To the Graduate Council·

I am submitting herewith a dissertation written by Philipus Pangloli entitled "Flavor and Storage Stability of Potato Chips Fried in Cottonseed and Sunflower Oils and Sunflower:Palm Olein Oil Blends." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirement for the degree of Doctor of Philosophy, with a major in Food Science and Technology.

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FLAVOR AND STORAGE STABILITY OF POTATO CHIPS FRIED IN COTTONSEED AND SUNFLOWER OILS AND SUNFLOWER.PALM OLEIN OIL BLENDS

A DISSERTATION

PRESENTED FOR THE

DOCTOR OF PHILOSOPHY DEGREE

THE UNIVERSITY OF TENNESSEE, KNOXVILLE

PHILIPUS PANGLOLI

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DEDICATION

The fear of the Lord is the beginning of knowledge (Proverbs 1 7).

This dissertation is dedicated to my wife Alexandra Lydia G Pangloli and my daughters Alphidia Lorensia Pangloli and Alviony Febrina Pangloli for their love, understanding, and prayers.

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Above of all, praise the Lord for only His grace the author may have such wonderful opportunities and accomplish any work in his life.

ABSTRACT

To increase stability of sunflower oil (SFO) during frying and of potato chips during storage, 20 and 40% palm oil olein (POO) were added to SFO and compared to cottonseed oil (CSO) The oils/blends were sampled fresh, after break-in heating and at 2 5- and 5-hr frying Oils were analyzed for of fatty acid composition, C18 2/C16:0 ratio, total polar compounds (TPC), free fatty acids (FFA), conjugated dienoic acids (CDA), and color Moisture and fat levels and Agtron color of fresh chips were determined. Potato chips from each oil/blend were stored for 0 wk and 3 or 6 wk in dark or light and analyzed for peroxide values (PV), headspace flavor volatiles and sensory attributes.

SFO contained 65.8% C18.2 compared to 51.7, 54 6 and 43 3% in CSO, and 20:80 and 40:60 POO·SFO, respectively. Levels of all fatty acids and C18:2/C16·0 ratio remained unchanged during frying, except for C18:1, which increased. Levels of TPC, FFA and CDA differed among oils/blends and increased during frying but TPC increased at the fastest rate in SFO. Addition of POO to SFO retarded oil degradation rate during frying to that of CSO

Fresh chips had 1.96% moisture, 39.2% fat, and an Agtron color of 60.5. During dark storage, PV increased only in SFO-fried chips at 6 wk and were lower than in chips stored in light. Addition of 40% POO to SFO increased chip stability to that of CSO-fried chips during dark storage and greater than that of same chips during light storage. Of 10 volatiles identified in chips, only hexanal increased progressively during storage in dark and light, the desirable fried flavor volatile (t,t-2,4-decadienal) level did not change After 6 wk in light, only CSO-fried chips had increased intensities ($p<0.05$) of oxidative rancidity and off-flavors (OF), while chips fried in 20% POO:SFO had a lower intensity of

OF than SFO-fried chips Characteristic potato chip flavor was similar (p>0 05) in intensity among frying oils/blends and did not change during chip storage Addition of POO to SFO improved the stability of SFO-fried chips without sacrificing characteristic potato chip flavor

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CHAPTER I

INTRODUCTION

Sunflower oil (SFO) is one of the many oils listed on the labels of fried potato chips produced in the United States. However, the extent to which SFO is used largely depends upon its cost. Of oils produced in the United States, SFO generally costs more than cottonseed, corn or soybean oils (Asbridge, 1995). Research at The University of Tennessee showed that the flavor of fresh potato chips fried in SFO was liked more than the flavor of those fried in cottonseed oil (CSO) (Lin, 1993). However, the hedonic flavor score of the SFO-produced chips decreased ($p<0.05$) during 4-wk storage in a sealed container in the dark, while the score of the CSO-produced chips did not change significantly (Lin, 1993). The higher level of linoleic acid (C18:2) in the SFO might be the reason for the more desirable but less stable flavor of the SFO-fried chips, but this has not been shown conclusively. According to Pokorny (1989), oxidation of C18.2 during frying produces t,t-2,4-decadienal that imparts desirable flavor to fried foods. However, the exact level of C18:2 necessary to produce the most desirable flavor in potato chips is unknown. Silaula (1997) found that refined, bleached and deodorized (RBD) SFO contained 70% C18:2 while CSO used to fry potato chips may contain 44-57% C18 2 (Han, 1989, Lin, 1993, Melton et al., 1993)

A saturated oil that has received a reputation of being "unhealthy" but is the least expensive and second most abundantly produced oil in the world is palm oil (Asbridge, 1995) Palm oil is the main oil produced and consumed in Indonesia. Krawczyk (1997) reported that Indonesia produced 4.6 million metric tons (MMT) of palm oil or 31% of the total world production in 1996. Palm oil is not favored in the United States and other

developed countries due to consumer concern about saturated fatty acids. Palm oil contains approximately 50% saturated fatty acids, with 46.8% palmitic acid (C16:0) (Weiss, 1983). The saturated fatty acids which increase cholesterol level in blood serum are lauric (C12 0), myristic (C14 0) and C16·0, a higher serum cholesterol level increases the risk for coronary heart disease (Khosla and Hayes, 1994). However, the second most abundant fatty acid in palm oil is oleic acid (C18.1) at 37.6%, which lowers serum cholesterol levels by decreasing the "low-density lipoprotein" (LDL) or "bad" form of serum cholesterol without affecting the "high-density lipoprotein" (HDL) or the "good" form of serum cholesterol (Mattson and Grundy, 1985). Kock-Wai (1994) and Wood et al. (1993) indicated that diets containing crude or refined palm oil did not increase total serum cholesterol. Wood et al. (1993) found that diets with refined palm oil resulted in the highest levels of HDL compared to several other oils. These results show that palm oil might have been accused unjustly for increasing serum cholesterol levels in humans.

