value was proportional but

not linear to the decrease of linoleic acid in sunflower oil.

Canola Oil

The "rape" in "rapeseed" originates from the Latin *rapum* which means "turnip". Rapeseed comes from several species belonging to the genus *Brassica* (Shahidi, 1990). Canola refers to rapeseed cultivars of *Brassica napus* and *Brassica campestris* that have been bred to produce oil containing less than 2% erucic acid. In addition, the seed must contain low levels of glucosinolates since they may enhance the development of thyroid disease and lead to produce unpleasant sulfur odor during heating of the oil (Abraham and deMan, 1988; White, 1992). Introduction of low erucic acid and low glucosinolate varieties of rapeseed has increased the planted acreage in North America and Europe. This increased acreage has made rapeseed jump from the eighth ranked oil in world production 25 years ago to the third ranked oil today (Haumann et al., 1988). Canola oil was granted the status of Generally Recognized as Safe (GRAS) by Food and Drug Administration of the United States in 1985 (White, 1992).

The fatty acid composition of canola oil is dependent on the variety of rapeseed. An acceptable variety of *B. nupus*, Westarr, produces an oil containing 4% C16:0, less

than 1% palmitoleic (C16:1), 2% C18:0, 62% C18:1, 18% C18:2, 9% linolenic (C18:3), 2% eicosenoic acid (C20:1), and less than 1% erucic acid (C22:1). Because of its high linolenic acid content, even good quality canola oil may develop an unpleasant room odor when heated to frying temperatures (Eskin et al., 1989). Although it is reported that the fatty acid composition of canola oil is highly desirable, scientists are still investigating new varieties of rapeseed which can produce less linolenic acid in oil (Auld et al., 1992). The variety, *B. nupus* L., Stellar, produces an oil containing less than 3% linolenic acid and is now in commercial production in Canada. The oil derived from the Stellar variety was 17.5% more stabile than the oil obtained from the cultivar, Westar (Scarth et al., 1988).

Eskin et al. (1989) reported that reduction in linolenic acid content of canola oil from 8-9% to 1.6% reduced significantly the development of undesirable room odor during frying and improved flavor quality and storage stability. However, the room odor of the canola oil from the low linolenic acid cultivar was still too strong to be considered acceptable when it was used for frying. They concluded that even a small amount (1.6%) of linolenic acid in canola oil can trigger the development of undesirable room odor.

According to Hawrysh (1990), a high quality canola oil

should have a peroxide value (PV) below 2.0 meq/kg, since PVs below 2 are associated with sensory scores indicating that oils are bland in odor and flavor. The type of storage container for canola oil during storage also affects its stability. Canola oil stored in an amber glass bottle has greater oxidative stability than that stored in a clear glass bottle (Warner et al., 1989).

Warner et al. (1989) reported that LEAR and sunflower oils were significantly more stable than soybean oil under the presence of citric acid in light-exposure tests (7535 lux at 30°C). However, in the absence of citric acid, LEAR was less stable than sunflower and soybean oils in light-exposure tests.

Sattar et al. (1976) used different wavelengths of light ranging from 350 to 750 nm, which are usually used in supermarket stores, to examine the effect of light on stability of oils, including LEAR. They found that the oil oxidation rate increased as the wavelength of light decreased. The most deleterious wavelengths were those below 455 nm. Wavelengths longer than 595 nm produced minimal effect of photooxidation on oils. Exposed to light with wavelength less 595 nm, LEAR appeared to be less stable than soybean, corn, and coconut oils (Sattar et al., 1976). Hawrysh (1990) noted that light is an important factor affecting production of off flavors in canola oil.

Melton et al. (1993) investigated the flavor and stability of potato chips fried in partially hydrogenated canola, cottonseed, and canola and cottonseed oil blends (85:15 and 70:30). They reported that the chips fried in partially hydrogenated canola oil were as acceptable as those fried in cottonseed oil. There was no significant difference in flavor and overall acceptance scores among the chips fried in these oils. There were also no significant differences in peroxide values among the chips stored in the light and in the dark for up to 4 wk or in the chips fried in the different oils. However, PV increased with increasing storage time from 0 to 4 wk. Melton et al. (1993) concluded that partially hydrogenated canola oil can produce chips with just as desirable flavor as cottonseed oil.

As stated previously, use of more unsaturated oils for production of potato chips than cottonseed oil possibly could result in a healthier diet for U.S. consumers. Three oils which meet this criterion are sunflower oil, high oleic sunflower oil and unhydrogenated canola oil. Although the quality of chips fried in regular and high oleic sunflower oils have been studied, the flavor volatiles of chips fried in these oils have not been determined. Neither has the quality of chips fried in canola oil been investigated. Therefore, an experiment is needed in which the flavor and

stability of chips fried in the sunflower and canola oils compared with those of chips fried in cottonseed oil is investigated.

CHAPTER III

MATERIALS AND METHOD

1. EXPERIMENTAL PLAN

This experiment was divided into 4 separate parts: (1) frying oil performance, (2) raw potato and potato chip characteristics, (3) chip stability during storage, and (4) chip flavor and acceptability. The dependent variables for frying oil performance included measurement of oil free fatty acid content, peroxide value, and fatty acid composition over time. For frying oil performance, a single replication consisted of evaluating each of four frying oils (cottonseed, sunflower, high oleic sunflower, and canola) when fresh, after being heated for 3 hr at 163°C and raised to 193°C for chip production (0 hr), and at every hr (up to 4 hr) that the oil was used for frying. The dependent variables for the second part of the experiment were raw potato specific gravity and potato chip color and fat and moisture concentrations of potato chips. For chip characteristics, a single replication consisted fresh chips fried in each oil, and for potato specific gravity, a single replication consisted of fresh potatoes selected for chips fried in each oil. For chip stability during storage, the

dependent variable was peroxide value of oil extracted from the chips, and a single replication consisted of chips that were fried in each of the oils (oil = 4) and then stored for 0 (fresh), and in the light and dark for 2 and 4 wk (storage = 5) at 23°C. For the fourth part of the experiment, chip flavor volatiles were identified and their concentration determined, and the flavor and acceptability of the chips were analyzed by sensory evaluation. Also, in the measurement of chip volatiles, Kovat's Index for each identified volatile and the percentage recovery for several of the volatiles using simultaneous distillation extraction and analysis by gas chromatography were determined. For chip flavor volatiles and sensory flavor and acceptability scores, a single replication consisted of chips fried in the different oils (oil = 4) and stored for 0 wk (fresh) and for 4 wk in the light and dark (storage = 3). In each part of the experiment, 3 replications were completed. The order in which the oils were used for potato chip production was randomized across replications as shown in Table 1, and enough potato chips were fried in a single day to complete all planned evaluations. The experimental design of the experiment for parts 1 and 3 and for the flavor volatiles in part 4 was a split plot with the whole plots being the oils used for chip production and the split in each plot being the oil sampling times in part 1 and the chip storage

Table 1 -- Dates potatoes were obtained from Tom's Snack Foods, their specific gravity and randomized order in which oils-replications were done

Date	Potato sp. gravity	Order	Oil used for frying	Replication
07/27/92	1.080	1	Cottonseed	1
07/29/92	1.081	2	Cottonseed	3
07/30/92	1.082	3	High Oleic Sunflower	2
08/03/92	1.077	4	High Oleic Sunflower	1
08/05/92	1.076	5	High Oleic Sunflower	3
08/06/92	1.072	6	Regular Sunflower	3
08/10/92	1.068	7	Canola	1
08/12/92	1.074	8	Canola	2
08/13/92	1.070	9	Regular Sunflower	1
08/24/92	1.082	10	Cottonseed	3
08/25/92	1.076	11	Regular Sunflower	2
08/26/92	1.077	12	Canola	3

treatments and times in parts 3 and 4. Part 2 was a completely randomized block design, and the sensory evaluation in part 4 was an incomplete block design as explained later.

2. SOURCES OF RAW MATERIAL FOR FRYING AND STORAGE OF POTATO CHIPS

Enough (72 kg) of each oil (canola, regular sunflower, high oleic sunflower, and cottonseed) was obtained at one time from a fat and oil processor in the United States to complete the entire experiment. The potatoes (Atlantic, OH, cultivar) and chip salt (2 kg) were obtained from Tom's Snack Foods, Knoxville, TN. Raw potatoes (45.8 kg) were used the same day as they were obtained. Glass jars (0.45 and 1.9 L) and polyethylene bags (3.8 L) for chip storage were obtained from local suppliers.

3. FRYING OIL HANDLING AND SAMPLING

For each oil-replication (Table 1) in this experiment the oil was used to fry potato chips for 4 hr. Before frying started, 13.6 kg of oil were placed in a Gold Medal Model FW-12 Shallow Fryer (Gold Medal Products Co., Cincinnati, OH) and heated at 163°C for 3 hr. The oil

temperature was raised from 163 to 194°C (approximately 15 min) prior to beginning of chip frying. The oil was sampled (200g) immediately before the first batch of chips was fried (0 hr) and every hour of frying use (up to 4 hr). Each oil sample was placed in a 0.45-L glass jar, cooled to ambient temperature, flushed with nitrogen, sealed and stored at -18°C in the dark until analyzed. Fresh oil was added back to the fryer as needed (approximately 500 mL per hour) to keep the level near the full mark during chip production. The free fatty acid level, the peroxide value (PV), and the fatty acid composition of each oil sample were determined as described later.

4. PRODUCTION AND STORAGE OF POTATO CHIPS

In this experiment, the planned analyses of chips for each oil-replication in parts 2, 3, and 4 of the experiment required 27 1.9-L glass jars, each containing 125-g chips, and four 3.8-L polyethylene freezer bags, each containing 200 g of chips. For part 2 of the experiment, the specific gravity of the raw potatoes was obtained from Tom's Snack Foods at the time of pick-up (Cline, 1992) and fresh chips from each oil-replication were analyzed for moisture and fat contents and color. For part 3 of this experiment, chips from each oil-replication were stored for 0 wk and in the

light and dark at 23°C for 2 and 4 wk and were analyzed for peroxide value of the oil extracted from the chips. For part 4, chips fried in each oil-replication and stored for 0 wk and in the light and dark at 23°C for 4 wk were analyzed for flavor volatiles and for flavor and acceptability by sensory evaluation. For each oil-replication, the jars of chips were randomly assigned to storage for 0 wk (3 jars), in the dark for 2 wk (2 jars) or 4 wk (10 jars) or storage in the light for 2 (2 jars) and 4 wk (10 jars). The 4 bags of potato chips at 0 wk were used for sensory evaluation of fresh chips. Containers of chips at 0 wk storage were flushed with nitrogen as quickly as possible, sealed and stored in cardboard boxes at -18°C until they were analyzed. When jars of chips reached the required storage time, they were treated and stored in the same way. Descriptions of all analyses are given later.

For each oil-replication, 45.5 kg of raw potatoes were washed and peeled with a Model 6015P abrasive potato peeler (Hobart Manufacturing Co., Troy, OH). The peeled potatoes were sliced into 0.127-cm thick slices using a Hobart slicer, Model 84142 (Hobart Manufacturing Co., Troy, OH). The potato slices were washed 3 min in warm water (35°C) two times in order to get rid of surface starch. The washed potato slices were sorted and drained. Potato slices, which were evenly sliced and had the proper thickness, were spread

in a single layer in a shallow pan and dried for 8 min under forced air flow at room temperature (23°C). A batch (400 g) of potato slices was placed between doughnut frying racks, lowered into the frying oil and fried for 3 min and 25 sec. Each batch of chips was drained on paper towels for 1.5 min, placed in a covered 27-L plastic barrel, and shaken with 1.0% (w/w) salt by inversion of the barrel 10 times. After each inversion, the barrel was rotated 360°. Five batches of chips were fried per hr. Chips were packed and sealed in 1.9-L clear glass jars (125 g chips/jar) or closed in 3.8-L polyethylene freezer bags (200 g chips/bag). Potato chips in randomly selected jars were stored at 23°C in fluorescent light or placed in cardboard boxes (dark) for 2 and 4 wk as previously described. The intensity of the fluorescent light on the chips was measured by a LI-185 Photometer (Lambda Instruments Corporation, Lincoln, NE).

5. CHEMICAL ANALYSIS OF FRYING OIL SAMPLES

Peroxide Value of Frying Oils

The peroxide value (PV) of frying oil samples was determined by measuring the milliequivalents (meq) of iodine (peroxide oxygen) formed per kg of fat according to AOCS (1973) Official Method Cd 8-53. Approximately 5 g of frying oil was weighed into a 250-mL glass-stoppered Erlenmeyer

flask and dissolved in 30 mL of acetic acid-chloroform (3:2, V/V) solution. A 0.5-mL aliquot of saturated potassium iodide solution was added to the sample, and the mixture was allowed to stand for 1 min in dark before 30 mL of distilled water was added. The mixture was then titrated with 0.1 N sodium thiosulfate solution. The sodium thiosulfate solution was added gradually until the yellow color of the free iodine had almost disappeared. Then 1 mL of 1% soluble starch solution was added. The endpoint of titration was determined by disappearance of blue color. The actual concentration of thiosulfate solution was determined according to AOCS (1973) Official Method Cd 1-25. PV of the frying oil was expressed as milliequivalents of peroxide per kg of oil sample and was calculated by using the following equation:

$$PV\ (meq\ peroxide\ per\ kg\ oil) = \frac{(S-B)\ X\ N\ X\ 1000}{Wt.\ of\ Sample\ (g)}$$

where B = titration of blank in mL; S = titration of sample in mL; and N = normality of sodium thiosulfate. The peroxide value of each oil sample was determined as the mean of duplicate measurements.

Free Fatty Acids of Frying Oils

Free fatty acid content in frying oil samples was determined according to AOCS (1974) Official Method Ca 5a-40. Approximately 56 g of fresh oil or 30 g of used oil were weighed into a 125-mL flask. Fifty milliliters of hot (80°C) neutralized alcohol and 2 mL of 1% phenolphthalein indicator solution (W/V in 95% alcohol) were added. The mixture was titrated immediately with approximately 0.1 N potassium hydroxide solution until the color of the mixture turned from clear to a pale pink color which lasted for approximately 30 sec. During titration the flask was vigorously shaken to make sure that the acid mixed well with the alkali. The actual concentration of potassium hydroxide was determined according to AOAC (1975) Official Method 50.003. The percentage of free fatty acids in frying oils was expressed as percentage of oleic acid in oil and calculated from the following equation:

$$\textit{Free fatty acids (\% oleic acid)} = \frac{\textit{mL of alkali X N X 28.2}}{\textit{Wt. of Sample (g)}}$$

where N = normality of potassium hydroxide. The factor 28.2 is milliquivalent weight of oleic acid in g multiplied by 100. The free fatty acid content of each oil sample was determined as the mean of duplicate determinations.

Fatty Acid Composition of Frying Oils

The fatty acid composition of frying oil samples was determined according to AOCS (1983) Official Method Ce 2-66. Triglycerides were converted to methyl esters of their fatty acids before they were analyzed by gas chromatography (GC). The fatty acids were esterified by the saponification-trans-esterification method of Metcalf et al. (1966). Approximately 100 mg of frying oil sample were weighed into a 18-mL culture tube with a PTFE-faced rubber lined cap. After 4 mL of 0.5 N methanolic sodium hydroxide were added, the tube was capped, shaken with a Vortex mixer Model S8223-1 (American Scientific Products Inc, Stone Mountain, GA), and heated in a boiling water bath for 10 min. Then the tube was cooled to room temperature and 5 mL of 14% boron trifluoride-methanol reagent (Supelco Inc., Bellafonte, PA) added. The tube was capped and shaken again with the Vortex mixer. The tube was heated in a boiling water bath for another 2 min and cooled to room temperature before 5 mL of pentane and 3 mL of saturated sodium chloride solution was added. The tube was capped and shaken with the Vortex mixer to extract fatty acid methyl esters (FAME). Pentane solution (3-4 mL) was transferred into a test tube and dried with a small amount of anhydrous sodium sulfate. The FAME of frying oil samples were analyzed within 24 hr after they were prepared.

FAME were analyzed on a 0.25 mm i.d. X 27 m long fused silica SP2330 column (Supelco, Inc., Bellefonte, PA), in a Shimadzu Model 9-AM GC (Shimadzu, Columbia, MD). The GC was equipped with a flame ionization detector (FID), a Shimadzu automatic sample injector Model AOC-9, and a Shimadzu CR-5A data processor connected to Shimadzu Chromatopack data processing software installed in a IBM personal computer Model XT (International Business Machine Corporation, Armonk, NY). For each sample, FAME extract (1.5 μL) was automatically injected into and analyzed by the GC with injector and detector temperatures of 250°C. FAME were analyzed by using a column temperature program starting at 150°C which was increased to 220°C at 2°C/min and a 2 mL/min flow rate of helium carrier gas. A standard solution containing known concentrations of the major fatty acids, similar to concentrations present in the sample, was analyzed by the GC method and used to determine fatty acid composition of frying oil samples. Identification of individual components in each sample was determined by comparison of their GC retention times with those of the known standards. AOCS Oil Reference Mixture RM-1 (Matreya, Inc., Pleasant Gap, PA) was used to determine calibration factors for analysis of fatty acid composition in cottonseed oil, and a rapeseed oil mixture (low erucic acid) was used for sunflower (regular and high oleic) and canola oils. The

calibration factors were calculated by comparison of relative GC response of each fatty acid component with that of methyl palmitate according to AOCS (1983). The percentages of the following fatty acids in each frying oil sample were determined: myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), eicosenoic (C20:1), behenic (C22:0), erucic (C22:1), and lignoceric (C24:0).

6. CHEMICAL AND PHYSICAL ANALYSES OF CHIPS

For analysis of moisture and fat contents, approximately 40 g of potato chips were ground by a Braun commercial coffee grinder (Braun, Inc., Lynnfield, MA). Ground chips were placed in polyethylene bags, flushed with nitrogen, and stored at -18°C in dark until they were analyzed.

Specific Gravity of Potatoes

The specific gravity of potatoes was measured in the following manner. Potatoes (3.64 kg) were weighed into a metal basket. The basket was hung in a barrel (0.75 m in diameter by 1 m in height) of water with a Potato Hydrometer

(Potato Chip Institute International, Cleveland, OH). The specific gravity of the potatoes was read directly from the Potato Hydrometer and recorded.

Moisture Content of Chips

The percentage of moisture in the potato chips was determined according to AOAC (1980). Coded aluminum pans with lids were dried in a 100°C oven for 1 hr, transferred to vacuum desiccators, cooled to room temperature, and then weighed. For each of the 12 chip samples, approximately 2 g of blended potato chips were weighed into an aluminum pan with a lid, and duplicates were run. The pan with the lid open was heated in the vacuum oven at 95°C and 584.2 mmHg for 5 hr. The samples were transferred to vacuum desiccators, cooled to room temperature and weighed. The moisture in each duplicate was calculated by the following equation:

$$Moisture\ (\%) = \frac{W1-W2}{W1} X\ 100$$

where W1 = weight (g) of potato chips before drying and W2 = weight (g) of potato chips after drying. An average moisture concentration was calculated for each fresh chip sample.

Fat Content of Chips

The fat content of fresh potato chip samples (n=12) was measured by a modified Babcock procedure (Hefnawy et al., 1978) in duplicate. Duplicate measurements were made for each sample. For each duplicate, approximately 2.25 g of potato chips were weighed into a Babcock test bottle (scale up to 50%). One mL of N-amyl alcohol was added into the Babcock test bottle. Then 15 mL of hydrochloric acid (about 30% of HCl) was added into the bottle. The contents of the bottle were mixed thoroughly by swirling, and the bottle was kept in a 80°C water bath for 3 min. During the incubation of duplicates, the bottles were removed, swirled, and placed back into the water bath at 30 sec intervals. After 3 min incubation, the bottles were removed from the water bath, and 80°C hot water was added to each to bring the level to approximately 1 cm below the bottle neck. The bottles were swirled, and more hot water was added to each bottle to bring the aqueous layer level to approximately the 40% mark on the bottle neck. The bottles were centrifuged for 5 min in a Babcock centrifuge and tempered in a water bath at 60°C for 2-3 min. The percentage of oil in potato chips was determined by the following equation:

$$Oil\ (\%) = S\ X\ \frac{Wt.\ of\ Sample\ (g)}{2.25}\ X\ 4$$

where S = % fat in a 9 g sample and 2.25 = g chips analyzed.

The fat content of each sample was determined as the mean of duplicate measurements.

Color of Potato Chips

The color of potato chips was measured using a Hunter Color Difference Meter Model D25M-2 (Hunter Association Laboratory, Inc., Reston, VA) which was standardized by white tile No. C2-21125 with L = 91.03, a = -1.3, and b = +1.6. Approximately 50 g of potato chips were crushed with a fork and split evenly between two glass cuvettes. The color was measured on both samples by the color meter according to Anonymous (1979). Mean Hunter color values, L, a, and b were recorded for each potato chip sample. For each sample color, chroma $(a^2 + b^2)^{1/2}$, and hue angle $(\tan^{-1} a/b)$ were calculated from the Hunter color values as described by Clydesdale (1984).

PV of Oil Extracted from Potato chips

PV of the oil in each potato chip sample was determined according to Mehlenbacher (1960). Potato chips (30 g) were placed in a blending jar with 250 mL of chloroform. The mixture was blended by a Waring Blendor for 30 sec and then filtered through Whatman No. 1 filter paper in a Buchner funnel with vacuum suction. Beakers (50-mL) were dried with

a 100°C oven for 30 min; then, they were cooled in vacuum desiccators and weighed. A 25-mL aliquot in duplicate of the chloroform extract of each sample was transferred into a 50-mL dried beaker. The chloroform was evaporated on a steam bath under a gentle stream of nitrogen. The beakers were dried in a vacuum oven at 95°C and 584.2 mm Hg for 30 min, cooled to room temperature in vacuum desiccators, and weighed. The average weight of fat in the 25-mL aliquots of the chloroform extract was calculated and used as the sample weight for PV calculation.

Two 25-mL aliquots of the chloroform extract were each placed in 125-mL flasks and analyzed for PV separately. Glacial acetic acid (37 mL) and 1 mL of an aqueous saturated solution of potassium iodide were added to each 25-mL chloroform aliquot. The mixture was placed in dark for 1 min with occasional swirling. Distilled water (30 mL) and 1 mL of 1% soluble starch solution were added to the mixture. Then, the mixture was titrated with approximately 0.001 N sodium thiosulfate solution until the blue color in the mixture disappeared. The volumes required for titration of the duplicates were averaged and used for calculation of PV of the chip oil. The actual concentration of thiosulfate solution was determined according to AOCS (1973) Official Method Cd 1-25. PV of chips was expressed as milliequivalents of peroxide per Kg of fat in the chips and

was obtained with the following equation:

$$PV\ (meq\ peroxide/per\ kg\ oil) = \frac{(S-B)\ X\ N\ X\ 1000}{Wt.\ of\ sample\ (g)}$$

where B = titration of Blank in mL; S = average titration of sample in mL; and N = normality of sodium thiosulfate.

7. FLAVOR VOLATILE ANALYSES

The volatiles of each potato chip sample were isolated by the modified simultaneous distillation extraction (SDE) described by Melton et al. (1993) which was a modification of the method of MacLeod and Cave (1975). Volatiles of potato chips fried in each oil and stored 0 wk (fresh) or for 4 wk in the light or dark were extracted and isolated according to the following procedures and analyzed by gas chromatography.

Volatile Extraction

Volatiles in potato chips were extracted as follows. Potato chips (125 g) were blended with 700 mL warm (60-70°C) water in an Osterizer commercial 1.9-L blender (Appliance & Electric Service, Co., Knoxville, TN) for 5 min. The emulsion was transferred to a 1-L round bottom flask which was equipped with an inlet side tube extending to the center and near bottom of the flask. The flask was immersed in a

128°C silicone oil bath heated by a Fry Daddy® deep fryer (Presto Inc., Eau Clarie, WI). The temperature of the oil bath was controlled by a rheostat (Staco, Inc., Dayton, OH) set at 43 (56 volts output). The volatiles were extracted with 45 mL of HPLC grade methylene chloride which was placed in a 125-mL Erlenmeyer flask heated by a Corning PC-35 hot plate (Corning Glass Works, Inc., Corning, NY) set at range 2. During collection of the volatiles, nitrogen passed through the side tube, bubbled gently through the emulsion and passed over a dry ice-ethanol cold trap and out of the SDE-system through HPLC water. Dry ice was added to the cold trap every 15-20 min to maintain the cold temperature (-60°C). The extraction of volatiles from the chip-water emulsions in the SDE-system required 2.5 hr after the hot plate was turned on and the emulsion flask was set in the heated hot oil bath. The volatiles were extracted from the vapor phase of the heated emulsion by methylene chloride for approximately 2 hr using this SDE-system. After extraction, 1 mL pyrogallol (0.1 mg/mL methanol) was added to each volatile extract to prevent oxidation of the volatiles.

The extract was dried with anhydrous sodium sulfate and concentrated to 1.0 mL by the gas entrainment method of MacLeod and Cave (1975) as follows. The extract was transferred to a test tube under a positive flow of nitrogen gas. The test tube was immersed in an ice bath (0°C) and

also was connected to a cold trap which was immersed in liquid nitrogen. The pressure inside the cold trap and test tube was reduced by vacuum, and the solvent distilled into the cold trap mainly because of the temperature difference between the test tube and cold trap and the vacuum. Part of each concentrated volatile sample was loaded into a 0.1-mL vial and analyzed by GC as described later. In order to determine possible artifacts, blank extractions were made periodically using the same procedures as those used for the samples except the potato chips were omitted.

Standard Solutions of Known Volatiles

Solutions containing different concentrations of 19 volatiles (Appendix A-1) commonly found in potato chips (Melton et al., 1993) were prepared and analyzed by GC as described later. For each volatile that could be separated by GC analysis, the equation of a standard curve, $Y = mX + b$, were y = GC peak area, X = concentration or amount of volatile injected, m = slope and b = Y-intercept was determined by linear regression.

Recovery of Volatiles By SDE

Recoveries of selected volatiles for SDE of potato chips were determined in duplicate. Each of two 125-g samples of fresh potato chips fried in canola oil was spiked

with 1.00 mL of a solution containing the concentrations of 19 volatiles listed in Appendix A-1. Volatiles of each spiked sample and two unspiked samples of the same chips were extracted by SDE, concentrated as previously described and analyzed by GC as described later. GC peak areas for each volatile that could be analyzed were obtained for the same injection volumes of (a) standard solution or A_s, (b) concentrated volatile extract from spiked sample or A_x, and (c) concentrated volatile extract from unspiked sample or A_n. Since the volumes remained the same throughout for the standard solution, the spiked sample and the unspiked sample, the recovery or R_x was calculated from the following equation:

$$R_x\ (\%) = \frac{Ax - An}{A_s}\ X\ 100$$

An average percentage recovery was calculated for each volatile analyzed.

GC Analysis of Volatiles

Volatiles for each chip sample, volatiles of spiked chip samples extracted by SDE and standard solutions of known volatiles were analyzed on a 57 m X 0.25 mm fused silica SP-2330 capillary column (Supelco Inc., Bellafonte, PA). Two SP2330 columns (30- and 27-m lengths) were joined

together to obtain the 57-m column. The concentrated volatile sample (1.5 μL) was analyzed by the same GC used for FAME analysis except that the GC was cooled by a liquid nitrogen cryogenic unit. The injector and detector temperature of the GC were 250°C. Volatiles were injected at an initial column temperature of 25°C which was increased to 50°C at a rate of 1°C/min and then, to 220°C at a rate of 2°C/min. For each 36 samples, a chromatogram and data giving the retention time and area of each peak in the chromatogram were obtained.

Volatile Quantification

The concentration of each volatile in a chip sample was determined by the following equation:

$$C_x = \frac{A_x \; X \; C_s}{A_s \; X \; R_x}$$

where A_x = peak area of volatile, A_s = peak area of standard compound, C_s = concentration of standard compound, R_x = recovery rate of volatile. In the case of a volatile for which a percentage recovery was not determined, the recovery and GC response per unit concentration (C_s/A_s) of a standard volatile with the closest GC retention time to that volatile was substituted to calculate the concentration. The concentration of each volatile was expressed in mg

volatile/125 g chips.

Kovat's Indices

Saturated alkanes containing 5-20 carbons were analyzed under the same conditions as described in GC analysis of volatiles. Kovat's index (Pomeranz and Meloan, 1987) was calculated for each volatile peak in sample chromatograms of solution of known volatiles according to the following equation:

$$Kovat's\ Index = 100\ X\ \frac{(\log_{10} RT - \log_{10} RT_n)}{(\log_{10} RT_{n+1} - \log_{10} RT_n)} + 100\ X\ n$$

where RT = retention time (min) of volatile, n = number of carbons in saturated alkane, RT_n = retention time (min) of saturated alkane with n carbons, RT_{n+1} = retention time of saturated alkane with n+1 carbons.

Volatile Identification

Positive identification for each sample volatile was made after analysis by gas chromatography-mass spectroscopy. Volatiles from fresh and stored samples of chips fried in each oil were analyzed by the same type GC and conditions as previously described except that the column was interfaced directly with a Shimadzu Model QP1000 mass spectrometer instead of a FID. The GC also was equipped with a carbon

dioxide cryogenic unit instead of a liquid nitrogen cryogenic unit. Mass spectra of the volatiles were obtained at an ion source energy level of 70 eV and temperature of 250°C as they eluted from the column. Positive identification of a volatile was determined by matching a sample mass spectrum and retention time with the corresponding spectrum and retention time of a known compound analyzed under the same conditions as the sample. The retention time of the volatile from GC-FID analysis of the sample also had be the same as that of the known compound from GC-FID analysis.

For some volatiles, tentative identification was made by matching its sample peak mass spectrum with that of a known compound through a computerized search of a mass spectra library. A tentative identification was a match of spectra with a similarity index of 70 or greater. Also, a peak in any sample GC chromatogram with the same retention time as that of a known volatile, which was analyzed under exactly the same GC conditions, was identified tentatively as that volatile.

9. SENSORY ANALYSIS

Untrained panelists (n=150) were recruited from the faculty, staff, and students at The University of Tennessee, Knoxville. Fifty panelists evaluated potato chips fried in each oil and stored 0 wk (fresh) or at 23°C in the dark and light for 4 wk from one replication in a single session (8:00-11:00 a.m.) per day. Three sessions were required, one for each experimental replication.

Prior to evaluation, chip samples (n=12) were removed from frozen storage (-18°C) and thawed for 18 hr at ambient temperature (23°C). Each sample was coded with a randomly selected three-digit number. E4 (Evolutionary Software, Inc., 1991) was used to generate an incomplete block design such that each panelist evaluated six of the twelve samples, and each sample was evaluated by 25 panel members in any one session. Samples (1-2 chips) were presented, one at a time, under fluorescent lights, to panelists for evaluation of flavor and acceptability on an 8-point scale where 1=dislike extremely to 8=like extremely. A sample scorecard is shown in Appendix A-2. Before the first sample was served, each panelist was given a questionnaire (Appendix A-3) to obtain information about gender, age, and the frequency of eating potato chips. Panelists were instructed also to rinse their mouths with water between samples.

10. STATISTICAL ANALYSIS

For the first part of the experiment to assess frying oil performance, peroxide values, free fatty acid concentrations and percentages of individual fatty acids in the oils were analyzed statistically as a function of oil (n=4), replication (n=3), use time (n=6), and the interaction of oil x time as shown in Table 2. PROC GLM (General Linear Models) of SAS® (SAS Institute Inc., 1985) was used for the analysis of variance. Least-squares means for independent variables (oil and time) were obtained, and significantly different means were identified by the PDIFF option of PROC GLM and shown in tables. When a significant ($P < 0.05$) oil x time interaction was found for a dependent variable, except for free fatty acid concentration, significantly ($P < 0.05$) different means for each oil-time combination (n=24) were separated by the PDIFF option and illustrated in a bar graph. The levels of free fatty acids for each oil-time combination were also shown in a bar graph.

The raw potato specific gravity and moisture content, fat content, and color (Hunter *L* value, chroma, and hue angle) of fresh potato chips were analyzed statistically as a function of type of oil in which the chips were fried and replication. The PROC GLM option in SAS® (SAS Institute

Table 2 -- Analysis of variance model for measurements of frying oils when fresh, after being heated at 163°C for 3 hr and used for frying potato chips up to 4 hr

Source	Degrees of freedom
Oil	3
Rep	2
Error A (Oil x Rep)[a]	6
Time of use	5
Oil x Time	15
Error B[b]	40
Total	71

[a]Error term of Oil and Rep.
[b]Error term of Time and Oil X Time.

Inc., 1985) was used to run the analysis. Least-squares means were obtained using PROC GLM and significantly ($P < 0.05$) different means identified by the PDIFF option as described previously.

The peroxide value of oil extracted from fresh chips and chips stored for 2 and 4 wk in the dark and light was analyzed statistically as a function of the independent variables, oil (n=4), replication (n=3), storage treatments (ST) (n=5), and the interaction of oil with storage treatments (n=20). Statistical analysis was run, least-squares means were obtained and significantly different means identified as described previously.

The concentration of each identified volatile and a single unknown in chips was analyzed as a function of frying oil (n=4), storage condition (n=3), and their interaction (n=12) by PROC GLM as described already. Least-squares means were obtained for the independent variables, oil and storage, and significantly ($P < 0.05$) different means were identified by the PDIFF option. When a significant oil x storage interaction ($P < 0.05$) was found for any volatile except for t,t-2,4-decadienal, significantly different means for each oil-storage combination (n=12) were identified by the PDIFF option of the Least-squares Means in PROC GLM (SAS Institute Inc., 1985) and illustrated in a bar graph. Because of the importance of t,t-2,4-decadienal to the

flavor of potato chips, the least-squares mean concentration of this volatile for each oil-storage combination was treated as a significant oil x storage interaction.

The analysis of variance model for the sensory scores of flavor and acceptability is given in Table 3. The analysis was done using the PROC GLM of SAS Institute Inc. (1985) and least-squares means were obtained for the independent variables, oil and storage (ST). Significant oil x ST interactions ($P < 0.05$) were treated as described before.

Table 3 -- Analysis of variance model for the flavor and acceptability scores from sensory evaluation of chips fried in different oils and stored for 0 wk (fresh) and for 4 wk at 23°C in the dark and light

Source	Degrees of freedom
Oil	3
Rep	2
Error A (Oil x Rep)[a]	6
ST[c]	2
Oil x ST	6
Panel (Rep)	147
Error B[b]	733
Total	899

[a]Error term for Oil and Rep.
[b]Error term for Storage, Oil X ST, and Panel (Rep).

CHAPTER IV

RESULTS AND DISCUSSION

1. OIL CHARACTERISTICS AND FRYING PERFORMANCE

Peroxide Value and Free Fatty Acid Content

The analyses of variance for the peroxide value and free fatty acid content of frying oils are shown in Appendix B-1. Peroxide value and free fatty acid content were affected significantly by oil and time of oil use (heating and potato chip frying). Peroxide value also had a significant oil x time interaction.

The least-squares mean peroxide values of each oil when fresh, after heating for 3 hr at 163°C and during frying of potato chips for 1-4 hr are plotted in Fig. 1 and given in Appendix B-2. Peroxide value did not differ ($P > 0.05$) among fresh frying oils and ranged from 1.6 to 2.9 meq/kg oil. The peroxide value of each oil increased significantly when each oil was heated prior to frying (0 hr compared with fresh oil) with the largest increase occurring in the sunflower oil followed by that in cottonseed oil. Heated sunflower oil (0 hr) had the largest peroxide value (8.2) of all oils at any time, and heated cottonseed oil (0 hr), the second largest (6.6).