Palm olein oil (POO) is a fraction produced from palm oil during the production of ghee, the stearine portion of palm oil. Palm oil is more saturated than POO which contains 38.3% C16·0, 42.1% C18 1 and 10.6% C18.2 (Han, 1989). POO is the portion of palm oil used for frying (Pokorny, 1989). POO produces potato chips with less desirable flavor than those fried in cottonseed oil, but with stable flavor when stored in closed, light-barrier containers for up to 4 wk (Han, 1989, Melton et al., 1993)

CSO, which is the most frequently used oil for frying potato chips in the southern United States (Weiss, 1983), contains approximately 25% C16·0 in addition to the 44 to 57% C18:2 (Han, 1989, Melton et al , 1993). Also, CSO generally costs less than SFO in the United States (Asbridge, 1995)

Based on the fatty acid composition of SFO, CSO and POO, as well as, the results of the previous studies, the possibility exists that the blends of the more saturated POO and the more unsaturated SFO could produce a more stable flavor but one which is still just as or more desirable than that produced by the pure SFO. A 40 60 blend of POO with SFO (40% POO) would have a similar fatty acid composition to the CSO used to produce potato chips in the southern United States and should produce chips with flavor that is as stable as that of CSO produced chips. Such a blend would contain approximately 20% C16.0 and 50% C18:2, and based on average 1990-92 prices for crude oils, the 40% POO blend would cost 21.5 ¢/lb compared to 22.1¢/lb for CSO (Asbridge, 1995). Also, frying potato chips in POO:SFO blends containing a higher amount of SFO might produce a more stable flavor than that found in chips fried in pure SFO, particularly if the blend was 20:80 POO:SFO (20% POO). No reports were found in which the flavor stability of any food fried in POO.SFO blends had been studied Research is needed to determine if POO:SFO blends might produce potato chips with as stable of a flavor as that of CSO-produced chips and chips with a more stable flavor than SFO-produced chips. In addition, the stability of such blends during frying of potato chips needs to be determined. Such research could lead to more stable, and possibly more desirable, flavored snack-foods for the United States at an increased profit to the snack-food processor and to increased use of Indonesian-produced POO in the United States without increased health hazard to consumers.

The objectives of the present study were as follows

1 To fry potato chips in CSO, SFO and POO.SFO blends and determine the deterioration of the oils and oil blends during the frying of the potato chips

2 To determine the level of oxidation in fresh potato chips fried in the different

oils and oil blends and in those same potato chips after storage for up to 6 wk in closed clear glass containers under fluorescent light or in the dark at room temperature.

3. To determine color of fresh potato chips.

4 To isolate and measure flavor volatiles present in the fresh and stored potato chips.

5 To evaluate sensorially the color lightness and flavor characteristics (characteristic potato chip flavor, oxidative rancidity and off-flavors) of fresh and stored potato chips fried in two different oils and two oil blends.

CHAPTER II

LITERATURE REVIEW

A. GENERAL AND HEALTH ASPECTS OF OILS

Oils or fats provide several functions in foods (Pomeranz, 1991). They may contribute to flavor, color, texture and appearance of various foods Oils also serve as a rapid heat transfer medium in food processing which has increased their use in the commercial frying industry. Nutritionally, dietary fats have five functions (Melton, 1996). They are the building materials for cell structure, provide the essential fatty acids, serve as the medium of essential fat-soluble vitamins and act as a factor in control of serum lipids and lipoproteins. Dietary fats also represent the most concentrated chemical energy available to humans. They contain more than twice the caloric value of an equivalent weight of carbohydrate or protein

On the other hand, high fat intake is associated with risk of obesity, some types of cancer and gallbladder disease (Vanderveen, 1996) The levels of saturated fatty acids together with total fat are associated with high incidence of colon, prostate and breast cancers (NRC, 1989). According to Reddy (1983), dietary fat increased secretion of bile acids into the gut and modified the activity of the microflora that could enhance the formation of secondary bile acids in the colon. The secondary bile acids might act as tumor promoters. Carroll (1983) reported that the incidence of cancer might be reduced by decreasing the level of dietary fat intake.

Saturated fatty acids, particularly C12 0-C16·0, may raise the levels of total blood cholesterol and low-density lipoprotein (LDL) cholesterol; therefore, they increase

risk of coronary heart disease (NRC, 1989). Diets containing a high amount of saturated fat resulted in higher levels of triacylglycerol, total cholesterol and LDL cholesterol in blood compared to diets with high levels of mono- and polyunsaturated fats (Mattson and Grundy, 1985). Unlike other saturated fatty acids, however, stearic acid (C18:0) did not significantly affect plasma cholesterol (Haumann, 1998). It has been hypothesized that stearic acid is absorbed poorly by the body and thus is excreted, or it may be converted rapidly into oleic acid (C18:1) in the body.