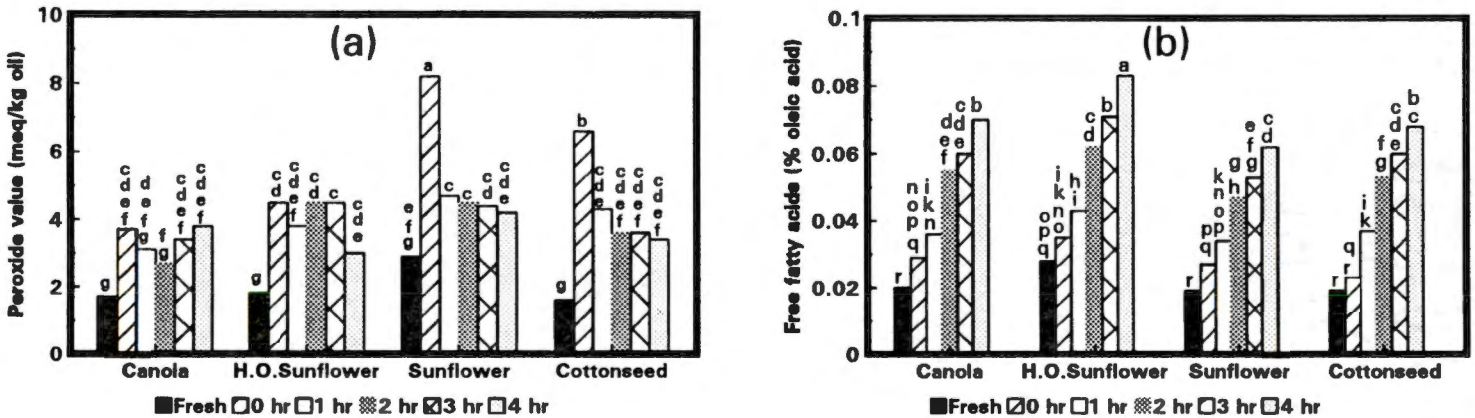


Fig. 1 -- Least-squares means (n=3) of (a) peroxide value (meq/kg oil) and (b) free fatty acid content (% oleic acid) in fresh and heated oils (0 hr) and in oils used for frying potato chips (1-4 hr); in any one graph, bars with unlike letters are different ($P < 0.05$).

The peroxide values of sunflower and cottonseed oils decreased significantly during the first hour (1 hr) of frying potato chips but those of heated canola and high oleic sunflower oils did not (Fig. 1). Continued frying of chips after 1 hr did not affect the peroxide value of any oil significantly (Fig. 1). The different trends in peroxide value over time for each oil are reflected in the significant oil x time interaction.

The increase in oil peroxide value, and subsequent decrease, with increasing heating/frying times agree with the observations of Gray (1978) and Chang et al. (1978) who noted that the peroxide value of frying oil may increase first and then decrease with increased frying time. During the initial period of heating (3 hr at 163°C), unstable hydroperoxides were formed by oxidation of the unsaturated fatty acids in the frying oils exposed to high temperature and oxygen (Gray, 1978; Melton et al., 1993; Stevenson et al., 1984). When the oils were used for frying potatoes, the peroxides may have degraded into volatile compounds or formed polymers, resulting in a decrease in the peroxide value (Gray, 1978). The lack of a continued increase in the peroxide value with increasing oil frying time makes it a poor indicator for frying fat deterioration which is in agreement with Fritsch et al. (1979) who reviewed methods for measurement of frying oil degradation.

The least-squares mean free fatty acid levels are plotted for each oil at each time of heating/frying in Fig. 1-b and are given in Appendix B-2. The free fatty acid levels in the fresh oils ranged from 0.019 to 0.028% oleic acid. In general, with increased use of each frying oil, the free fatty acid content increased. However, within the fresh oils or oils used for frying potato chips for 3 or 4 hr, high oleic sunflower oil had significantly higher free fatty acid concentrations than any of the other oils. High oleic sunflower oil used for frying potato chips for 4 hr had the maximum free fatty acid level (0.083% oleic acid) found in any oil at any time (Fig. 1b). The steady increase in frying oil free fatty acid levels with increased heating/frying time is in agreement with results of several other investigators (Chang et al., 1978; Stevenson et al., 1984) who found a steady increase in the free fatty acid concentration of frying oils over frying time.

Measurement of levels of free fatty acids is a commonly used method for monitoring degradation of a frying fat (Melton, 1993; Stevenson et al., 1984). However, other researchers have found that concentrations of free fatty acids are not fully related to deterioration of frying oils (Fritsch, 1981; Gutiérrez et al., 1988). The fatty acid composition of the frying oil, the type and amount of food fried, the temperature of frying, the amount of steam

released from the food, etc., all have an effect on the concentration of free fatty acids in the frying oil at any given time. In addition, free fatty acids present in a fat can hydrolyze triglycerides and accelerate their own formation (Handel and Guerrieri, 1990). This may be the reason for the higher levels of free fatty acids in high oleic sunflower oil at 3 and 4 hr compared with other oils in the present study.

For the oils used in the present study, the concentrations of free fatty acids at the various times show that the oils were of good quality through out the time used. All of the fresh oils had free fatty acid concentrations below 0.05%, which is an indication of high quality (Weiss, 1983). Also, none of the oils at 4 hr had free fatty acid levels above 0.5%, the level at which chip frying oil should be discarded because of the deleterious effect on chip stability (Weiss, 1983).

Fatty Acid Composition of Frying Oils

The analyses of variance for the effects of oil and frying time (time) on the fatty acid composition of frying oils are shown in Appendix B-3. Twelve fatty acids C14:0, C16:0, C16:1, C18:0, C18:1, C18:2, C18:3, C20:0, C20:1, C22:0, C22:1, and C24:0 were identified in the oils. However, the concentrations of only 10 fatty acids were

analyzed statistically; percentages of the following fatty acids: C16:0, C16:1, C18:0, C18:1, C18:2, C18:3, C20:0, C20:1, C22:0, and C24:0 were significantly ($P < 0.05$) different among the frying oils. The percentages of the following fatty acids: C18:0, C18:1, C18:2, C18:3, C20:0, C20:1, C22:0, and C24:0 were significantly affected by heating/frying time. A significant ($P < 0.05$) interaction between oil and time was found for the percentages of the following fatty acids: C16:0, C18:1, C18:3, and C20:1.

Mean percentages of selected fatty acid in each frying oil are summarized in Table 4. Canola oil had the highest amount of C20:0 and the least amount of C18:0 among all oils. High oleic sunflower oil contained the highest amounts of C18:0, C22:0, and C24:0 and the least amount of C18:2 among all oils. The percentage of linoleic acid (C18:2) in sunflower oil was higher than that found in the other oils. Palmitoleic acid (C16:1) was present in canola and cottonseed oils only with the level of C16:1 in cottonseed oil being significantly highest.

Mean percentages of fatty acids averaged across frying oils for each heating/frying time are given in Table 5. In general, the percentages of C18:0 and C24:0 increased with increasing time of heating/frying, while the percentage of C18:2 decreased. These changes over time, however, were small in comparison with differences in fatty acid

Table 4 -- Least-squares means[ab] of fatty acid concentrations (%) in oils averaged across heating and frying time

Acid	Canola oil	H.O. sunflower oil[c]	Sunflower oil	Cottonseed oil
C14:0	---	---	---	0.70
C16:1	0.20b	---	---	0.50a
C18:0	1.98d	4.15a	3.99b	2.08c
C18:2	22.41c	12.36d	66.07a	57.38b
C20:0	1.36a	0.30c	0.41b	0.31c
C22:0	0.30b	1.00a	---	---
C22:1	0.50	---	---	---
C24:0	0.21c	0.34a	0.27b	0.11d

[a]Means in a row followed by unlike letters are different ($P < 0.05$).
[b]N = 18.
[c]High oleic sunflower.

Table 5 -- Least-squares means[ab] of fatty acid concentrations (%) in frying oils averaged across types of oils while fresh, heated for 3 hr at 163°C (0 hr) and used for frying potato chips (1-4 hr)

Acid	Fresh	0 hr	1 hr	2 hr	3 hr	4 hr
C16:1	0.35a	0.35a	0.35a	0.37a	0.35a	0.33a
C18:0	3.00c	3.03bc	3.05ab	3.07ab	3.08a	3.08a
C18:2	40.17a	39.74b	39.49c	39.40cd	39.31cd	39.19d
C20:0	0.59a	0.59a	0.58a	0.59a	0.60a	0.60a
C22:0	0.50a	0.50a	0.50a	0.50a	0.50a	0.50a
C24:0	0.21b	0.24a	0.23ab	0.23ab	0.23ab	0.24a

[a]Means in a row followed by unlike letters are different ($P < 0.05$).
[b]N = 12.

composition among oils (Table 4 and Fig. 3).

For those acids with a significant interaction of oil with time, the interaction occurred because the rate of concentration change was different in each oil or the level was not affected at all by oil use. For example, C16:0 concentration increased significantly only in cottonseed oil with use, decreased between fresh and 3 hr heating (0 hr) in canola oil and was not affected in the other oils as shown in Fig. 2(a). This figure also shows that cottonseed oil contained significantly higher levels of C16:0 than all the other oils, and sunflower had more C16:0 than either canola or high oleic sunflower oil. For C18:1, the percentage concentration increased over heating/frying time in all oils but sunflower oil; however, the rate of change was dependent upon the oil as illustrated in Fig. 2(b). Over all, high oleic sunflower oil contained the highest amount of C18:1 of all oils, followed by canola oil, sunflower oil, and cottonseed oil. The percentage C18:3 decreased only in canola oil as seen in Fig. 2(c), and canola oil contained the most C18:3 of all oils. In contrast, the percentage concentration of C20:1 increased with increasing heating/frying time in canola and cottonseed oils only, with the largest increase being in canola oil as shown in Fig 3.

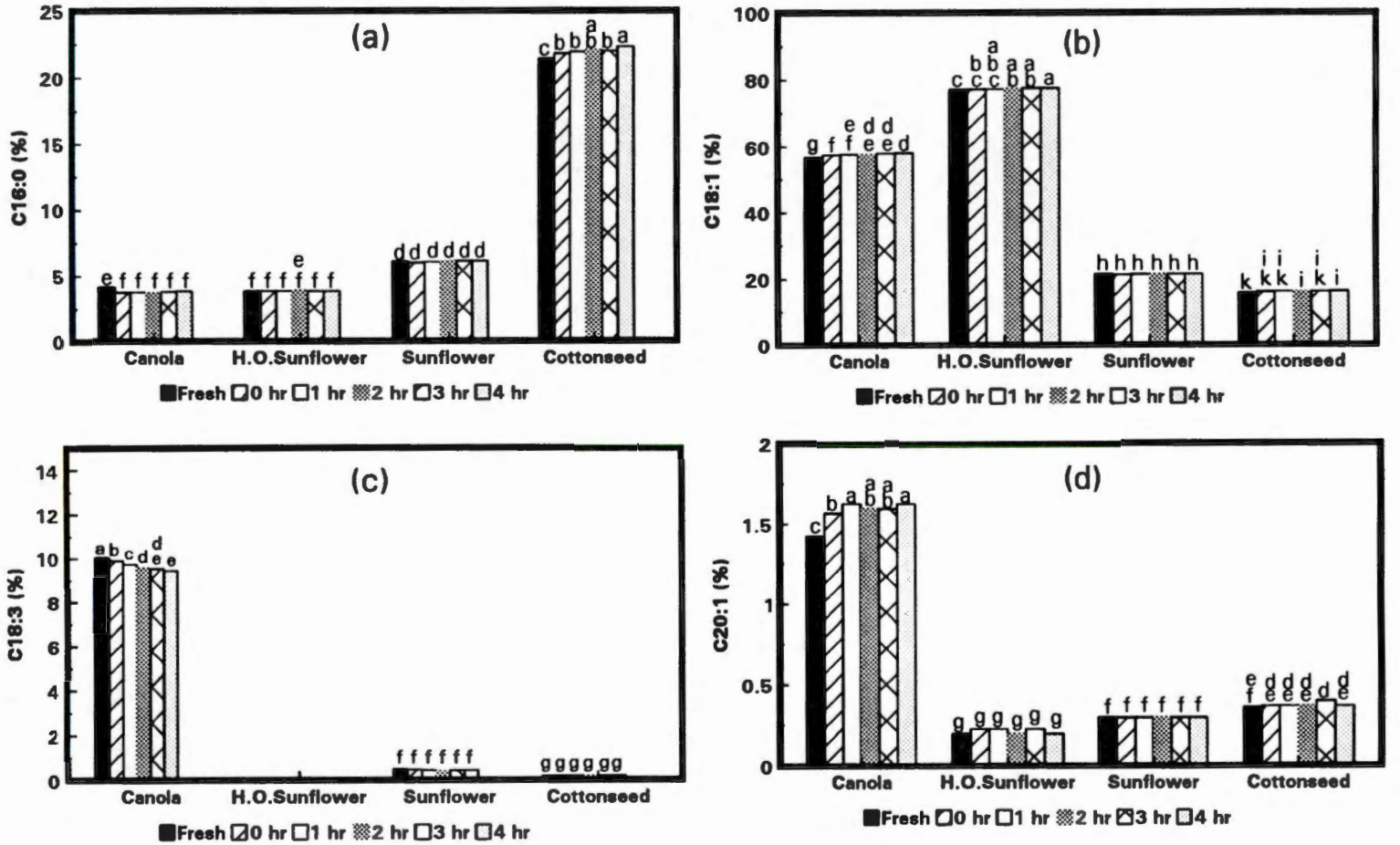


Fig. 2 -- Least-squares mean (n=3) concentrations (%) of (a) palmitic or C16:0, (b) oleic or C18:1, (c) linolenic or C18:3, and (d) eicosenoic or C20:1 acids in fresh and heated oils (0 hr) and oils used for frying potato chips (1-4 hr); for each oil, bars with unlike letters are different ($p < 0.05$).

2(d). Least-squares means for the percentages of C16:0, C18:1, C18:3, and C20:1 are given in Appendix B-4.

Oxidation of unsaturated fatty acids such as C18:2 and C18:3 in oil heated to high temperatures in presence of oxygen is to be expected. McGill (1980) reported that when oil is heated to 191°C in presence of air, the double bonds in such fatty acids as C18:2 and C18:3 break and produce new compounds such as shorter chain fatty acids. Melton (1993) reported that the oxidation rate of an oil is roughly proportional to its degree of unsaturation with the relative rate of oxidation of C18:3, C18:2, and C18:1 being 20:10:1. The destruction of these unsaturated acids results in a decrease in the iodine value and an apparent increase in the saturation degree of the fatty acids. Since concentrations of fatty acids expressed in percentages are relative measurementS, any degradation of unsaturated acids in an oil will result in a decrease in their percentage and result in an increase in the percentage of the more stable, saturated fatty acids. This is what was found in the present study.

2. QUALITY OF POTATO CHIPS FRIED IN DIFFERENT OILS

Specific Gravity of Raw Potatoes

Since the frying equipment and processing procedure were well controlled in the present study, the only variable analyzed that is related to composition and color of potato chips except measurements of frying oil characteristics was the specific gravity of potato tubers. The specific gravity of potatoes has been an indicator of potato quality for chip production for over a century (Poter et al., 1964). The analysis of variance for the specific gravity of potato tubers as a function of frying oil and replication are given in Appendix C-1. The specific gravity of potatoes used for chips fried in different oils was significantly different among oils. The least-squares means for the specific gravity of potatoes used for chips fried in each oil are given in Table 9. Chips fried in high oleic sunflower and cottonseed oils were from potatoes with higher specific gravities than chips fried in canola and sunflower oils. The specific gravities of all potatoes, however, were still within the acceptable range for potatoes used for chip production (Poter et al., 1964).

Moisture and Oil Content of Potato Chips

The analyses of variance for the effects of oil and replication on the moisture and fat contents of potato chips are shown in Appendix C-1. There were significant differences in moisture content in the chips fried in different oils, but not in the fat content. The mean concentrations of moisture and fat for potato chips fried in different oils are presented in Table 6.

Chips fried in high oleic sunflower oil had the greatest moisture content of chips fried in any of the oils; chips fried in regular sunflower oil had the lowest moisture content. As seen in Table 6, the moisture content of the chips ranged from 1.06 to 1.51%. Han (1989) fried potatoes in different oils and reported that the moisture content of the resulting chips ranged from 1.41% for chips fried in cottonseed oil to 1.89% for those fried in soybean oil. Han (1989) indicated that chips prepared from tubers with lower specific gravities tended to have higher moisture contents. Results of the present study are in disagreement with this latter observation since the chips prepared from the tubers with the lower specific gravities (1.073) had the lowest moisture contents (Table 6). However, the

Table 6 -- Least-squares means[ab] of specific gravity for raw potatoes used for production of potato chips fried in different oils and the moisture and fat concentration of the chips.

Oil	Potato specific gravity	Chips	
		Moisture (%)	Fat (%)
Canola	1.073b	1.21b	47.4a
H.O.sunflower[c]	1.078a	1.51a	43.7a
Sunflower	1.073b	1.06c	45.3a
Cottonseed	1.081a	1.27b	45.0a

[a]Means in a column with unlike letters are different ($P < 0.05$).
[b]N=3.
[c]High oleic sunflower oil.

moisture contents of the potato chips fried in the different oils were below 2%, which is an indication that the chips were acceptable quality (Gamble et al., 1987) and had acceptable texture (Gamble and Rice, 1988).

The oil content of potato chips in the present study was somewhat higher than the oil contents (40.5-41.5%) reported by Han (1989) in potato chips fried in soybean, palm olein and cottonseed oils. However, the lack of a significant effect of the type of frying oil on oil content in fried chips is agreement with Han (1989). The levels of oil found in the potato chips of the present study are more in agreement with the oil concentrations in the potato chips produced by Lulai and Orr (1979). These latter investigators prepared chips from potatoes with specific gravities of 1.070, 1.075 and 1.080; the chips prepared from these tubers had 44.38, 43.05 and 41.72% oil, respectively. According to Lulai and Orr (1979), the oil content of potato chips decreased linearly with increasing specific gravity in the raw potatoes from 1.060 to 1.110. Results of the current study are not in agreement with this finding; however, the specific gravity range was narrower than that investigated by Lulai and Orr (1979). Also, other factors such as thickness of potato slices and temperature and time used for frying chips affect the oil content of chips (Lisińska and Leszczyński, 1989; Smith, 1987). The extent

to which these factors are related to the chip oil content in the present study are unknown. Efforts were made to control and randomize such factors during the experiment.

Potato Chip Color

The analyses of variance for the effects of frying oil and replication on the color of potato chips in terms of the Hunter *L* value, chroma and hue angle are shown in Appendix C-2. None of the color measurements were affected significantly by type of frying oil. The Hunter *L* value for potato chips produced ranged from 53.8 to 55.2; the chroma ranged from 27.0 to 27.4 and the hue angle for chips fried in any oil was 88.3.

The Hunter *L* values are less than the *L* values of 57.1-59.3 found by Han (1989). In the present study, potato slices of the same thickness as that used by Han (1989) were fried at the same temperature (194°C) for a shorter period of time (3 min 25 sec versus 4 min) to produce a darker chip. Chip color depends upon several factors: thickness of potato slices, length of frying time, frying temperature, sugar content of raw potatoes, etc. (Smith, 1987). Longer frying times rather than shorter would be expected to produce darker chips if all other conditions were the same. Perhaps, potatoes used in the current study had higher sugar levels than those used by Han (1989).

The insignificant effect of type of frying oil on the color of potato chips is in disagreement with other investigators who have reported that the type of oil used for frying potato chips affects chip color (Han, 1989; Robertson et al., 1978). However, the color of the chips fried in any of the oils is still acceptable since the *L* values are all greater than 40 which is the minimum acceptable limit for commercial chips (Parkin and Schwobe, 1990). Also, potato specific gravity was not related to chip color as has been reported previously (Smith, 1987); perhaps because the specific gravity range was not large enough in the present study.

The mean hue angle of 88.3 for the potato chips indicates that the color of the chips was very close to yellow. Hue angles of 0 and 90 represent red, yellow, respectively (Francis, 1985).

3. STABILITY OF POTATO CHIPS FRIED IN DIFFERENT OILS

The analysis of variance for the effects of oil, replication, storage (ST), and oil X ST interaction on the peroxide value (PV) of oils extracted from chips fried in different oils is listed in Appendix D-1. The PV was significantly affected by the oil in which the chips were fried and by the conditions (0 wk and 2 and 4 wk in light or

dark) under which the chips were stored. Also, a significant ($P < 0.05$) interaction of oil by storage (ST) was found for PV.

The PV of oil extracted from chips fried in different oils and stored for 0 wk and at 23°C in the dark and light for 0, 2 and 4 wk are plotted in Fig. 3 and listed in Appendix D-2. Frying the potato chips in different oils had no significant effect on the PV (3.4-5.1 meq/kg oil) of oil from fresh chips before storage. For chips fried in canola and high oleic (H.O.) sunflower oils, chip oil PV increased ($P < 0.05$) only when the chips were stored in the light for 4 wk. For chips fried in cottonseed oil, storage in the dark for up to 4 wk had no significant effect on oil PV, but during storage in the light, chip oil PV increased ($P < 0.05$). Compared with chips fried in the other oils, chips fried in sunflower oil were the most unstable to oxidation during storage. The oil PV of sunflower oil fried chips increased significantly over time when the chips were stored for up to 4 wk in the dark and increased at a greater rate when they were stored for up to 4 wk in the light (Fig. 3). The PV of the oil from sunflower oil fried chips stored for 4 wk in the light was the greatest (35.7) among those from all chips. In fact, for each specific storage time (2 and 4 wk) and condition (dark or light), except for fresh chips, the oil PV of chips fried in sunflower oil was greater than

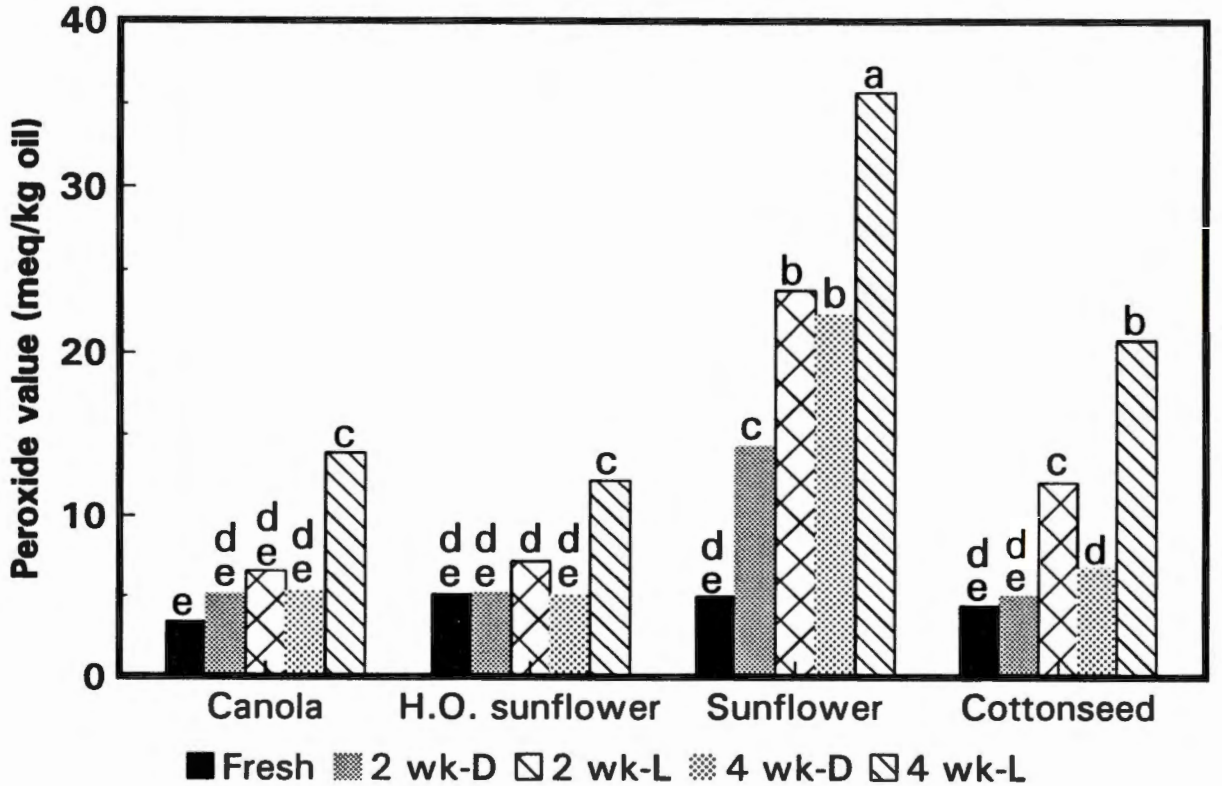


Fig. 3 -- Least-squares mean (n=3) peroxide values of oils extracted from potato chips fried in different oils and stored 0 wk (fresh) and at 23°C for 2 wk in the dark (2 wk-D) and light (2 wk-L) and for 4 wk in the dark (4 wk-D) and light (4 wk-L); bars with unlike letters are different ($P < 0.05$).

that of chips fried in the other oils. Therefore, the rates of PV increase over storage time was dependent not only on the conditions under which the chips were stored but also on the oil in which they were fried before storage. This is the cause of the significant interaction between frying oil and storage time-conditions for PV of oil extracted from the potato chips.

According to Melton (1993), the oxidation rate of fat is roughly proportional to the degree of unsaturation; the greater the degree of unsaturation, the greater the oxidation rate. As shown in Table 7, the total percentages of polyunsaturated fatty acids or PUFA (C18:2 plus C18:3) in sunflower, cottonseed, canola, and high oleic sunflower oils were 66.55, 57.58, 32.15, and 12.36%, respectively. Sunflower oil with the highest percentage of PUFA was the most unsaturated frying oil used and produced chips that underwent the most oxidation during storage. Cottonseed oil had the second highest percentage of PUFA and produced chips that were more stable to oxidation than sunflower oil, but not as stable as those fried in canola or high oleic sunflower oils. Even though canola oil contained more than two and a half times the level of PUFA in the high oleic sunflower oil, chips fried in canola oil were as resistant to oxidation during storage as those fried in high oleic sunflower oil.

With the exception of PV of stored chips fried in canola and high oleic sunflower oils, the results found in the present experiment are in agreement with those reported by Han (1989). This researcher found that PV increased in stored chips in proportion to the levels of PUFA in the oils in which they were fried. In the present study, the possibility exists that the canola oil had a higher level of natural antioxidants, such as tocopherols, than did high oleic sunflower oil. This higher antioxidant level would have protected the chips fried therein better from oxidation during storage.

For all frying oils used in the present study, the PV of the oil extracted from the chips stored in the light for 4 wk was significantly higher than that of chips stored in the dark for 4 wk (Fig. 3). This finding also agrees with Han (1989) who reported that the PV of oil in chips stored in the light increased faster than that of chips stored in the dark over a 4 wk storage period. According to Fuller et al. (1971), fluorescent light is an effective accelerator of oxidation at ambient temperature. Frankel (1991) and Neumann et al. (1991), both of who measured the formation of hydroperoxides, found that compared with normal oxygen, singlet oxygen reacted with unsaturated fatty acids during photosensitized oxidation 1500 times faster. One of photosensitizers--chlorophyll (Frankel, 1991), which is

present in potato tubers (Smith, 1987), may trigger photosensitized oxidation of the fat in potato chips. Also, unsaturated fatty acids are more sensitive to photosensitized oxidation than saturated fatty acids (Nawar, 1985). This may be the reason that the PV of oil from chips fried in sunflower and cottonseed oils and stored in the light was higher than the PV of oil from chips fried in the more saturated canola and high oleic sunflower oils and stored in the light (Fig. 3).

4. FLAVOR OF POTATO CHIPS FRIED IN DIFFERENT OILS

Volatile Compounds Isolated From Potato Chips

Recovery of volatile compounds. The retention times and Kovat's Indices from gas chromatographic analysis of known volatile compounds in potato chips and the recovery of those volatiles from simultaneous distillation extraction (SDE) of potato chips are listed in Table 7. The recoveries of 16 volatiles were determined, and the recoveries ranged from 29.5% for diacetyl to 67.6% for 2-n-pentylfuran. Three volatiles, pyrrole, benzaldehyde, and 1-octanol, in the standard solution were not found in the chromatograms of the standard solution and their recoveries were not determined. Although Schirle-Keller et al. (1992) found that the vapor

Table 7 -- Gas chromatographic retention times (RT) and Kovat's Indices (I) of volatile compounds identified in potato chips and recoveries of those volatiles from simultaneous distillation extraction of potato chips

Volatile	RT (min)	I	Recovery[a] (%)
Diacetyl	22.4	1090	29.4
Hexanal	31.4	1191	62.2
2-n-Pentylfuran	37.6	1268	67.6
2-Methylpyrazine	44.5	1358	47.9
2,3-Dimethylpyrazine	51.7	1464	51.4
2,3,5-Trimethylpyrazine	55.0	1516	47.3
1-Octen-3-ol	56.3	1539	28.9
Nonanal	58.8	1579	52.1
2-Furaldehyde	61.5	1626	60.9
t-2-Octenal	61.8	1632	48.9
Decanal	63.0	1655	51.3
t,t-2,4-heptadienal	66.3	1717	65.0
t-2-Nonenal	68.0	1750	56.4
t-2-Decenal	74.0	1873	49.6
Phenylacetaldehyde	76.6	1928	33.1
t,t-2,4-Decadienal	84.3	2102	49.5

[a]N=2.

pressure of volatile compounds was dependent on how soluble they were in simple water, fat, and fat replacer systems, the extent to which that applies to simultaneous distillation extraction of volatiles from complex systems is not known. In the present experiment, the volatiles were dispersed in an emulsion containing approximately 56 g fat, 700 g water, approximately 60 g of carbohydrates and a small amount of protein. This mixture was heated to boiling and the vapor was extracted by methylene chloride. Therefore, the recovery of any given compound is dependent not only on solubility in this complex system, but also on the partitioning of the compound between water and methylene chloride.

The recoveries given in Table 7 are too low (< 95%) for SDE to be considered an accurate analytical method (Pomeranz and Meloan, 1987). However, if a method is precise, it is possible to use a correction factor to make the method accurate. The coefficients of variation for the recoveries of the volatiles listed in Table 11 from SDE were 5-10%. showing the method was precise enough to be corrected (Pomeranz and Meloan, 1987).

Identification and quantification of chip volatiles. The analyses of variance for the effects of oil, storage condition (TR) on the concentrations of volatile compounds

isolated from chips are shown in Appendix E-1. Twenty-four identified volatile compounds and one unknown volatile compound were analyzed in this study. The concentrations of the following volatile compounds were significantly different among the chips fried in different oils: hexanal, 2-pentylfuran, 2 ethyl-6-methylpyrazine, 1-octen-3-ol, 2-furaldehyde, benzaldehyde, t,t-2,4-heptadienal, t-2-decenal, t-2-undecanal, c,t-2,4-decadienal, and t,t-2,4-decadienal. The concentrations of the following volatile compounds were affected significantly by storage conditions (TR): diacetyl, hexanal, 2-furaldehyde, benzaldehyde, t,t-2,4-heptadienal, c,t-2,4-decadienal, and t,t-2,4-decadienal. A significant interaction between oil and TR ($P < 0.10$) was observed for the following volatile compounds: hexanal, 2-ethyl-6-methylpyrazine, 2-furaldehyde, benzaldehyde, t,t-2,4-heptadienal, t-2-nonenal, and c,t-2,4-decadienal.

Mean concentrations of volatiles isolated from chips fried in the different oils are summarized in Table 8. With the exception of those volatiles, which had significant interactions of oil X TR, and t,t-2,4-decadienal, the following differences were found in concentrations of volatiles among the oils. The mean concentrations of 2-pentylfuran in chips fried in sunflower and cottonseed oils were significantly higher than those isolated from chips

Table 8 -- Least-squares mean (n=9) concentrations[a] (mg/125 g chips) of volatiles extracted by simultaneous distillation extraction from potato chips fried in different oils

Volatile	Oil			
	Can-ola	H.O.sun flower	Sun-flower	Cotton-seed
Diacetyl	0.279	0.294	0.340	0.399
Hexanal	0.232b	0.353b	0.991a	0.610b
2-Pentylfuran	0.038b	0.054b	0.123a	0.109a
2-Methylpyrazine	0.194	0.412	0.226	0.355
2,5-Dimethylpyrazine[b]	0.250	0.555	0.325	0.490
2,6-Dimethylpyrazine[b]	0.113	0.171	0.116	0.168
2,3-Dimethylpyrazine	0.059	0.082	0.062	0.081
2-Ethyl-5-methylpyrazine[b]	0.086	0.148	0.096	0.142
2-Ethyl-6-methylpyrazine[b]	0.201b	0.265b	0.389a	0.402a
2,3,5-Trimethylpyrazine	0.112	0.192	0.123	0.183
1-Octen-3-ol	0.182b	0.508a	0.091c	0.081c
UNKNOWN	0.140	0.251	0.147	0.235
Nonanal	0.093	0.110	0.099	0.128
2-Furaldehyde	0.046c	0.061c	0.121a	0.090b
t-2-Octenal	0.060	0.079	0.054	0.072
Decanal	0.071	0.110	0.073	0.082
Benzaldehyde	0.074a	0.037b	0.037b	0.027b
t.t-2,4-Heptadienal	0.060a	0.017b	0.021b	0.017b
1-Octanol	0.029	0.041	0.024	0.021
t-2-Nonenal	0.023	0.029	0.033	0.029
t-2-Decenal	0.013b	0.025a	0.006c	0.004c
Phenylacetaldehyde	0.721	0.772	0.484	0.658
t-2-Undecenal[b]	0.223b	0.422a	0.119b	0.086b
c,t-2,4-Decadienal[b]	0.107c	0.121c	0.633a	0.306b
t,t-2,4-Decadienal	0.929c	1.054c	4.617a	2.552b

[a]Means in a row followed by unlike letters are different ($P < 0.05$).
[b]Tentatively identified.

fried in canola and high oleic sunflower oils. Chips fried in high oleic sunflower oil had the highest levels of 1-octen-3-ol and t-2-decenal among chips fried in different oils. Chips fried in canola oil had higher levels of these latter two volatiles than chips fried in sunflower and cottonseed oils.

Mean concentrations of volatile compounds isolated from fresh (0 wk) chips and chips stored in the light and dark for 4 wk are summarized in Table 9. Again, the concentrations of volatiles with significant oil X TR interactions and t,t-2,4-decadienal are discussed later. The concentration of diacetyl isolated from chips stored in the light for 4 wk was significantly greater than that found in fresh chips and chips stored in the dark for 4 wk. The concentration of diacetyl isolated from chips stored in the dark for 4 wk was not significantly different from that found in fresh chips.

The concentrations of diacetyl in chips fried in the different oils were not significantly different (Table 8). But in chips stored in the light for 4 wk it was significantly higher than levels in fresh chips and chips stored in the dark for 4 wk (Table 9). Therefore, during storage, light triggered the formation of diacetyl which has a characteristic butter-like flavor (Nawar, 1985). This

Table 9 -- Least-squares mean (n=12) concentrations[a] (mg/125 g chips) of volatiles extracted by simultaneous distillation extraction from potato chips stored for 0 wk (fresh) or at 23°C for 4 weeks in the dark (4 wk-D) and in the light (4 wk-L)

Volatile	Chip storage condition		
	Fresh	4 wk-D	4 wk-L
Diacetyl	0.237b	0.306b	0.437a
Hexanal	0.155c	0.487b	0.999a
2-Pentylfuran	0.068	0.078	0.097
2-Methylpyrazine	0.290	0.330	0.270
2,5-Dimethylpyrazine[b]	0.396	0.443	0.376
2,6-Dimethylpyrazine[b]	0.144	0.143	0.139
2,3-Dimethylpyrazine	0.070	0.076	0.068
2-Ethyl-5-methylpyrazine[b]	0.116	0.123	0.115
2-Ethyl-6-methylpyrazine[b]	0.189b	0.228b	0.536a
2,3,5-Trimethylpyrazine	0.148	0.163	0.147
1-Octen-3-ol	0.222	0.215	0.221
UNKNOWN	0.195	0.208	0.177
Nonanal	0.084	0.119	0.120
2-Furaldehyde	0.053b	0.069b	0.112a
t-2-Octenal	0.069	0.069	0.062
Decanal	0.083	0.088	0.082
Benzaldehyde	0.026c	0.038b	0.064a
t-2,4-Heptadienal	0.015b	0.025b	0.046a
1-Octanol	0.029	0.042	0.024
t-2-Nonenal	0.027	0.026	0.032
t-2-Decenal	0.011	0.011	0.014
Phenylacetaldehyde	0.605	0.732	0.639
t-2-Undecenal[b]	0.222	0.244	0.171
c,t-2,4-Decadienalb[b]	0.185b	0.281b	0.409a
t,t-2,4-Decadienal	1.799b	2.327ab	2.738a

[a]Means in a row followed by unlike letters are different ($P < 0.05$).
[b]Tentatively identified.

indicates that diacetyl is a product of photo-synthesized lipid oxidation.