Both mono- and polyunsaturated fats significantly reduced LDL cholesterol; however, polyunsaturated fat also reduced high-density lipoprotein (HDL) cholesterol (Mattson and Grundy, 1985) Ruiz-Gutierrez et al. (1997) reported that diets containing monounsaturated fatty acids from olive or high oleic sunflower oil reduced plasma LDL cholesterol by 9 and 6% and increased plasma HDL cholesterol by 18 and 12%, respectively. Diets high in polyunsaturated fatty acids such as linoleic acid (C18:2) in sunflower oil decreased both LDL and HDL cholesterols (Wood et al , 1993). Omega-6 polyunsaturated fatty acid may lower total serum, LDL cholesteroland HDL cholesterol. Omega-3 fatty acids lower plasma triglycerides, increase blood clotting time (Vanderveen, 1996)and may be anticarcinogenic (Pariza, 1996). Trans fatty acids (TFA) also have been associated with some diseases. Hydrogen atoms of the double bonds of TFA located in the opposite position create straight molecules that pack together solidly and result in properties similar to saturated fatty acids (Watkins, 1998; Willet and Ascherio, 1994). TFA may increase total and LDL cholesterol, decrease HDL cholesterol and, therefore, could cause coronary heart disease Wood et al. (1983) found that trans fatty acids of hard margarine reduced levels of HDL cholesterol more

than saturated fatty acids of palm oil Also, conjugated linoleic acid (CLA) may inhibit carcinogenesis by regulating energy metabolism and retention within the body (Pariza, 1996).

B. PRINCIPLES AND DYNAMICS OF DEEP-FAT FRYING

Frying is one of the oldest cooking methods and has been an important method of food preparation worldwide Although there is a tendency to reduce dietary fat consumption in the United States, the popularity of frying continues to increase (Orthoefer et al., 1996) It is a fast and convenient technique of food preparation and contributes desirable flavor, texture and appearance to fried food.

Types of frying mainly consist of pan or griddle and deep-fat frying (Orthoefer et al., 1996; Weiss, 1983). Deep-fat frying in a continuous system is the most common practice used by the multimillion-dollar snack food industry in the United States (Singh, 1995). In deep-fat frying, the food is completely immersed into the oil. In all types of frying, however, the oil functions as an effective medium for heat transfer from heat source to the surface of the frying food. Water of the frying food will further transfer heat energy conductively from surface to the interior of food (Blumenthal, 1991; Orthoefer et al., 1996)

In addition to the heat transfer, frying also involves mass transfer and interaction between food and frying medium (Blumenthal, 1991; Saguy and Pinthus, 1995; Singh, 1995). Upon contact with the hot oil, water on the surface of frying food evaporates to form water vapor. The loss of water on the surface leads to migration of the water from inside food outward and that further protects against charring or burning of food surface

from hot oil The water movement creates a higher pressure inside the food that limits penetration of frying oil to the interior of foods and may prevent excessive dehydration of the surface of food (Orthoefer et al., 1996) According to Saguy and Pinthus (1995), evaporation of the water on the outer surface of the food leads to the formation of crust that acts as a diffusion barrier and adds palatable characteristics to the fried food. Frying at high temperature also creates explosive boiling of the water inside the food that forms capillary holes and voids. The frying oil is then absorbed into the food through the holes and voids and fills the space left by water and keeps the food structure from shrinking or collapsing Oil uptake into the fried food is increased by a reduction of internal pressure due to water loss and cooling. The dehydration of food surface and fat absorption to some extent imparts desirable flavor and texture. The high temperature during frying also promotes reactions among food components which develop the unique appealing characteristics of fried foods (Orthoefer et al , 1996) In addition to water vaporization and crust formation, some chemical and physical changes such as starch gelatinization and protein denaturization may occur during frying (Singh, 1995).

Flavor desirability of fried food differs with the phases through which a frying oil proceeds during use (Blumenthal, 1991; Pokorny, 1989; Stier and Blumenthal, 1993). The flavor is less desirable in the early and the last stages of frying oil useable life The flavor desirability is optimum in the mid-stage due to the formation of decadienal isomers in the frying oil (Jacobson, 1991, Pokorny, 1989). According to Pokorny (1989), 2-*trans*,4-*trans*-decadienal imparted good fried flavor when added to fresh oil and was

detected in fresh fried potato chips Decadienal isomers, however, are easily oxidized to hexanal and octenal that contribute to rancid flavor (Jacobson, 1991).

Another important quality parameter of fried food is the amount of oil absorbed during frying Factors affecting oil uptake during frying include frying temperature and duration, product shape, roughness and composition, prefrying treatments and porosity (Pinthus et al., 1993; Saguy and Pinthus, 1995) Oil uptake generally decreases with increasing in frying temperature and increases with increasing frying time. Rough surface of food increases overall surface area which results in increase oil uptake High initial moisture or fat content may increase oil adsorption of the fried food. On the other hand, high natural calcium content of potatoes decreases oil uptake. Prefrying treatments such as blanching and freezing also lessen oil uptake Pinthus et al. (1995) found a positive linear relation between oil uptake during frying and porosity of the food prior to frying.

The structure of fried food consists of two distinctive parts: outer and inner zones (Stevenson et al., 1984) The outer zone is a golden brown surface resulting from Maillard reaction and crispy "skin" or crust formed by dehydration during frying. The absorbed fat or oil in the outer zone imparts a tenderizing effect on the crust and wetting effect on the fried food that produces pleasant eating characteristics The inner zone is a cooked, moist component resulting from heat penetration rather than fat absorption

During frying, the oil is subjected to several agents moisture, air and high temperature, as well as, the components of food being fried, which results in hydrolytic, oxidativeand thermolytic reactions Such reactions lead to the formation of volatile and

nonvolatile decomposition products (Handel and Guerrieri, 1990, Pokorny, 1989, Stevenson et al., 1984; White, 1991) Under normal frying conditions, approximately 5-15% of frying oils are converted to volatile compounds (Pokorny, 1989); most of the volatiles are removed by the steam generated during frying However, some of the volatile products may be retained in the fried food and affect its flavor. According to Singh (1995), oil becomes contaminated with food materials leaching into frying medium, water vapor condensing in oil, thermal breakdown of oil and oxygen absorbed at the oil-air interface during frying.