Mean concentrations of hexanal isolated from chips fried in the different oils and stored for 4 wk in the dark and light are plotted in Fig. 4 and listed in Appendix E-2. During storage in the light for 4 wk, the concentration of hexanal increased in chips fried in sunflower and cottonseed oils but not in those fried in canola and high oleic sunflower oils. Chips fried in sunflower oil and stored in the light had the highest concentration of hexanal (2.126 mg/125 g chips) of all chips (Fig. 4). Chips fried in cottonseed oil and stored in light had a hexanal level that was significantly greater than that of fresh chips fried in any oil or of 4 2k-D chips fried in canola oil. The hexanal level in 4 wk-L cottonssed oil chips was not different from that of other chips except for 4 wk-L sunflower oil chips.

Hexanal is a typical product of lipid oxidation (Min and Schweizer, 1983; Nawar, 1985). It is produced mainly from oxidation of linoleic acid (Hawrysh, 1990), which was more abundant in sunflower (66.07%) and cottonseed (57.38%) oils than in canola (22.46%) and high oleic acid sunflower (12.36%) oils. Light, in particular, catalyzed production of hexanal in the linoleic acid rich oils. The lack of significant differences in the hexanal content between chips

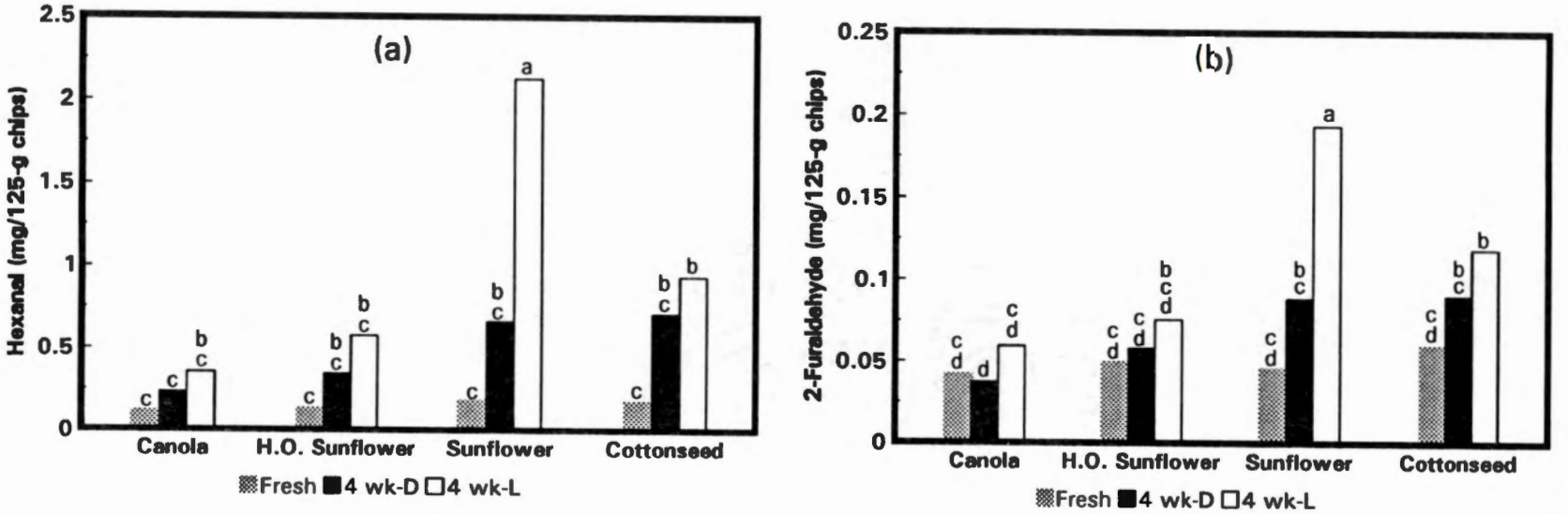


Fig. 4 -- Least-squares means (n=3) of concentrations (mg/125-g chips) for (a) hexanal and (b) 2-furaldehyde isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L); for each compound bars with unlike letters are different ($P < 0.05$).

fried in canola oil and those fried in high oleic sunflower oil may be due to (1) a more abundant level of natural antioxidants in canola oil as suggested previously and/or (2) to an increased rate of oxidation in canola oil because of its high content of linolenic acid compared with high oleic sunflower oil (9.3 versus 0.47%). The oxidation of linolenic acid, which is more rapid than linoleic acid (Nawar, 1985), could have resulted in destruction of hexanal formed from C18:2 in the canola oil. Hexanal is a secondary reaction product of lipid oxidation, but can react to form other products (Heath and Reineccius, 1986).

Mean concentrations of 2-furaldehyde in chips fried in the different oils and stored under different conditions are also shown in Fig. 4 and Appendix E-2. Concentrations of 2-furaldehyde increased in chips fried in sunflower and cottonseed oils after the chips were stored in the light for 4 wk. The level of 2-furaldehyde in chips fried in sunflower oil and stored in the light for 4 wk was the highest among all chips (Fig. 4). After 4 wk storage in light (4 wk-L), chips fried in sunflower and cottonseed oils had 0.194 and 0.119 mg 2-furaldehyde per 125 g of chips, respectively. These latter two concentrations were significantly different from each other and significantly higher than those found in 4 wk-L stored chips fried in canola (0.076 mg/125 g chips) or H.O. sunflower oil (0.076

mg/125 g chips). No other significant differences were found among concentrations of 2-furaldehyde in the chips fried in different oils and stored for 0 and 4 wk in the dark and light. The 2-furaldehyde may be formed via dehydration of thermal degradation of sugars (Nawar, 1985) or from the nonenzymatic browning or Maillard reaction (Heath and Reineccius, 1986). It has been identified in the products of the Maillard reaction in a model system containing methionine and glucose (Arroyo and Lillard, 1970). According to Flink (1983) nonenzymatic browning reactions occur in dried foods stored in an environment with very low water activity because of increased concentrations and proximities of solutes (reactants) in the dried foods. These reactants include amino acids which exist at three to four times the concentration of sugars in potato tubers and malonaldehyde, a lipid oxidation product (Linsińska and Leszczyński, 1989; Nawar, 1985). Robertson et al. (1978) found that nonenzymatic browning occurred in potato chips during storage. Also, malonaldehyde concentration increases during oxidation of fat (Nawar, 1985; Stevenson et al., 1984). Thus, increasing concentrations of malonaldehyde may react with amino acids (Leszkowiat et al., 1990) during storage of potato chips to form increasing concentrations of 2-furaldehyde.

Mean concentrations of 2-ethyl-6-methylpyrazine found

in chips fried in different oils and stored 0 wk and for 4 wk in the light and the dark are shown in Fig. 5 and listed in Appendix E-3. During storage in the light for 4 wk, concentrations of 2-ethyl-6-methylpyrazine increased in chips fried in sunflower, cottonseed, and canola oils. The concentration of 2-ethyl-6-methylpyrazine did not increase in chips fried in high oleic sunflower oil during storage in the light or in chips fried in any of the oils and stored for 4 wk in the dark. The possibility exists that this particular pyrazine could be formed via the nonenzymatic browning reaction during storage of the chips and that lipid oxidation resulting in reactive aldehydes such as malonaldehyde could have contributed to its concentration increase (Maga and Sizer, 1973). The reason is not known why only the level of 2-ethyl-6-methylpyrazine, but not the other pyrazines found in the present study (Table 12), increased during chip storage. Since this particular pyrazine has been only tentatively identified, the possibility exists that it may be some other compound.

Mean concentrations of t-2-nonenal isolated from chips fried in the different oils and stored under different conditions are shown in Fig. 5 and Appendix E-3. The only significant increase of t-2-nonenal concentration occurred during storage in the light for 4 wk in chips fried in sunflower oil. Concentrations of t-2-nonenal in chips fried

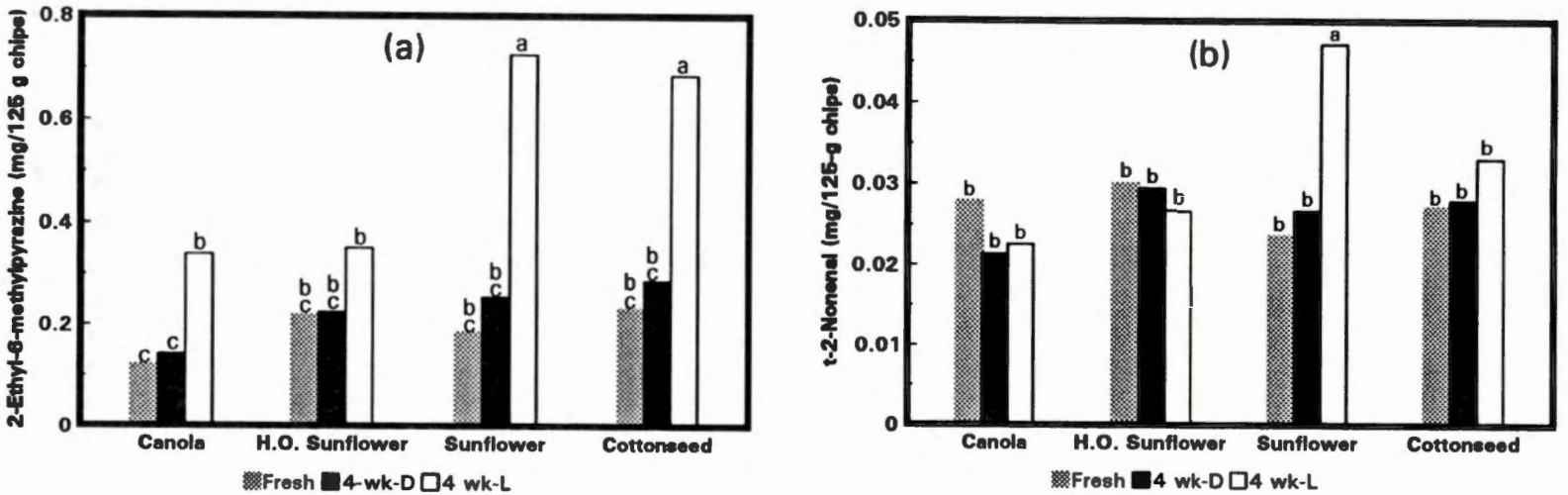


Fig. 5 -- Least-squares means (n=3) of concentrations (mg/125-g chips) for (a) 2-ethyl-6-methylpyrazine and (b) t-2-nonenal isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L); for each compound bars with unlike letters are different ($P < 0.05$).

in other oils and stored for 0 wk and for 4 wk in light or dark were not significantly different. The compound, t-2-nonenal, is produced by oxidation of C18:2; sunflower oil had the highest concentration of C18:2 of all the oils (Table 4).

Mean concentrations of benzaldehyde and t,t-2,4-heptadienal in chips fried in different oils and stored under different conditions are presented in Fig. 6 and Appendix E-4. Chips fried in canola oil and stored in the light for 4 wk had significantly greater concentrations of benzaldehyde and 2,4-heptadienal than did any of the other chips shown in Fig. 6. Also, fresh chips fried in canola oil had a higher level of benzaldehyde than did fresh chips fried in sunflower and cottonseed oils. Both benzaldehyde and t,t-2,4-heptadienal are produced from oxidation of C18:3 (Frankel, 1980; 1991). Among the frying oils used in the present study, only canola oil had any appreciable amount of C18:3 (Fig. 3).

Mean concentrations of c,t- and t,t-2,4-decadienal in chips fried in different oils and stored under different conditions are plotted in Fig. 7 and listed in Appendix E-5. Concentrations of c,t-2,4-decadienal in chips fried in sunflower and cottonseed oils increased after they were

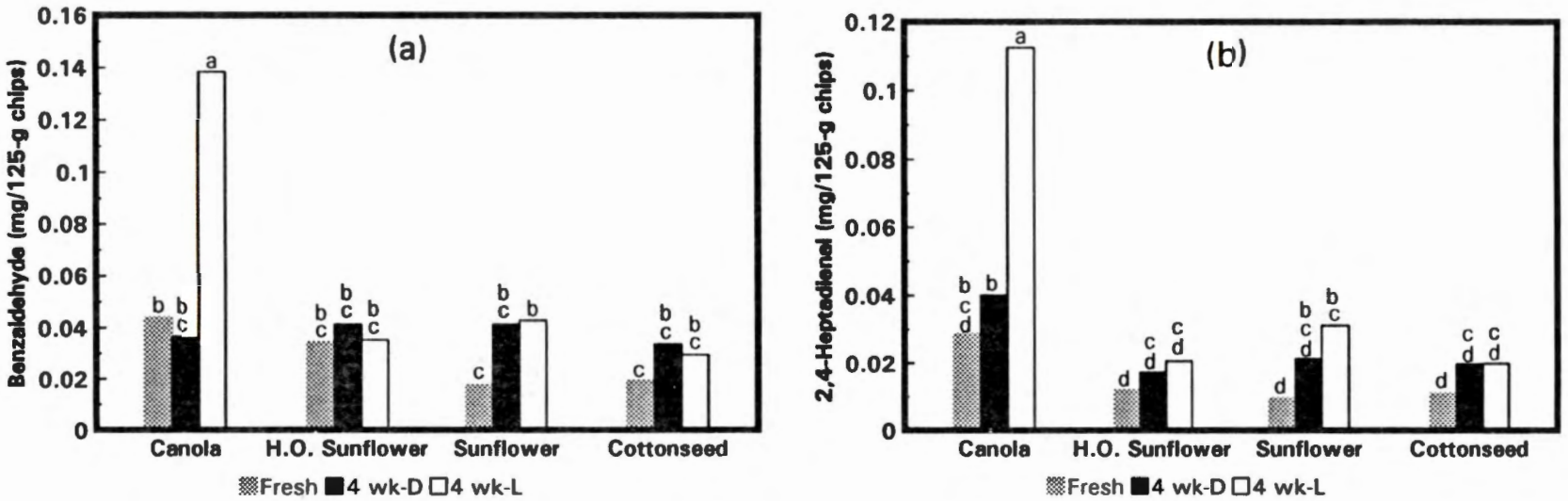


Fig. 6 -- Least-squares means (n=3) of concentrations (mg/125-g chips) for (a) benzaldehyde and (b) t,t-2,4-heptadienal isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L); for each compound bars with unlike letters are different ($P < 0.05$).

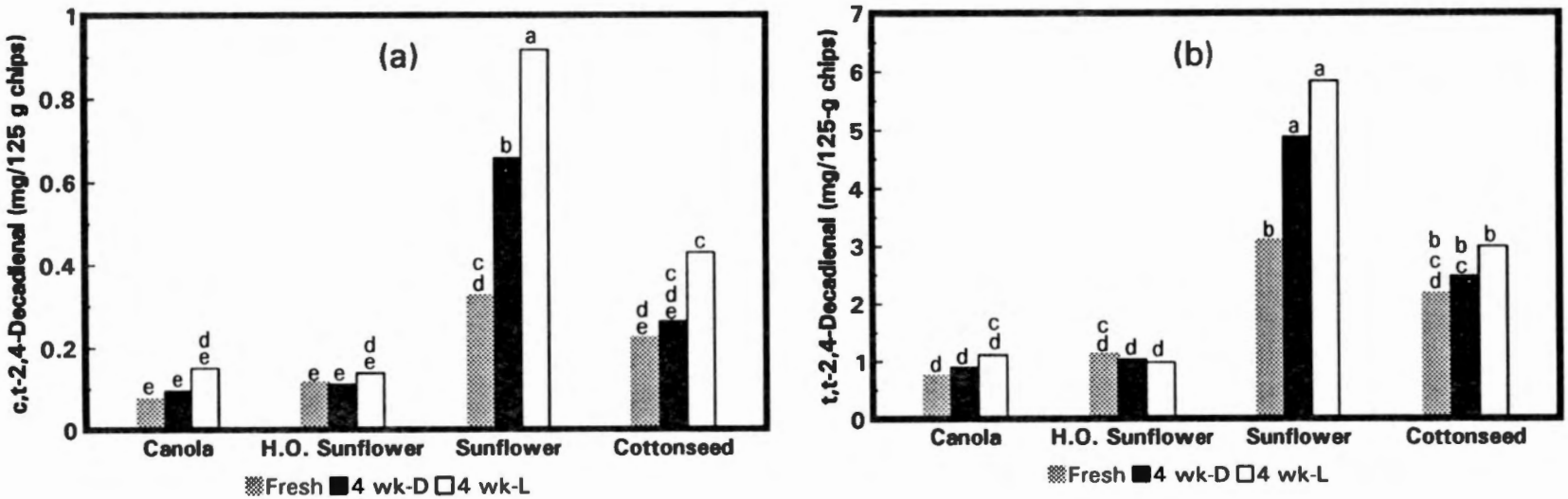


Fig. 7 -- Least-squares means (n=3) of concentrations (mg/125-g chips) for (a) c,t-2,4-decadienal and (b) t,t-2,4-decadienal isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L); for each compound bars with unlike letters are different ($P < 0.05$).

stored in the light for 4 wk. A significant increase in the level of c,t-2,4-decadienal in chips fried in sunflower oil was found also during storage for 4 wk in the dark. Storage in light or dark for 4 wk of chips fried in canola or high oleic sunflower oils failed to increase the concentration of c,t-isomer. Fresh chips fried in sunflower oil had higher levels of c,t-2,4-decadienal than canola oil or high oleic sunflower oil fried chips when they were fresh or after 4 wk storage in the dark.

Significant increases in t,t-2,4 decadienal concentrations during storage were found only in chips fried in sunflower oil; storage in both dark and light increased the concentration of the t,t-isomer in such chips. Levels of t,t-2,4-decadienal in stored sunflower oil fried chips were significantly higher than levels in fresh or stored chips fried in the other oils. The t,t-2,4-decadienal concentration in fresh chips fried in sunflower oil was significantly higher than those found in fresh or stored chips fried in the other oils except for cottonseed oil. Because 2,4-decadienals (all geometrical isomers) are produced from oxidation of linoleic acid (Hawrysh, 1990), higher linoleic acid contents in sunflower and cottonseed oils than in the other oils (Table 4) contributed to higher levels of decadienals in chips fried therein. The lack of significant increases in the t,t-2,4-decadienal levels with

increasing lipid oxidation during storage of chips fried in cottonseed oil (as shown in Fig. 3) may be due to equivalent rates of formation and degradation of the volatile itself. Pokorny (1989) reported that during storage of fried products, t,t-2,4-decadienal is produced but also is easily oxidized further to hydrocarbons, lower aldehydes, and unsaturated acids.

Sensory Evaluation of Potato Chips

The analyses of variance for the effects of oil and storage condition (TRT) on sensory flavor and acceptability scores are shown in Appendix E-6. Both flavor and acceptability scores were significantly affected by oil, TRT, and the interaction between oil and TRT. Mean hedonic flavor and acceptability scores of chips fried in the different oils and stored 0 wk (fresh) and in the light and the dark at 23°C for 4 wk are plotted in Fig. 8 and listed in Appendix E-7.

The 150 panelists recruited for the sensory panel consisted of 79 females and 71 males. Most of panelists (61%) were in the age range between 18 and 24; 52% were in the age range between 25 and 34; 21% were in the age range between 35 and 44; 9% in the age range between 45 and 54; 4% were from 55 to 64 years old and 3% of panelists were over

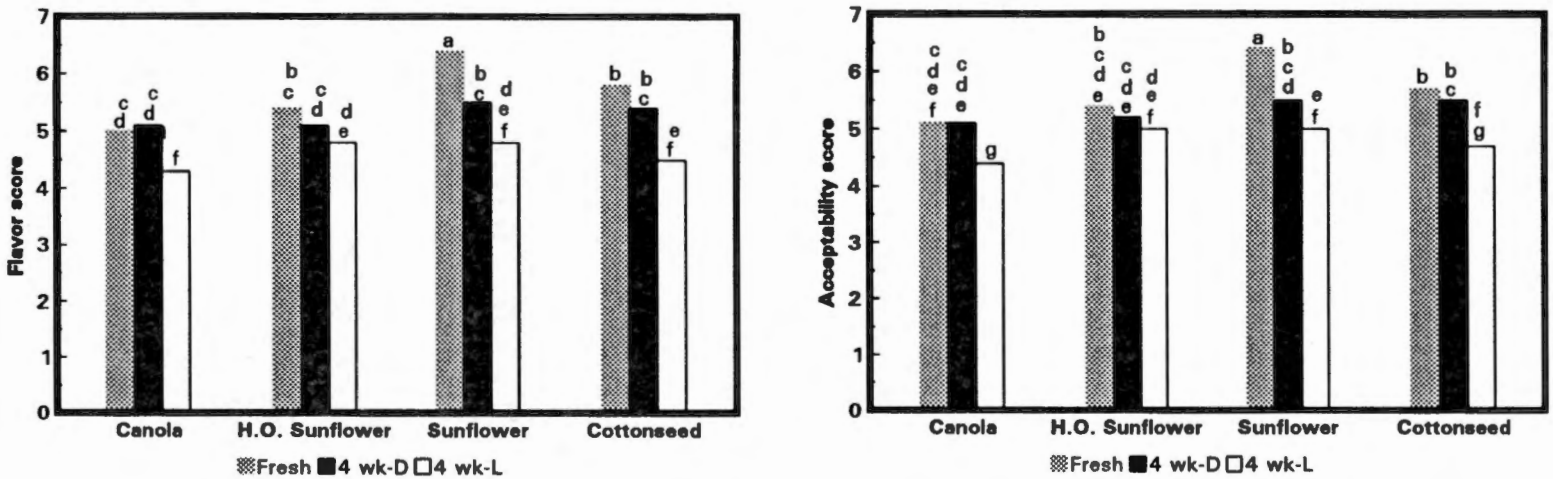


Fig. 8 -- Least-squares mean (n=75) hedonic (a) flavor and (b) acceptability scores (8-point scale where 1=dislike extremely and 8=like extremely) of chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L); for either flavor or acceptability, bars with unlike letters are different ($P < 0.05$).

65 years old. As shown in Appendix E-8, 3.3% of panelists consumed potato chips every day; 30% of panelists consumed potato chips several times a week; 44.7% of panelist ate potato chips several times a month; 20.7% of panelists had chips several time a year and 1.3% of panelists answered that they never eat potato chips.

Fresh potato chips (0 wk) fried in sunflower oil received the highest flavor (6.4) and acceptability (6.4) scores of all chips evaluated (Fig. 8). Panelists liked these chips and their flavor moderately to very much. The flavor scores (5.4-5.8) of fresh chips fried in cottonseed and high oleic sunflower oils and 4 wk-D stored chips fried in sunflower and cottonseed oils were not significantly different. The flavor of fresh, cottonseed oil fried chips was liked better than that of fresh, canola oil fried chips. Also, no significant differences existed among flavor scores (5.0-5.5) of fresh chips fried in canola or high oleic sunflower oils and 4 wk-D stored chips fried in any of the oils. Panelists liked the flavor of these chips slightly to moderately. The flavor scores of 4 wk-L stored chips fried in canola, sunflower, or cottonseed oils were not different ($P < 0.05$), but for each oil, were significantly lower than that of their fresh counterparts. The flavor of 4 wk-L stored chips fried in H.O. sunflower oil was liked better than that of 4 wk-L stored, canola oil fried chips. But,

storage for 4 wk in the light also decreased the flavor score of the H.O. sunflower oil fried chips. Storage in the dark for 4 wk significantly decreased only the hedonic flavor score of chips fried in sunflower oil. Generally, the acceptability scores followed the same pattern as the hedonic flavor scores (Fig. 8), one exception to this general statement is that chips fried in either sunflower oil and stored for 4 wk in the light were more acceptable than the canola oil fried chips stored under the same conditions (Fig. 8).

According to Han (1989), chips stored in the light (1.51-1.69 foot candles) for 4 wk developed less desirable flavor than those stored in the dark. Robertson et al. (1978) indicated that although the flavor of chips degraded slowly with increasing storage time from 0 to 10 wk at 31°C, light increased the rate of degradation. Dornseifer and Powers (1965) noted that chips fried in cottonseed oil and stored under sunlight at ambient temperature for 5 days developed rancid and oxidized flavor.

Pokorny (1989) noted that oils with higher levels of C18:2 produce better fried potatoes. This researcher also reported C18:2 is desirable in frying oil because it is a precursor of t,t-2,4-decadienal, a volatile which imparts a deep-fat fried flavor to potatoes. As stated previously, sunflower oil had the highest level of C18:2 of all oils in

the present study (Table 4) and produced the most desirable fresh chips (Fig. 8). However, the level of the t,t-2,4-decadienal present in the chips may be a better indicator of flavor desirability than the level of C18:2 in the oil. In the present study, t,t-2,4-Decadienal, was present in fresh potato chips fried in sunflower, cottonseed, high oleic sunflower and canola oils at 3.12, 2.18, 1.13, and 0.76 mg/125 g chips, respectively (Appendix E-5), and the flavor scores for the chips fried in these same oils were, respectively, 6.4, 5.7, 5.4, and 5.1 (Appendix E-7). But, the concentration of t,t-2,4-decadienal in chips fried in sunflower and cottonseed oils increased during storage (Fig. 7) while the flavor became less acceptable (Fig. 8).

The flavor of any food product is not dependent on a single flavor volatile, but usually on several volatile compounds and their concentrations, sometimes relative one to the other. Pokorny (1989) reported that alkanals and 2-alkenals containing 7-10 carbons and heptadienal and other alkadienals all affect the sensory quality of frying oils and fried foods. In combination with increasing levels of t,t-2,4-decadienal in chips fried in sunflower and cottonseed oils, concentrations of hexanal, 2-furaldehyde, 2-ethyl-6-methylpyrazine, t-2-nonenal, and t,t-2,4-heptadienal (Figs. 4-6) also increased during storage. Therefore, even though the concentrations of t,t-2,4-

decadienal and 2-ethyl-6-methylpyrazine, which have characteristic roasted and hazelnut flavors, (Maga and Sizer, 1973), increased during storage, the benefits may be decreased by increasing concentrations of the other volatile compounds which have a deleterious effect on fried food flavor. Such volatiles as hexanal, 2-nonenal, and 2-furaldehyde impart rancid and oxidized flavors to foods (Frankel, 1980; Nawar, 1985).

The volatile, t,t-2,4-heptadienal, is of particular interest since it has been reported to cause inferior flavor and is an oxidation production of linolenic acid (Pokorny, 1989). Canola oil fried chips, which had the lowest flavor scores, had the highest levels of t,t-2,4-heptadienal chips (Fig. 6). The extent to which the higher concentrations of t,t-2,4-heptadienal contributed to the less desirable flavor is unknown at the present time.

In conclusion, chips produced by the four oils had similar chemical composition and color. During chip production, the oils showed only slight deterioration as measured by slight increases in the free fatty acid content and small decreases in the polyunsaturated fatty acid concentrations. Oxidation occurred in the chips fried in all oils during 4 wk storage, particularly when in the light, as shown by the increasing peroxide value of the oil extracted from the chips. Under the same storage

conditions, chips fried in the linoleic acid rich sunflower and cottonseed oils oxidized to a greater extent than those fried in high oleic sunflower oil and canola oils.

During storage, concentrations of aldehydes, hexanal, 2-nonenal, and the 2,4-decadienals, produced by oxidation of linoleic acid increased to a greater extent in the chips fried in the linoleic acid rich oils and the aldehydes, benzaldehyde, and t,t-2,4-heptadienal, produced by oxidation of linolenic acid increased more in the canola oil fried chips. Differences in the flavor desirability among the chips fried in different oils and the decreases in the flavor desirability with increasing storage may be due to concentration differences in these specific volatiles as already discussed. If potato chips are stored in light barrier bags for up to 4 wk, results of the present study indicate that chips fried in both sunflower oils or in canola oil may be as desirable as those fried in cottonseed oil. Therefore, it may be possible to substitute any of the oils studied for cottonseed oil in potato chip production and decrease the saturated:unsaturated fat ratio in the diet for consumers who eat potato chips regularly.

CHAPTER V

SUMMARY

In this study, unhydrogenated canola, high oleic sunflower, regular sunflower, and cottonseed oils were used continuously to produce potato chips for 4 hr. Frying oil samples were taken hourly and analyzed for peroxide value (PV), free fatty acid (FFA) level and fatty acid composition. Chips fried in each oil were stored for 0 wk (fresh) and in florescent light or dark at 23°C for 2 and 4 wk (5 storage conditions). A single replication consisted of the chips fried in the four oils and the 5 storage conditions. Three replications were completed. Fresh chips fried in each oil were analyzed for moisture and oil contents and color. Chips fried in each oil and from each storage condition were analyzed for peroxide value of extracted oil. Chips fried in each oil from 0 wk and 4 wk storage in light and dark were analyzed quantitatively and qualitatively for flavor volatile components and by sensory evaluation.

For measurement of oil degradation during use, PV was not a reliable indicator since it increased and then decreased with increasing heating/frying time. However, FFA level increased from 0.022 to 0.071% ($P < 0.05$) with

increasing heating/frying time. The highest FFA level in any oil was well below 0.5%, the level at which chip frying oil is discarded. Higher FFA levels than 0.5% contribute to a shorter potato chip shelf life.

In fatty acid composition, the C18:2 levels in sunflower, cottonseed, canola, and high oleic sunflower oils were, respectively, 66.07, 57.38, 22.41, and 12.36%. The C18:1 acid levels in high oleic sunflower, canola, sunflower, and cottonseed oils were, respectively, 77.59, 57.86, 21.66, and 16.38%. Canola oil was the only oil to contain appreciable amounts of C18:3 (9.74%) and cottonseed contained by far the most C16:0 (21.98%). The levels of C18:2 in all oils and the percentage C18:3 in canola oil decreased slightly with increased heating/frying use. Levels of more saturated fatty acids, C16:0, C18:0, and C18:1, increased as the levels of polyunsaturated fatty acids decreased since the concentrations of the acids were expressed in relative percentages.

Although the type of frying oil affected ($P < 0.05$) the moisture concentration in the chips, it was not important to the quality of the chips. The chips produced contained an average of 1.3% moisture and 45.5% fat. The moisture level was low enough (<2.0%) to assure a crisp texture, and the fat concentration was similar to that regularly found in potato chips. The color of the potato chips was not

affected ($P > 0.05$) by type of frying oil. The average Hunter *L* value of the chips was 54.3, the mean chroma value was 27.2 and the hue angle was 88.3 (yellow color). Frying the potato chips in different oils had no significant effect on the PV (3.4 - 5.1 meq/kg oil) of oil from fresh chips. For chips fried in canola and high oleic sunflower oils, chips oil PV increased ($P < 0.05$) only when the chips were stored in the light for 4 wk. For chips fried in cottonseed oil, storage in the dark for up to 4 wk had no significant effect on chip oil PV, but during storage in the light, chip oil PV increased significantly. The oil PV of sunflower fried chips increased significantly over time during storage for up to 4 wk in the dark, but increased at a greater rate when the chips were stored for up to 4 wk in the light. Compared with chips fried in the other oils, chips fried in sunflower oil were the most unstable to oxidation during storage. The rates of PV increase over storage time was dependent not only the conditions under which the chips were stored but also on the oil in which they were fried before storage.

The mean recoveries of standard volatile compounds extracted from spiked potato chips by simultaneous distillation extraction (SDE) ranged from 29.5% for diacetyl to 64.6% for 2-n-pentylfuran. Recoveries also were precise enough to correct accurately the concentrations of volatiles

isolated by SDE from chip samples. Twenty-four identified volatile compounds and one unknown volatile compound were quantitated in this study. Chips fried in sunflower and cottonseed oils, which had higher levels of C18:2 than the other oils, contained higher concentrations of C18:2 oxidation products: hexanal, 2-pentylfuran, c,t-2,4-decadienal, and t,t-2,4-decadienal. Chips fried in the C18:1 rich oils, canola, and high oleic sunflower, contained highest concentrations of C18:1 oxidation products, t-2-decenal, t-undecenal, and 1-octen-3-ol. Chips fried in canola oil, which had the highest level of C18:3, also had the greatest concentrations of C18:3 oxidation products: benzaldehyde and t,t-2,4-heptadienal. Chips fried in sunflower and cottonseed oils also had higher concentrations of 2-ethyl-6-methylpyrazine and 2-furaldehyde than chips fried in the other oils. Storage of chips in the dark for 4 wk increased concentrations of hexanal and benzaldehyde in the chips but storage for 4 wk in the light increased the concentration of more volatiles: diacetyl, hexanal, 2-furaldehyde, benzaldehyde, t,t-2,4-heptadienal, c,t-2,4-decadienal, and t,t-2,4-decadienal. However, the effect of storage on the concentrations of chip volatiles, hexanal, 2-ethyl-6-methylpyrazine, 2-furaldehyde, benzaldehyde, t-2-nonenal, t,t-2,4-heptadienal, and c,t-2,4-decadienal depended upon the oil in which the chips were fried.

Fresh chips fried in sunflower oil were liked "moderately" to "very much" by a consumer sensory panel, and their flavor was more desirable than that of fresh chips fried in other oils. Fresh chips fried in cottonseed oil were liked "slightly" to "moderately", and their flavor was liked better than the flavor of fresh chips fried in canola oil, but not more than that of chips fried in high oleic sunflower oil. Storage for 4 wk in the dark significantly reduced the flavor desirability of chips fried in sunflower oil, but not that of chips fried in the other oils. Storage of chips fried in any oil except high oleic sunflower oil in the light for 4 wk decreased their flavor and acceptability scores significantly.

The more desirable flavor of fresh chips fried in sunflower oil may be due to higher concentrations of t,t-2,4-decadienal, a volatile compound which imparts desirable flavor to deep-fat fried foods. The less desirable flavor of chips fried in the sunflower and cottonseed oils after storage in light for 4 wk may be related to their higher concentrations of hexanal, 2-furaldehyde, and 2-nonenal, volatiles which impart rancid, oxidized odors to stored fatty foods. The less likable flavor of canola oil fried chips may be because of their higher concentration of the 2,4-heptadienal, an oxidation product of linolenic acid.

Chips fried in canola and high oleic sunflower oils had

better stability for flavor and oxidation than those fried in cottonseed oil. Chips fried in sunflower oil had the least flavor and oxidation stability among chips fried in the different oils. However, the hedonic sensory scores suggests that flavor of chips fried in canola, high oleic sunflower and regular sunflower are as desirable as that of chips fried in cottonseed oil when stored in the dark up to 4 wk. Sunflower oil and high oleic sunflower oils, and if chips are packaged in barrier bags, even canola oil, may be substituted for cottonseed oil in potato chip production without extensive quality loss in the potato chips.

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APPENDIXES

APPENDIX A.

STANDARD VOLATILE ANALYSES AND SENSORY SCORECARD AND QUESTIONNAIRE

Appendix A-1--The concentration, retention time, peak area and Kovat's Indices of known chip volatile compounds in a standard solution and recovery of those volatiles from SDE extraction of potato chips

Standard Compound	RT (min)	Conc. (mg/ml)	Peak Area	Recovery %	Kovat's Indices
Diacetyl	22.40	0.1054	6592	29.35	1089.99
Hexanal	31.396	0.0984	7202	62.20	1191.47
2-n-Pentylfuran	37.555	0.1094	15338	67.64	1268.09
2-Methylpyrazine	44.465	0.1012	11047	47.89	1357.78
2,3-Dimethyl -pyrazine	51.654	0.1128	13816	51.42	1463.67
2,3,5-Trimethyl -pyrazine	54.968	0.0918	11920	47.31	1516.28
1-Octen-3-ol	56.306	0.1018	16053	28.94	1538.55
Nonanal	58.832	0.0996	14625	52.07	1579.18
Pyrrole[a]	---	0.1038	---	---	---
2-Furaldehyde	61.461	0.1142	11668	60.87	1625.61
t-2-Octenal	61.769	0.0966	8664	48.92	1631.64
Decanal	62.999	0.1096	4600	51.33	1655.43
Benzaldehyde[a]	---	0.1220	---	---	---
t,t-2,4-Hepta -dienal	66.281	0.1000	30483	64.98	1717.37
1-Octanol[a]	---	0.0998	---	---	---
t-2-Nonenal	68.001	0.1134	18728	56.36	1749.54
t-2-Decenal	74.043	0.0880	16042	49.62	1872.90
Phenylacet -aldehyde	76.623	0.1138	11045	33.08	1927.94
t,t-2,4-Deca -dienal	84.283	0.0932	5669	49.51	2101.91

[a] Peaks were missed through GC analysis probably due to unstable standard samples.