Formation of nonvolatile components (NVC) caused primarily by thermal oxidation and polymerization of unsaturated fatty acids in the oil is of interest since the NVC remain in the frying oil, promote further oil degradation and may be absorbed by the fried food which can lead to adverse health effects of consumers. In addition to off flavors, NVC are responsible for physical changes such as dark color, increased viscosity and foaming of the oil. Other chemical changes also related to the formation of NVC include increases in levels of free fatty acids, carbonyl value, hydroxyl content and saponification value. These increases result in the formation of high molecular weight products and decrease the oil smoke point (Pokorny, 1989; Stevenson et al., 1984). Ultimately, deteriorated frying oil imparts poor flavor, dark color and greasy texture to the fried food and must be discarded.

The stability and fry life of a frying oil depend on several factors including type of food, fryer equipment, frying practices and conditions and type of oil (Jacobson, 1991, Stevenson et al., 1984, Varela, 1988; Weiss, 1983). A high level of egg solids in foods causes early foaming, breaded, battered and strongly flavored foods contribute to burnt

and off-flavors; and excessive moisture on the food surface could increase fat hydrolysis (Stevenson et al., 1984). Frying equipment containing copper catalyzes the oxidation of hot oil, enhancing oil deterioration. The recommended metal for fryer equipment is stainless steel (Stevenson et al., 1984). Frying temperatures above 196°C result in rapid degradation of frying oil Heating the oil without frying increases oil breakdown, therefore, the temperature of frying oil should be lowered to 95-120°C during standby (Stevenson et al., 1984, Weiss, 1983). Evidence for heating oil developing increased degradation compared with frying foods in the oil is provided by Dobarganes et al. (1993). These researchers showed that high-oleic sunflower, olive and regular sunflower oils heated at 180°C for 10 hr were degraded more than the same oils when they were used for frying potatoes for 15 hr

Turnover rate, the proportion of fresh oil added daily into fryer to keep its level constant, is another important factor for maintaining oil quality. Proper turnover of 15-25% will dilute hydrolytic and oxidative products in the fryer and keep the level of free fatty acids low (Pokorny, 1989; Stevenson et al , 1984; Weiss, 1983) Removal of food particles and breading materials by filtration of the oil (Jacobson, 1991) and regular proper cleaning to remove deposited materials also prolong the fry life of fat (Stevenson et al. 1984)

Unsaturated fatty acids of a frying oil especially are susceptible to oxidation during frying. Addition of antioxidants such as tertiary butylhydroquinone (TBHQ) and butylated hydroxyanisole (BHA) inhibit fat deterioration during frying. Silicones (methyl polysiloxane) reduce gum formation, aid in retention of the tocopherols, the natural antioxidants present in the oil (Jacobson, 1991), and may form thin films on the surface

of frying oil, preventing foaming and contact with oxygen (Pokorny, 1989). Therefore, combining antioxidants with silicones should efficiently at retard high temperature oxidation and extend the life of frying oil

C. CHEMICAL AND PHYSICAL CHANGES OF FRYING OIL

During frying, the oil is exposed to high temperatures in the presence of moisture and oxygen that cause the oil to undergo three major reactions: hydrolytic, oxidative and thermolitic reactions (Dobarganes and Marquez-Ruiz, 1996; Nawar, 1996; White, 1991). Hydrolysis of the oil occurs due to the released moisture from frying foods and causes the release of the more polar and lower molecular weight compounds than triacylglycerols in the oil. These compounds include fatty acids, monoacylglycerols and diacylglycerols (Dobarganes and Marquez-Ruiz, 1996). The hydrolytic products reduce the thermostability of frying oil. Accumulation of free fatty acids, for example, decreases smoke point and increases foaming of the oil. In addition, free fatty acids are more susceptible to oxidation (Nawar, 1996). Several factors stimulating hydrolytic reaction are outlined by Pokorny (1989) which include partial glycerol esters and other surface active agents, cations or anions, free fatty acids and low molecular weight acidic products resulted from oil oxidation, acidic phospholipids and amino acidsand other oxidation products.

Oxidation during frying generally follows the same initial steps as autooxidation at room temperature, which involves the formation and decomposition of hydroperoxides However, oxidation at elevated temperature proceeds much more rapidly (Nawar, 1996) During frying, both saturated and unsaturated oils undergo

oxidation by initial formation of free radicals that will be further attacked by oxygen to form hydroperoxides. In addition to heat, the formation of free radicals may be due to metals, light, radiation or singlet oxygen

Although saturated oil is more stable to oxidation, upon heating at elevated temperature above 150°, oxygen attack may occur at methylene groups to form monohydroperoxides (Nawar, 1996). According to Pokorny (1989), oxidation of saturated oil results in numerous decomposition products since each carbon atom in the fatty acid chain, except the first and the last carbons, has the same probability of being attacked by oxygen. On the other hand, oxidation of unsaturated fatty acids concentrates at the α-carbon position, the closest neighbor to double bonds. Due to resonance stabilization, the formation of free radicals in the oxidation of unsaturated fatty acids may be accompanied by a shift in position of the double bonds that results in the formation of conjugated diene groups (Nawar, 1996)

Since they are unstable, hydroperoxides undergo further decomposition reactions starting with scission at the oxygen-oxygen bonds that results in formation of alkoxy and hydroxy radicals. Carbon-carbon cleavage then takes place on either side of the alkoxy group giving products that may undergo various reactions (Nawar, 1996). Hydroperoxides of saturated fatty acids decompose rapidly to form long chain alkanes, aldehydes, ketones and lactones. Those of unsaturated fatty acids decompose to volatile and dimeric products According to White (1991), oxidation products of fatty acids in oil during frying could undergo scission into smaller fragments or remain in the triacylglycerol molecule and cross-link each other, leading to formation of dimeric and higher polymeric compounds

Thermolytic reactions occur simultaneously with oxidation during frying Generally, saturated fatty acids in the oil are stable to thermal decomposition. According to Nawar (1996), however, heating saturated fat above 200°C yielded detectable non-oxidative decomposition products, mainly hydrocarbons, acids and ketones. The main thermolytic reactions of unsaturated fatty acids heated in the absence of oxygen are the formation of dimeric compounds Nawar (1996). Free radicals formed by thermolytic oxidation undergo several reactions through carbon-carbon linkages to form acyclic and cyclic dimers, either between two triacylglycerol molecules or within one molecule. Formation of bonds between two radicals (intermolecular addition) results in acyclic dimer, while linkage within one molecule (intramolecular addition) produces cyclic dimers. These compounds further cross-link to form polymers with high molecular weight (Dobarganes and Marquez-Ruiz, 1996, Nawar, 1996; White, 1991).

White (1991) classified decomposition products resulting from oil during frying into two groups. volatile decomposition products (VDP) and non-volatile decomposition products (NVDP). The first group included hydrocarbons, aldehydes, ketones, furans and carboxylic acids. The VDP are important since some contribute to the flavor of fried foods. For example, 2-*trans*, 4-*trans* decadienal produces the typical pleasant flavor in fresh potato chips, while lactones impart a characteristic deep-fried flavor to foods These compounds result from thermal oxidation of linoleic acid (Pokorny, 1989). However, decadienal isomers are easily oxidized to hexanal and octenal that contribute to rancid flavors (Jacobson, 1991). In addition, the VDP might result in adverse health effects if inhaled (Stevenson et al., 1984; White, 1991)

The NVDP include polar and nonpolar compounds such as cyclic monomers, noncyclic monomers, dimersand other higher molecular compounds. These compounds remain in the frying fat to promote further degradation and may be absorbed by the fried food.

The formation and accumulation of NVDP are responsible for physical changes in the oil such as the increase in viscosity, color and foaming. They also cause chemical changes such as increases in free fatty acids (FFA), carbonyl value, hydroxyl content and saponification value, decreases in unsaturationand, ultimately, increases in the formation of high molecular weight products (Stevenson, 1984; White, 1991) Tseng et al (1996) reported some physical and chemical changes in soybean oil during frying of tortilla chip dough for 60 hr. They found a decrease in surface tension, an increase in color reading with increasing oil degradation and development of foam and off flavors after 20-hr frying Oil viscosity also increased with increases in frying time and temperature. The FFA content increased from 0.03 to 0.61%, while total polar compounds increased from 3.35 to 61.54%

D. QUALITY PARAMETERS OF FRYING OILS

The quality of a frying oil may have a significant impact on the quality of fried products prepared in it As the frying time period proceeds, the quality of frying oil decreases due to the chemical and physical changes and so does the quality of the foods fried. During frying, an oil passes through five degradation stages: break-in, fresh, optimum, degrading and runaway. The quality of the oil changes from fresh to discarded at the runaway stage and each stage gives different qualities to the foods

prepared in it (Blumenthal, 1991) The high quality products that have a golden-brown color, crispy and rigid surface, delicious flavor, fully cooked center and optimal oil absorption are obtained during the optimum oil phase.

The quality parameters used to assess fresh frying oils at point of purchase may vary with vendors. General parameters include free fatty acids (FFA) (0 05-0.08%), peroxide value (PV) (maximum 1 0 meq/kg oil), iodine value, active oxygen method (AOM) (60 hr), smoke point (minimum 200°C), moisture content (maximum 0 1%), melting point colorand flavor (Stevenson et al , 1984). FFA content is an indication of proper refining, while PV is a sign of freshness. Specifying a smoke point ensures the oil will not smoke excessively when first used Light color and bland flavor will enhance the eating quality of the foods fried in the oil.

Various criteria have been proposed and/or adopted to control frying oil degradation In restaurants or food service institutions, the criteria to discard the frying oil are generally based on characteristics such as dark color, foaming height and smoke point, odor and length of use of frying medium, as well as, flavor and greasiness of the fried foods. In addition to the physical tests and sensory evaluation, food processors who have laboratory facilities may perform chemical tests such as measurements of FFA, thiobarbithuric acids (TBA) value, PV, iodine value, AOM, dienes, carbonyls petroleum insolubles and total polar compounds (Stevenson, 1984; Melton et al., 1994) Standard methods that have been widely used for measurement of frying oil degradation include total polar compounds, conjugated dienoic acidsand fatty acid analyses (White, 1991).

Several quick tests, which have been developed to provide rapid procedures for testing frying oil abuse, include the Food Oil Sensor (FOS), Rau-Test, Fritest®, Spot-Test, alcaline contaminant material (ACM) (Melton et al., 1994; White, 1991). The Fritest® and Spot-Test measure the concentration of VDP, while the FOS, Rau-Test and ACM test detect NVDP (Melton et al., 1994) According to White (1991), the FOS kit measures the frying oil dielectric constant which is correlated to the level of polar compounds present. An FOS reading of 4.0 is the limit beyond which a used oil should be discarded. The Rau-Test kit marketed under the name of Oxifrit-Test is a colorimetric test kit to detect the total amount of oxidized compounds. The color resulting from the mixture of sample and reagents is compared to a four-point color scale: 1, good; 2, still good; 3, intermediate; and 4, bad In the Fritest®, a colorimetric test that is sensitive to carbonyl compounds, the mixture of sample and reagent is compared to three diagnostic colors: 1, good, 2, intermediate, and 3, bad. The Spot-Test is a colorimetric test used to monitor FFA, while the ACM test is used to measure concentration of alkaline contaminant materials such as soaps, a result of the interaction of foods and oil degradation products. According to Firestone et al. (1991), some of the results of the quick tests correlated well with those of the standard method for determining polar compounds. FOS values of 3.1 and 3.5 corresponded to the TPC values of 27 and 29%, respectively. An Oxifrit Test reading of 3 5 corresponded to TPC values of 27-29%, while a Spot Test value of 2 was equal to TPC values of 25-29%.