Appendix A-2. Sensory scorecard

SCORECARD

PANELIST NUMBER_____ SAMPLE NUMBER_____

You will receive 6 samples today. Rinse mouth between samples. You may expectorate the sample into the cup provided or swallow it as you wish.

Place a check in the blank beside the term that best describes your feelings about the flavor of the sample and the overall quality of the chips.

FLAVOR

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

OVERALL ACCEPTABILITY

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

Appendix A-3. Sensory questionnaire

DEMOGRAPHIC QUESTIONNAIRE

Panelist number_____

Please provide the information requested below. The information will be used only to describe the panel that evaluated the chips. All information is anonymous.

1. Male_____ Female_____

2. Age_____ less than 18

_____ 18-24

_____ 25-34

_____ 35-44

_____ 45-54

_____ 55-64

_____ 65 and over

3. How often do you eat potato chips?

_____ every day

_____ several times a week

_____ several times a month

_____ several times a year

_____ never

APPENDIX B.

MEASUREMENT OF OIL DEGRADATION AND FRYING PERFORMANCE - ANALYSES OF VARIANCE AND MEANS

Appendix B-1--Analyses of variance for peroxide value (PEROX) and free fatty acid (FFA) content of oils for frying performance determination

General Linear Models Procedure

Dependent Variable: PEROX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	145.46444	4.69240	6.26	0.0001
Error B[a]	40	29.99671	0.74992		
Corrected Total	71	175.46115			

R-Square	C.V.	Root MSE	PEROX Mean
0.829041	22.47938	0.8660	3.8523

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	29.772256	9.924085	13.23	0.0001
REP	2	0.622123	0.311061	0.41	0.6633
OIL*REP (Error A)[b]	6	1.619383	0.269897	0.36	0.8998
TIME	5	84.304305	16.860861	22.48	0.0001
OIL*TIME	15	29.146377	1.943092	2.59	0.0083

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	29.772256	9.924085	36.77	0.0003
REP	2	0.622123	0.311061	1.15	0.3771

General Linear Models Procedure

Dependent Variable: FFA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	0.0251345	0.0008108	41.61	0.0001
Error B	40	0.0007795	0.0000195		
Corrected Total	71	0.0259140			

R-Square	C.V.	Root MSE	FFA Mean
0.969921	9.700252	0.0044	0.0455

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0017834	0.0005945	30.51	0.0001
REP	2	0.0001395	0.0000697	3.58	0.0372
OIL*REP (Error A)	6	0.0003093	0.0000515	2.65	0.0296
TIME	5	0.0225780	0.0045156	231.73	0.0001
OIL*TIME	15	0.0003243	0.0000216	1.11	0.3792

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0017834	0.0005945	11.53	0.0067
REP	2	0.0001395	0.0000697	1.35	0.3274

[a]Error B is the error term for TIME and OIL*TIME.
[b]Error A is the error term used to test significance of OIL and REP.

Appendix B-2 -- Least-squares mean (n=3) of (a) peroxide value (meq/kg oil) and (b) free fatty acid content (% oleic acid) in fresh and heated oils[a] (0 hr) and in oils used for frying potato chips (1-4 hr)

(a)

Oil	Fresh	0 hr	1 hr	2 hr	3 hr	4hr
Canola	1.7	3.7	3.1	2.7	3.4	3.8
H.O. Sunflower	1.8	4.5	3.8	4.5	4.5	3.0
Sunflower	2.9	8.2	4.7	4.5	4.4	4.2
Cottonseed	1.6	6.6	4.3	3.6	3.6	3.4

(b)

Oil	Fresh	0 hr	1 hr	2 hr	3 hr	4hr
Canola	0.020	0.029	0.036	0.055	0.060	0.070
H.O. Sunflower	0.028	0.035	0.043	0.062	0.071	0.083
Sunflower	0.020	0.027	0.034	0.047	0.053	0.061
Cottonseed	0.019	0.023	0.037	0.053	0.060	0.068

[a]Fresh oil heated 3 hr at 165°C.

B-3--Analyses of variance for fatty acid concentrations expressed in percentages (PT) as a function of frying oil (OIL), replication (REP), heating and chip frying time (ST)

---------- FA=C16:0 ----------

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	4112.9361	1370.9787	44225.12	0.0001
REP	2	0.1144	0.0572	1.85	0.1711
OIL*REP (Error A)[a]	6	0.2656	0.0443	1.43	0.2282
ST	5	0.2728	0.0546		
OIL*ST	15	1.4172	0.0945		
Error B[b]	40	1.2400	0.0310		
Corrected Total	71	4116.2461			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	4112.9361	1370.9787	30976.09	0.0001
REP	2	0.1144	0.0572	1.29	0.3413

---------- FA=C18:0 ----------

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	75.135000	25.045000	13871.08	0.0001
REP	2	0.005278	0.002639	1.46	0.2440
OIL*REP (Error A)	6	0.022500	0.003750	2.08	0.0776
ST	5	0.062778	0.012556	6.95	0.0001
OIL*ST	15	0.021667	0.001444	0.80	0.6707
Error B	40	0.072222	0.001806		
Corrected Total	71	75.319444			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	75.135000	25.045000	6678.67	0.0001
REP	2	0.005278	0.002639	0.70	0.5314

Appendix B-3--Continued

---------- FA=C18:1 ----------

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	46448.652	15482.884	99999.99	0.0001
REP	2	0.244	0.122	2.82	0.0717
OIL*REP (Error A)	6	0.260	0.043	1.00	0.4383
ST	5	3.104	0.621	14.35	0.0001
OIL*ST	15	1.611	0.107	2.48	0.0111
Error B	40	1.730	0.043		
Corrected Total	71	46455.600			

Tests of Hypotheses using the Type III MS for Oil*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	46448.652	15482.884	99999.99	0.0001
REP	2	0.244	0.122	2.81	0.1374

---------- FA=C18:2 ----------

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	36968.969	12322.990	99999.99	0.0001
REP	2	0.016	0.008	0.12	0.8910
OIL*REP (Error A)	6	0.749	0.125	1.82	0.1188
ST	5	7.557	1.511	22.10	0.0001
OIL*ST	15	0.834	0.056	0.81	0.6571
Error B	40	2.736	0.068		
Corrected Total	71	36980.860			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	36968.969	12322.990	98766.82	0.0001
REP	2	0.016	0.008	0.06	0.9391

Appendix B-3--Continued

---------- FA=C20:0 ----------

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	13.386237	4.462079	7160.83	0.0001
REP	2	0.010056	0.005028	8.07	0.0012
OIL*REP (Error A)	6	0.022341	0.003724	5.98	0.0002
ST	5	0.001698	0.000340	0.54	0.7411
OIL*ST	15	0.011843	0.000790	1.27	0.2705
Error B	37	0.023056	0.000623		
Corrected Total	68	13.748696			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	13.386237	4.462079	1198.34	0.0001
REP	2	0.010056	0.005028	1.35	0.3280

---------- FA=C18:3 ----------

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	2	1002.3928	501.1964	99999.99	0.0001
REP	2	0.0302	0.0151	3.96	0.0311
OIL*REP (Error A)	4	0.0682	0.0171	4.47	0.0067
ST	5	0.2841	0.0568	14.89	0.0001
OIL*ST	10	0.4600	0.0460	12.05	0.0001
Error B	27	0.1031	0.0038		
Corrected Total	50	1030.6251			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	2	1002.3928	501.1964	29389.15	0.0001
REP	2	0.0302	0.0151	0.89	0.4803

Appendix B-3--Continued

---------- FA=C20:1 ----------

General Linear Models Procedure

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	22.292278	7.430759	4746.49	0.0001
REP	2	0.030003	0.015001	9.58	0.0004
OIL*REP (Error A)	6	0.027205	0.004534	2.90	0.0197
ST	5	0.026302	0.005260	3.36	0.0128
OIL*ST	15	0.061672	0.004111	2.63	0.0079
Error B	39	0.061056	0.001566		
Corrected Total	70	22.552394			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	22.292278	7.430759	1638.82	0.0001
REP	2	0.030003	0.015001	3.31	0.1075

---------- FA=C22:0 ----------

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	6.7950000	2.2650000	99999.99	0.0001
REP	2	0.0000000	0.0000000	99999.99	0.0001
OIL*REP (Error A)	6	0.0000000	0.0000000	99999.99	0.0001
ST	5	0.0000000	0.0000000	99999.99	0.0001
OIL*ST	15	0.0000000	0.0000000	99999.99	0.0001
Error B	37	0.0000000	0.0000000		
Corrected Total	68	7.0594203			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	6.7950000	2.2650000	99999.99	0.0001
REP	2	0.0000000	0.0000000	1.07	0.4008

Appendix B-3--Continued

---------- FA=C24:0 ----------

General Linear Models Procedure

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.5093725	0.1697908	149.97	0.0001
REP	2	0.0068535	0.0034268	3.03	0.0606
OIL*REP (Error A)	6	0.0094637	0.0015773	1.39	0.2433
ST	5	0.0075051	0.0015010	1.33	0.2747
OIL*ST	15	0.0265185	0.0017679	1.56	0.1336
Error B	37	0.0418889	0.0011321		
Corrected Total	68	0.6133333			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.5093725	0.1697908	107.65	0.0001
REP	2	0.0068535	0.0034268	2.17	0.1951

---------- FA=C16:1 ----------

General Linear Models Procedure

Dependent Variable: PT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	1	0.7714286	0.7714286	1465.71	0.0001
REP	2	0.0016667	0.0008333	1.58	0.2312
OIL*REP (Error A)	2	0.0016667	0.0008333	1.58	0.2312
ST	5	0.0033333	0.0006667	1.27	0.3186
OIL*ST	5	0.0033333	0.0006667	1.27	0.3186
Error B	19	0.0100000	0.0005263		
Corrected Total	34	0.8068571			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	1	0.7714286	0.7714286	925.71	0.0011
REP	2	0.0016667	0.0008333	1.00	0.5000

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[a]Error A is the error term used to test significance of OIL and REP.
[b]Error B is the error term for ST (heating\frying time) and oil*ST.

Appendix B-4 -- Least-squares means (n=3) of concentration (%) of (a) palmitic, (b) oleic, (c) linolenic and (d) eicosenoic acids in fresh and heated oils (0 hr) and oils used for frying potato chips (1-4 hr)

(a)

Oil	Fresh	0 hr	1 hr	2 hr	3 hr	4hr
Canola	4.23	3.80	3.83	3.83	3.87	3.90
H.O. Sunflower	3.90	3.90	3.90	3.97	3.93	3.93
Sunflower	6.13	6.03	6.10	6.17	6.17	6.17
Cottonseed	21.50	21.87	22.00	22.10	22.07	22.37

(b)

Oil	Fresh	0 hr	1 hr	2 hr	3 hr	4hr
Canola	57.00	57.67	57.90	58.07	58.23	58.30
H.O. Sunflower	77.23	77.43	77.53	77.73	77.77	77.83
Sunflower	21.63	21.53	21.63	21.67	21.73	21.77
Cottonseed	16.10	16.33	16.43	16.47	16.43	16.53

(c)

Oil	Fresh	0 hr	1 hr	2 hr	3 hr	4hr
Canola	10.07	9.93	9.77	9.63	9.57	9.47
H.O. Sunflower	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	0.52	0.50	0.47	0.43	0.47	0.47
Cottonseed	0.20	0.20	0.20	0.20	0.20	0.20

(d)

Oil	Fresh	0 hr	1 hr	2 hr	3 hr	4hr
Canola	1.43	1.57	1.63	1.60	1.60	1.63
H.O. Sunflower	0.20	0.23	0.23	0.20	0.23	0.20
Sunflower	0.30	0.30	0.30	0.30	0.30	0.30
Cottonseed	0.36	0.37	0.37	0.37	0.40	0.37

APPENDIX C.

COMPOSITION AND COLOR OF POTATO CHIPS - ANALYSES OF VARIANCE

Appendix C-1--Analyses of variance for specific gravity (SPGR) of raw potatoes and moisture (MOIST) and fat (FAT) levels in potato chips fried in different oils

General Linear Models Procedure

Dependent Variable: SPGR

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.00015092	7.98	0.0162
REP	2	0.00004550	3.61	0.0936
Error (OIL*REP)	6	0.00003783		
Corrected Total	11	0.00023425		

Dependent Variable: MOIST

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.63224583	7.83	0.0169
REP	2	0.00050833	0.01	0.9906
Error (OIL*REP)	6	0.16139167		
Corrected Total	11	0.79414583		

Dependent Variable: FAT

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	41.97904583	0.81	0.5347
REP	2	116.79500833	3.36	0.1047
Error (OIL*REP)	6	104.14089167	24.18	0.0001
Corrected Total	11	262.91494583	33.30	0.0001

Appendix C-2--Analyses of variance for color (Hunter color value "L", chroma, and hue) of fresh potato chips fried in different oils (OIL)

Dependent Variable: L

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	6.734583	2.244861	0.28	0.8373
REP	2	28.675833	14.337917	1.80	0.2445
OIL*REP	6	47.854167	7.975694	28.96	0.0001
Corrected Total	11	83.264583			

Dependent Variable: CHROMA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.5847029	0.1949010	0.19	0.8967
REP	2	4.1103225	2.0551612	2.05	0.2101
OIL*REP	6	6.0260556	1.0043426	9.92	0.0005
Corrected Total	11	10.721081			

Dependent Variable: HUE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0033039	0.0011013	0.16	0.9215
REP	2	0.0046242	0.0023121	0.33	0.7317
OIL*REP	6	0.0421297	0.0070216	14.40	0.0001
Corrected Total	11	0.0500577			

APPENDIX D.

MEASUREMENT OF STABILITY OF POTATO CHIPS DURING STORAGE - ANALYSES OF VARIANCE AND MEANS

Appendix D-1--Analysis of variance for peroxide value of oil extracted from chips fried in different oils (OIL) and stored (ST) for 0 wk (fresh) or 2 and 4 weeks in the dark and light

General Linear Models Procedure

Dependent Variable: PV

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	27	4288.7520	158.8427	40.25	0.0001
Error B[a]	32	126.2982	3.9468		
Corrected Total	59	4415.0502			

R-Square	C.V.	Root MSE	PV Mean
0.971394	18.11307	1.9867	10.968

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	1805.7552	601.9184	152.51	0.0001
REP	2	12.1557	6.0779	1.54	0.2299
OIL*REP (Error A)[b]	6	23.4635	3.9106	0.99	0.4480
ST	4	1805.9786	451.4946	114.39	0.0001
OIL*ST	12	641.3989	53.4499	13.54	0.0001

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	1805.7552	601.9184	153.92	0.0001
REP	2	12.1557	6.0779	1.55	0.2858

[a]Error B is the error term for ST and OIL*ST.
[b]Error A is the error term used to test significance of OIL and REP.

Appendix D-2 -- Least-squares mean (n=3) of peroxide values of oils extracted from potato chips fried in different oils and stored for 0 wk and at 23°C for 2 wk in the dark (2 wk-D) and light (2 wk-L) and for 4 wk in the dark (4 wk-D) and light (4 wk-L)

Oil	Fresh	2 wk-D	2 wk-L	4 wk-D	4 wk-L
Canola	3.4	5.1	6.6	5.3	13.9
H.O. sunflower	5.1	5.2	7.2	5.1	12.2
Sunflower	5.0	14.3	23.8	22.3	35.7
Cottonseed	4.4	5.0	12.1	6.8	20.8

APPENDIX E.