Melton et al (1994) reported that many researchers considered TPC as one of the best indicators of frying oil quality They found significant correlations between TPC and FFA, TPC and FOSand TPC and color differences (ΔE) TPC, the sum of

nontriacylglycerol materials in a frying oil such as sterols, tocopherols, mono- and diacylglycerols, FFA and other oil-soluble components, increase during frying oil degradation. During induction time, in which the frying oil is heated for 3-4 hr at 180°C to develop oxidation products necessary for desirable flavor and color, the TPC contents range from 2-7%. In the optimum frying and flavor development stage, the TPC concentrations range from 7-20%and deteriorated oil may contain TPC 25-27% The optimum frying stage may be lengthened by oil replenishment. Frying oil with TPC content of more than 27% should be discarded.

Regulations and parameters for controlling frying oils differ among countries and with frying practices. Firestone et al. (1991) reported that no specific regulations exist to control frying oils in the USA, except that the oils and fats used in foodservices should be obtained from an approved source and should not be adulterated. The U.S. Department of Agriculture, however, has established guidelines for frying oil in factories producing fried meats On the other hand, some European countries including Austria, Belgium, France, Federal Republic of Germany, Spain, The Netherlands and Switzerland have regulations to control the end-point of frying oils Often, a polar compound of 25% and smoke point of 170°C are the limits to discard the frying oil. According to Melton et al (1994), most of the countries that have regulations to control frying oils still use sensory evaluation of frying oil and fried foods as the ultimate test.

E. GENERAL AND QUALITY ASPECTS OF POTATO CHIPS

The potato chip is one of the popular snack products consumed throughout the world. They are the most convenient form of potatoes to serve, requiring no preparation

and may be served anytime Also, potato chips provide some nutritional value. Generally, 100 g of potato chips contain 40 g fat, 5 g protein, 50 g carbohydrate, some minerals and vitamins and approximately 560 calories (Smith, 1987). The name of chips is originally American and refers to thin potato slices deep-fried in oil. A similar product in England is called potato crisp (Gamble and Rice, 1988; Lisinska and Leszczynski, 1989).

According to Smith (1987), potato chips are manufactured in every state in the United States, either in large- or in small-scale companies. In 1997, approximately 10% of the potato production in the US was processed into potato chips (USDA, 1998). In England, potato chips share about 70% of the snack market (Gamble and Rice, 1988).

Some important factors to be considered in the production of potato chips include yield, oil content and quality aspects such as color, flavor and texture (Lisinska and Leszczynski, 1989; Smith, 1987). The main factor affecting yield in manufacturing potato chips is the specific gravity of potatoes. In selecting potatoes for processing into chips, it is important that the tubers of high specific gravity (minimum 1 070) or dry matter content be used because this is the single most important factor determining yield of chips.

Yield and Oil Content

Yield and oil content of potato chips are two aspects related to each other. Oil is not only a costly material in the production of potato chips but also important to the quality of chips High oil absorption during frying will increase the production cost and may result in greasy chips. On the other hand, too low of oil content will cause the chips

to lack flavor, become harsh textured and produce a low yield (Smith, 1987). Therefore, it is necessary to maintain a desirable low level (35-39%) of oil in regular chips.

The main factor affecting yield and oil absorption of chips is the specific gravity of potatoes. Factors such as partial drying and thickness of potato slices, types of oil and frying time and temperature also affect oil absorption during frying (Smith, 1987).

Specific gravity of potatoes, indicating dry matter content of tubers, has been used as a single important criterion in selecting raw potatoes for chip production Some studies indicated that the yield of potato chips increased linearly and oil content of the chips decreased as the specific gravity of potatoes progressively increased from 1.060 to 1.110 (Lulai and Orr, 1979; Smith, 1987). The specific gravity itself is dependent on cultivar, maturity and cultural practices. Generally, specific gravity increases as the potatoes become mature (Smith, 1987). Sinha et al (1992) reported that year of production also influenced the specific gravity of potatoes and chip yield. DeBuchananne and Lawson (1991) studied the effect of plant populations and harvest timing on the quality of chips for Atlantic and Norchip cultivars. They reported that greater planting populations and delaying harvest until 16 wk after planting resulted in higher specific gravity for both cultivars.

Gamble and Rice (1988) studied the effect of slice thickness and frying time on the yield and composition of potato chips They reported that the final yield of chips increased with decreasing slice thickness, while increasing frying time from 3 to 5 min had no effect on the yield. Based on a regression model or equation, however, Gamble et al (1987) reported that the yield of potato chips decreased with increasing frying time or frying temperature from 145 to 185°C as moisture loss was more rapid than oil

uptake Gamble and Rice (1988) also found that the oil content of the chips decreased almost linearly as slice thickness increased and tended to increase with an increase in frying time.

Gamble et al. (1987) also reported that the oil content of potato chips increased with increasing frying temperature and frying time. Conversely, Smith (1987) reported that as frying temperature decreased from 204 to 138°C, the oil content of chips increased According to Gamble et al. (1987), the oil content was not directly related to frying temperature but more closely related to the remaining moisture in the chips The amount of oil uptake is directly proportional to the amount of moisture lost during frying. They theorized that the oil content of potato chips could be low when moisture loss is slow and continuous. This may be obtained with improved cellular adhesion within potato slices, either in selection of tubers or by performing a prefrying treatment on the potato slices.

The amount of oil uptake during frying of potato chips may be lowered by partial drying of potato slices before frying Such drying lowers the moisture content by 25% and thus increases specific gravity of potato slices (Smith, 1987). Partial drying also removes surface moisture and further shortens frying time (Lisinska and Leszczynski, 1989)

Color

Color is another important quality factor of potato chips. It is affected by the chemical composition of potatoes, particularly sugar and amino acid contents, and processing factors such as slice thickness, blanching water temperature and time, frying temperature and time and quantity of chips in the fryer (Lisinska and Leszczynski, 1989;

Smith, 1987). At a constant temperature, the color of potato chips becomes lighter as slice thickness increases On the other hand, the color of potato chips becomes darker as frying temperature or frying time is increased. Blanching potato slices in warm water for a short time may improve the color of potato chips.

According to Leszkowiat et al. (1990), there are three possibilities for color development during frying of potato chips caramelization, reaction of malonaldehyde and Maillard reaction In caramelization, sugars dehydrate and undergo a series of reaction to form caramel, dark colored pigments (deMan, 1999). A high temperature of above 160°C during frying may accelerate caramelization. Malonaldehyde, one of the oxidation products formed during frying, may react with amino acids to form brown-colored complexes. During the Maillard reaction, reducing sugars react with amino acids and protein to form dark brown colored substances.

Most of the studies report that color development in potato chips is closely related to sugar and amino acid levels of the potato tubers. According to Lisinska and Leszczynski (1989), the higher the content of reducing sugar in the tubers, the darker the color of chips. Sugar levels in potato tubers are dependent upon several factors such as cultivar, maturity, handling and storage (Smith, 1987).

Coffin et al. (1987) studied the effect of three potato cultivars on sugar content and the color of potato chips. They found that the cultivar having the lowest sugar content (~0.1%) produced the lightest, most acceptable color chips Herrman et al (1996) and Sinha et al (1992) reported similar findings from the studies of different cultivars. Cultivars with glucose levels higher than 2% (dry weight basis) or 0 03% (wet basis) produced darker chips.

Generally, more mature tubers produce lighter colored potato chips (Smith, 1987) Delaying harvest time to increase maturity of tubers produced lighter color chips (DeBuchananne and Lawson, 1991) Sinha et al (1992) also reported that the extension of harvest from 98 to 138 da after planting resulted in lighter colored chips for several different cultivars. In addition, they also found that the year of production affected the color of potato chips

During storage, sugars may accumulate in potato tubers and affect potato chip color. Sowokinos et al. (1987) reported that sucrose and glucose concentration in potato tubers increased after 9-mo storage and resulted in dark colored chips Coffin et al (1987) studied the effect of low-temperature storage on sugar concentration and chip color. They found that lowering storage temperature from 11 to 4°C increased sugar concentrations in tubers after 3-mo storage and resulted in a darker color in the chips However, Herrman et al (1996) found that potatoes held at 4°C for 6 mo after a gradual temperature decrease from 10°C with continued holding at 10°C for 3 mo contained less sugar and produced lighter chips after 12-mo storage compared to tubers stored at a constant 10°C during the same period. .Storage in modified atmospheres of 1,000 ppm ethylene in air and low oxygen decreased sugar accumulation within 8 wk and resulted in lighter color chips (Parkin and Schwobe, 1990).

Texture and Flavor

Texture is another quality factor of potato chips and is related to the dry matter content of raw potatoes. Potatoes with dry matter higher than 25% may produce chips with hard texture, whereas those of too low dry-matter content or low specific gravity may produce chips with high oil content and a greasy, sticky texture (Lisinska and

Leszczynski, 1989) The final moisture content of potato chips also affects the texture If the moisture content is higher than 2%, potato chips may be not crisp (Gamble and Rice, 1988). Kulkarni and Govinden (1994) studied the effect of dehydration of potato slices on the potato chip quality, using two potato cultivars. They found that the texture of potato chips from dehydrated slices was less acceptable than that of chips from fresh potato slices Rehydration of the dried slices, however, increased texture acceptability of chips to be similar to that of fresh potato slices They also reported that the cultivar affected the texture of potato chips.

Flavor of potato chips is dependent on various volatile compounds present in chips, flavor compounds inherent in the raw potatoes, frying oilsand added flavorings (Smith, 1987). However, the main constituents responsible for the potato chip flavor are carbonyl compounds (Dornseifer and Powers, 1965; Smith, 1987).

Several investigators have isolated and identified volatile compounds that impact either desirable or undesirable flavors in potato chips. Dornseifer and Powers (1965) identified 30 and 34 compounds from fresh and stored potato chips, respectively They reported that four higher molecular weight carbonyls (heptanal, octanal, 2-nonanoneand nonanal) found only in the stored chips might be responsible for the flavor changes

Mookherjee et al (1965) identified 18 monocarbonyl compounds in fresh potato chips fried in a mixture of 50% cottonseed and 50% corn oilsand 19 compounds in stale potato chips. The volatile, 2,4-decadienal, was present at about 55 and 7% of total volatile in the fresh and stale potato chips, respectively This compound originated mainly from decomposition of linoleic acid under deep- frying conditions Since 2,4-

decadienal imparts desirable flavor in fresh potato chips, they theorized that oils used for frying potato chips should contain a certain level of linoleic acid.