ANALYSIS OF FLAVOR VOLATILES AND SENSORY EVALUATION OF FRESH AND STORED POTATO CHIPS - ANALYSES OF VARIANCE AND MEANS

Appendix E-1--Analyses of variance for flavor volatiles (mg/125-g) isolated from potato chips fried in different oils and store 0 2k (fresh) or in light and dark for 4 wk

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----------DIACETYL----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0720391	0.0240130	1.13	0.3697
REP	2	0.0276020	0.0138010	0.65	0.5374
OIL*REP (Error A)[a]	6	0.0984774	0.0164129	0.77	0.6051
TR	2	0.2221017	0.1110509	5.21	0.0191
OIL*TR	6	0.1063015	0.0177169	0.83	0.5640
Error B[b]	15	0.3196900	0.0213127		
Corrected Total	34	0.8742814			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0720391	0.0240130	1.46	0.3158
REP	2	0.0276020	0.0138010	0.84	0.4765

----------HEXANAL----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	3.0419691	1.0139897	8.53	0.0013
REP	2	0.1132413	0.0566206	0.48	0.6297
OIL*REP (Error A)	6	1.5361515	0.2560252	2.15	0.1033
TR	2	4.3380477	2.1690238	18.24	0.0001
OIL*TR	6	3.0799527	0.5133254	4.32	0.0089
Error	16	1.902642	0.118915		
Corrected Total	35	14.012004			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	3.0419691	1.0139897	3.96	0.0714
REP	2	0.1132413	0.0566206	0.22	0.8078

----------2-PENTYLFURAN----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0460176	0.0153392	13.26	0.0001
REP	2	0.0014564	0.0007282	0.63	0.5454
OIL*REP (Error A)	6	0.0212914	0.0035486	3.07	0.0340
TR	2	0.0053157	0.0026578	2.30	0.1326
OIL*TR	6	0.0039591	0.0006598	0.57	0.7480
Error	16	0.0185026	0.0011564		
Corrected Total	35	0.0965427			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0460176	0.0153392	4.32	0.0604
REP	2	0.0014564	0.0007282	0.21	0.8200

Appendix E-1--Continued

----------2-METHYLPYRAZINE----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.2914870	0.0971623	12.50	0.0002
REP	2	0.3380711	0.1690355	21.75	0.0001
OIL*REP (Error A)	6	0.2353504	0.0392251	5.05	0.0044
TR	2	0.0226826	0.0113413	1.46	0.2618
OIL*TR	6	0.0123368	0.0020561	0.26	0.9456
Error	16	0.1243657	0.0077729		
Corrected Total	35	1.0242936			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.2914870	0.0971623	2.48	0.1587
REP	2	0.3380711	0.1690355	4.31	0.0691

----------2,5-Dimethylpyrazine----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.5417138	0.1805713	13.86	0.0001
REP	2	0.7087036	0.3543518	27.19	0.0001
OIL*REP (Error A)	6	0.6558315	0.1093052	8.39	0.0003
TR	2	0.0288707	0.0144353	1.11	0.3543
OIL*TR	6	0.0211043	0.0035174	0.27	0.9430
Error B	16	0.2084902	0.0130306		
Corrected Total	35	2.1647141			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.5417138	0.1805713	1.65	0.2747
REP	2	0.7087036	0.3543518	3.24	0.1110

----------2,6-Dimethylpyrazine----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0250743	0.0083581	7.26	0.0036
REP	2	0.0287356	0.0143678	12.49	0.0008
OIL*REP (Error A)	6	0.0285839	0.0047640	4.14	0.0134
TR	2	0.0005214	0.0002607	0.23	0.8001
OIL*TR	6	0.0020832	0.0003472	0.30	0.9257
Error B	14	0.0161084	0.0011506		
Corrected Total	33	0.1005897			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0250743	0.0083581	1.75	0.2553
REP	2	0.0287356	0.0143678	3.02	0.1240

Appendix E-1--Continued

----------2,3-DIMETHYLPYRAZINE----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0034846	0.0011615	3.35	0.0475
REP	2	0.0045685	0.0022843	6.59	0.0088
OIL*REP (Error A)	6	0.0074162	0.0012360	3.57	0.0213
TR	2	0.0004906	0.0002453	0.71	0.5086
OIL*TR	6	0.0010045	0.0001674	0.48	0.8110
Error B	15	0.0052005	0.0003467		
Corrected Total	34	0.0226813			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0034846	0.0011615	0.94	0.4780
REP	2	0.0045685	0.0022843	1.85	0.2369

----------2-Ethyl-5-methylpyrazine----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0251567	0.0083856	12.00	0.0003
REP	2	0.0486482	0.0243241	34.79	0.0001
OIL*REP (Error A)	6	0.0433534	0.0072256	10.34	0.0001
TR	2	0.0005494	0.0002747	0.39	0.6818
OIL*TR	6	0.0018028	0.0003005	0.43	0.8478
Error B	15	0.0104861	0.0006991		
Corrected Total	34	0.1317852			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0251567	0.0083856	1.16	0.3992
REP	2	0.0486482	0.0243241	3.37	0.1046

----------2-Ethyl-6-methylpyrazine----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.2572681	0.0857560	7.40	0.0025
REP	2	0.0022017	0.0011009	0.09	0.9099
OIL*REP (Error A)	6	0.0837236	0.0139539	1.20	0.3540
TR	2	0.8129653	0.4064827	35.06	0.0001
OIL*TR	6	0.1942259	0.0323710	2.79	0.0470
Error B	16	0.1854768	0.0115923		
Corrected Total	35	1.5358616			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.2572681	0.0857560	6.15	0.0292
REP	2	0.0022017	0.0011009	0.08	0.9251

Appendix E-1--Continued

----------2.3.5-Trimethylpyrazine----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0440652	0.0146884	8.90	0.0011
REP	2	0.0694735	0.0347368	21.04	0.0001
OIL*REP (Error A)	6	0.0835071	0.0139179	8.43	0.0003
TR	2	0.0018689	0.0009345	0.57	0.5788
OIL*TR	6	0.0018106	0.0003018	0.18	0.9775
Error B	16	0.0264162	0.0016510		
Corrected Total	35	0.2271416			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0440652	0.0146884	1.06	0.4346
REP	2	0.0694735	0.0347368	2.50	0.1627

----------1-Octen-3-ol----------

DEPENDENT VARIABLE: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	1.0588040	0.3529347	110.03	0.0001
REP	2	0.0031282	0.0015641	0.49	0.6235
OIL*REP (Error A)	6	0.0185033	0.0030839	0.96	0.4828
TR	2	0.0008258	0.0004129	0.13	0.8802
OIL*TR	6	0.0114312	0.0019052	0.59	0.7307
Error B	15	0.0481127	0.0032075		
Corrected Total	34	1.1478304			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	1.0588040	0.3529347	114.45	0.0001
REP	2	0.0031282	0.0015641	0.51	0.6259

----------Nonanal----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0065465	0.0021822	1.37	0.2875
REP	2	0.0074403	0.0037202	2.34	0.1287
OIL*REP (Error A)	6	0.0250592	0.0041765	2.62	0.0576
TR	2	0.0098248	0.0049124	3.09	0.0736
OIL*TR	6	0.0028461	0.0004743	0.30	0.9290
Error B	16	0.0254741	0.0015921		
Corrected Total	35	0.0771909			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0065465	0.0021822	0.52	0.6825
REP	2	0.0074403	0.0037202	0.89	0.4584

45Appendix E-1--Continued

----------2-Furaldehyde----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0179584	0.0059861	8.82	0.0016
REP	2	0.0008804	0.0004402	0.65	0.5378
OIL*REP (Error A)	6	0.0068409	0.0011402	1.68	0.1985
TR	2	0.0217840	0.0108920	16.05	0.0002
OIL*TR	6	0.0143275	0.0023879	3.52	0.0246
Error B	14	0.0095031	0.0006788		
Corrected Total	33	0.0766767			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0179584	0.0059861	5.25	0.0409
REP	2	0.0008804	0.0004402	0.39	0.6955

----------t-2-Octenal----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0031841	0.0010614	3.34	0.0501
REP	2	0.0032334	0.0016167	5.09	0.0218
OIL*REP (Error A)	6	0.0051296	0.0008549	2.69	0.0595
TR	2	0.0003313	0.0001657	0.52	0.6047
OIL*TR	6	0.0011587	0.0001931	0.61	0.7204
Error B	14	0.0044478	0.0003177		
Corrected Total	33	0.0177030			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0031841	0.0010614	1.24	0.3744
REP	2	0.0032334	0.0016167	1.89	0.2308

----------Decanal-----11----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0065626	0.0021875	6.29	0.0082
REP	2	0.0035753	0.0017876	5.14	0.0244
OIL*REP (Error A)	6	0.0067318	0.0011220	3.23	0.0398
TR	2	0.0001493	0.0000746	0.21	0.8098
OIL*TR	6	0.0017475	0.0002913	0.84	0.5638
Error B	12	0.0041705	0.0003475		
Corrected Total	31	0.0249217			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0065626	0.0021875	1.95	0.2230
REP	2	0.0035753	0.0017876	1.59	0.2786-

Appendix E-1--Continued

----------Benzaldehyde----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0096405	0.0032135	23.39	0.0001
REP	2	0.0007709	0.0003854	2.81	0.1001
OIL*REP (Error A)	6	0.0011525	0.0001921	1.40	0.2920
TR	2	0.0050234	0.0025117	18.28	0.0002
OIL*TR	6	0.0128814	0.0021469	15.63	0.0001
Error B	12	0.0016487	0.0001374		
Corrected Total	31	0.0349405			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0096405	0.0032135	16.73	0.0026
REP	2	0.0007709	0.0003854	2.01	0.2151

----------2,4-Heptadienal----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0121835	0.0040612	33.33	0.0001
REP	2	0.0001114	0.0000557	0.46	0.6411
OIL*REP (Error A)	6	0.0003331	0.0000555	0.46	0.8306
TR	2	0.0059337	0.0029668	24.35	0.0001
OIL*TR	6	0.0074480	0.0012413	10.19	0.0001
Error B	16	0.0019493	0.0001218		
Corrected Total	35	0.0279591			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0121835	0.0040612	73.15	0.0001
REP	2	0.0001114	0.0000557	1.00	0.4209

----------1-Octanol----------

Dependent Variable: CX

		Sum of	Mean		
OIL	3	0.0010556	0.0003519	0.27	0.8451
REP	2	0.0006280	0.0003140	0.24	0.8057
OIL*REP (Error A)	2	0.0001814	0.0000907	0.07	0.9349
TR	2	0.0005236	0.0002618	0.20	0.8326
OIL*TR	2	0.0000828	0.0000414	0.03	0.9692
Source	DF	Squares	Square	F Value	Pr > F
Error B	2	0.0026034	0.0013017		
Corrected Total	14	0.0055803			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0010556	0.0003519	3.88	0.2117
REP	2	0.0006280	0.0003140	3.46	0.2241

Appendix E-1--Continued

----------t-2-Nonenal----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0002963	0.0000988	1.85	0.1811
REP	2	0.0001412	0.0000706	1.32	0.2954
OIL*REP (Error A)	6	0.0004020	0.0000670	1.26	0.3337
TR	2	0.0002503	0.0001251	2.35	0.1297
OIL*TR	6	0.0008274	0.0001379	2.59	0.0634
Error B	15	0.0007997	0.0000533		
Corrected Total	34	0.0028153			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0002963	0.0000988	1.47	0.3132
REP	2	0.0001412	0.0000706	1.05	0.4053

----------t-2-Decenal----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.0025125	0.0008375	34.44	0.0001
REP	2	0.0000309	0.0000155	0.64	0.5423
OIL*REP (Error A)	6	0.0000199	0.0000033	0.14	0.9893
TR	2	0.0000579	0.0000289	1.19	0.3299
OIL*TR	6	0.0000441	0.0000074	0.30	0.9266
Error B	16	0.0003891	0.0000243		
Corrected Total	35	0.0030544			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.0025125	0.0008375	252.22	0.0001
REP	2	0.0000309	0.0000155	4.66	0.0601

----------Phenylacetaldehyde----------

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.4257063	0.1419021	2.44	0.1018
REP	2	0.3049840	0.1524920	2.62	0.1033
OIL*REP (Error A)	6	0.7058434	0.1176406	2.02	0.1216
TR	2	0.1037164	0.0518582	0.89	0.4290
OIL*TR	6	0.1623829	0.0270638	0.47	0.8235
Error B	16	0.9295107	0.0580944		
Corrected Total	35	2.6321438			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.4257063	0.1419021	1.21	0.3850
REP	2	0.3049840	0.1524920	1.30	0.3405

Appendix E-1--Continued

t-2-Undecenal

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	0.6196730	0.2065577	12.40	0.0002
REP	2	0.0242772	0.0121386	0.73	0.4979
OIL*REP (Error A)	6	0.0086634	0.0014439	0.09	0.9968
TR	2	0.0333136	0.0166568	1.00	0.3898
OIL*TR	6	0.0651368	0.0108561	0.65	0.6887
Error B	16	0.2665622	0.0166601		
Corrected Total	35	1.0176261			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	0.6196730	0.2065577	143.06	0.0001
REP	2	0.0242772	0.0121386	8.41	0.0182

c,t-2,4-Decadienal

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	1.6222994	0.5407665	41.30	0.0001
REP	2	0.0724859	0.0362429	2.77	0.0928
OIL*REP (Error A)	6	0.1098098	0.0183016	1.40	0.2750
TR	2	0.3024574	0.1512287	11.55	0.0008
OIL*TR	6	0.3096329	0.0516055	3.94	0.0131
Error B	16	0.2095035	0.0130940		
Corrected Total	35	2.6261890			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	1.6222994	0.5407665	29.55	0.0005
REP	2	0.0724859	0.0362429	1.98	0.2186

t,t-2,4-Decadienal

Dependent Variable: CX

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
OIL	3	79.771554	26.590518	39.40	0.0001
REP	2	3.430584	1.715292	2.54	0.1100
OIL*REP (Error A)	6	5.162755	0.860459	1.28	0.3227
TR	2	5.311564	2.655782	3.94	0.0407
OIL*TR	6	7.364725	1.227454	1.82	0.1586
Error B	16	10.79775	0.67486		
Corrected Total	35	111.83894			

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OIL	3	79.771554	26.590518	30.90	0.0005
REP	2	3.430584	1.715292	1.99	0.2168

[a]Error A is the error term used to test significance of OIL and REP.
[b]Error B is the error term for ST and oil*ST.

(a)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.115	0.229	0.354
H.O. Sunflower	0.138	0.344	0.577
Sunflower	0.185	0.663	2.126
Cottonseed	0.181	0.710	0.937

(b)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.0421	0.0375	0.0596
H.O. Sunflower	0.0501	0.0581	0.0758
Sunflower	0.0460	0.0884	0.1935
Cottonseed	0.0606	0.903	0.1188

Appendix E-2 -- Least-squares mean (n=3) of concentrations (mg/125-g chips) for (a) hexanal and (b) 2-furaldehyde isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L)

(a)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.121	0.142	0.339
H.O. Sunflower	0.219	0.225	0.351
Sunflower	0.185	0.255	0.726
Cottonseed	0.233	0.287	0.686

(b)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.02797	0.0214	0.0226
H.O. Sunflower	0.03010	0.0295	0.0268
Sunflower	0.02370	0.0268	0.0472
Cottonseed	0.02720	0.0280	0.0331

Appendix E-3-- Least-squares mean (n=3) of concentrations (mg/125-g chips) for (a) 2-ethyl-6-methylpyrazine and (b) t-2-nonenal isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L)

(a)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.0441	0.0366	0.1384
H.O. Sunflower	0.0343	0.0412	0.0352
Sunflower	0.0178	0.0412	0.0428
Cottonseed	0.0191	0.0335	0.0294

(b)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.0287	0.0401	0.1126
H.O. Sunflower	0.0120	0.0173	0.0206
Sunflower	0.0098	0.0214	0.0312
Cottonseed	0.0112	0.0198	0.0199

Appendix E-4 -- Least-squares mean (n=3) of concentrations (mg/125-g chips) for (a) benzaldehyde and (b) t,t-2,4-heptadienal isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L)

(a)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.077	0.094	0.150
H.O. Sunflower	0.115	0.110	0.138
Sunflower	0.325	0.657	0.918
Cottonseed	0.225	0.263	0.430

(b)

Oil	Fresh	4 wk-D	4 wk-L
Canola	0.76	0.90	1.12
H.O. Sunflower	1.13	1.04	0.99
Sunflower	3.12	4.88	5.84
Cottonseed	2.18	2.48	2.99

Appendix E-5 -- Least-squares mean (n=3) of concentrations (mg/125-g chips) for (a) c,t-2,4-decadienal and (b) t,t-2,4-decadienal isolated from chips fried in different oils and stored 0 wk (fresh) and at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L)

Appendix E-6--Analyses of variance for hedonic scores of flavor and acceptability of potato chips from sensory evaluation

General Linear Models Procedure

Dependent Variable: FLAVOR

Source	DF	Sum of Squares	F Value	Pr > F
Model	166	1222.68999243	3.72	0.0001
Error B[a]	733	1451.50889646		
Corrected Total	899	2674.19888889		

R-Square	C.V.	FLAVOR Mean
0.457217	27.17198	5.17888889

Source	DF	Type III SS	F Value	Pr > F
OIL	3	66.94831601	11.27	0.0001
REP	2	35.47555556	8.96	0.0001
OIL*REP (Error A)[b]	6	22.82535897	1.92	0.0749
TRT	2	169.16222222	42.71	0.0001
OIL*TRT	6	31.63052110	2.66	0.0146
PANEL(REP)	147	881.96665910	3.03	0.0001

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	F Value	Pr > F
OIL	3	66.94831601	5.87	0.0323
REP	2	35.47555556	4.66	0.0600

General Linear Models Procedure

Dependent Variable: ACCEPT

Source	DF	Sum of Squares	F Value	Pr > F
Model	166	1104.98110251	3.32	0.0001
Error B	733	1470.13445304		
Corrected Total	899	2575.11555556		

R-Square	C.V.	ACCEPT Mean
0.429100	27.03831	5.23777778

Source	DF	Type III SS	F Value	Pr > F
OIL	3	62.68059399	10.42	0.0001
REP	2	24.22888889	6.04	0.0025
OIL*REP (Error A)	6	28.52064584	2.37	0.0283
TRT	2	123.40222222	30.76	0.0001
OIL*TRT	6	30.61473784	2.54	0.0191
PANEL(REP)	147	830.98554696	2.82	0.0001

Tests of Hypotheses using the Type III MS for OIL*REP as an error term

Source	DF	Type III SS	F Value	Pr > F
OIL	3	62.68059399	4.40	0.0585
REP	2	24.22888889	2.55	0.1581

[a]Error B is the error term for TRT and OIL*TRT.
[b]Error A is the error term used to test significance of OIL and REP.

(a)

Oil	Fresh	4 wk-D	4 wk-L
Canola	5.0	5.1	4.3
H.O. Sunflower	5.4	5.1	4.8
Sunflower	6.4	5.5	4.8
Cottonseed	5.8	5.4	4.5

(b)

Oil	Fresh	4 wk-D	4 wk-L
Canola	5.1	5.1	4.4
H.O. Sunflower	5.4	5.2	5.0
Sunflower	6.4	5.5	5.0
Cottonseed	5.7	5.5	4.7

Appendix E-7 -- Least-squares mean (n=75) of hedonic (a) flavor and (b) acceptability scores (8-point scale where 1 = dislike extremely and 8 = like extremely) of chips fried in different oils and stored 0 wk (fresh) or at 23°C for 4 wk in the dark (4 wk-D) and light (4 wk-L)

Appendix E-8 -- Percentages of panelists for frequency of potato chips consumption

Frequency	Number	Percent	Accumulative Number	Accumulative Percent
Every day	5	3.3	5	3.3
Several time/week	45	30.0	50	33.3
Several times/month	67	44.7	117	78.0
Several times/year	31	20.7	148	98.7
Never	2	1.3	150	100.0

VITA

Hung-Wei Lin was born in Nan-Tao, Taiwan, Republic of China on December 24, 1961, to Chu-Yiu Lieu and Si-Chung Lin. In 1980, he graduated from Taichung First Senior High School. In 1984, he graduated from National Institute of Agriculture in Pingtong. In August, 1989, he entered the Food Technology and Science Department at The University of Tennessee, Knoxville. He married Yan Xu from Shanghai, China, on April, 11, 1991. One year later, he received his Bachelor of Science degree with a major in Food Science and Technology. At the same time, he entered the graduate program under the same department at The University of Tennessee in Knoxville. He completed requirements for a Master of Science degree in Food Science and Technology in August, 1993. He was also admitted to the doctoral program in Food Science and Technology at the same university.