Deck et al. (1973) identified 9 groups of volatiles or 53 compounds in potato chips with pleasant, desirable flavor. Volatiles contributing to the desirable flavor included the alkyl-substituted pyrazines, 2,4-dienals, phenylacetaldehyde and furyl methyl ketone. Pyrazines were formed via the Maillard reaction. Two important pyrazines, 2,5-dimethyl pyrazine and 2-ethyl pyrazine, were reported to impart either strong potato chip characteristics or roasted peanut flavor, while 2-ethyl-3,6-dimethylpyrazine imparted an earthy potato flavor. Phenylacetaldehyde, reported to have a very strong, pleasant odor, could be produced from the amino acid, phenylalanine, in the potato by Strecker degradation during frying. Furyl methyl ketone, having a potato-like aroma, might be formed from reducing sugars in the potato by dehydration under deep frying conditions. Deck et al. (1973) also identified the volatiles that imparted undesirable flavors to chips; these include pyridine, sulfur compounds and aromatic hydrocarbons. Several researchers at The University of Tennessee, Knoxville, have identified successfully various volatiles in potato chips fried in different oils (Han, 1989; Lin, 1993, Melton et al., 1993) and generally have found the same type of compounds as other researchers.

Type of Frying Oils

Type of oils used for frying potato chips also affect the quality of chips since the oils not only function as heat transfer media but also become an ingredient of fried foods. Depending on the fatty acid composition, different oils may produce different decomposition products during frying, which become part of the flavor compounds of

potato chips Each oil will contribute a flavor to the chips which is characteristic of the oil (Weiss, 1983).

Cottonseed oil is frequently used for frying potato chips in the southern region of the United States, especially where a bright finished product is desired (Weiss, 1983) In addition to cottonseed, other oils such as sunflower, corn, soybean, canola, peanut and safflower oils are listed on the labels of fried potato chips produced in the United States

Various studies have been conducted to assess the effects of different oils on the quality of potato chips Han (1989) reported that potato chips fried in cottonseed oil had a more desirable flavor and higher acceptability than chips fried in soybean or palm olein oils. The less desirable flavor of the soybean-fried chips was due to reversion compounds produced from linolenic acid or off flavors from isolinoleic acid formed during hydrogenation

Lin (1993) studied the effect of cottonseed, canola, regular sunflower and high oleic sunflower oils on the quality of potato chips. He found that fresh potato chips fried in regular sunflower oil had the highest flavor likability and overall acceptability scores, while those of chips fried in cottonseed, canola and high oleic sunflower oils were comparable However, the flavor of chips fried in regular sunflower was less stable than those fried in the other oils during a 4-wk storage The desirable flavor of chips fried in regular sunflower oil may have been due to the presence of t,t-2,4-decadienal in high amounts, which resulted from linoleic acid

Melton et al (1993) also reported that chips fried in cottonseed oil contained different amounts of flavor volatiles compared to the chips fried in partially hydrogenated

canola oil Their flavor likability and overall acceptability scores, however, were not significantly different Thus, partially hydrogenated canola oil could produce chips with flavor quality as high as that from cottonseed oil. In contrast, Hawrysh et al (1996) reported that trained panelists found higher characteristic potato chip flavor in fresh chips fried in cottonseed oil than that of chips fried in partially hydrogenated canola oil. They also found that the flavor of fresh chips fried in cottonseed was not different from that of chips fried in canola oil which was similar to the finding reported by Lin (1993). Chips fried in cottonseed oil had more desirable flavor than chips fried in soybean oil (Hawrysh et al., 1996), which was similar to the results reported by Han (1989) Chips fried in partially hydrogenated canola oil or soybean oil had more intense off flavors than other chips (Hawrysh et al , 1996)

F. STABILITY OF POTATO CHIPS DURING STORAGE

The stability during storage is one of the problems associated with the production and distribution of potato chips. Various studies indicate that formation of volatile compounds in stored chips is due to the oxidation of oil (Min and Scweizer, 1983, Mookherjee et al , 1965). As the storage time is extended, the volatile compounds increase and the flavor quality of chips decrease. According to Min and Schweizer (1983), a decrease in oxygen concentration and the presence of propane, butane and pentane in the headspace of air-tightly sealed bottles containing potato chips indicated the occurrence of lipid oxidation. Since potato chips contain 35-45% oil (Han, 1989, Mookherjee et al , 1965, Weiss, 1983), their stability during storage

depends on factors affecting oil oxidation including packaging, the presence of oxygen, light, temperature, antioxidants and frying oil composition

Packaging functions as a barrier for oxygen, moisture and light, all of which decrease the quality of potato chips during storage Kubiak et al (1982) studied the effects of various packaging, which differed in oxygen and moisture permeability and light transmitting properties, on potato chip stability They reported that packaging materials having good light-barrier properties provided protection to potato chips during 10-wk storage, even though they had high-oxygen permeability. Likewise, good oxygen-barrier packaging, yet without light-barrier properties, did not provide protection against loss of freshness and development of rancid flavor. The good oxygen-barrier packaging could prevent oxidation of potato chips during storage if the initial amounts of oxygen were restricted by flushing the packaging with nitrogen prior to sealing. They also found that short-wavelength visible light was capable of initiating oxidation reactions in the lipids of potato chips.

Han (1989) reported that flavor likability and overall acceptability scores of potato chips stored under light at ambient temperature for 4 wk did not decrease significantly, while those of chips stored in the dark remain unchanged Peroxide values, an oxidation test of oils extracted from potato chips fried in canola, high-oleic sunflower or cottonseed oils, significantly increased after 4-wk storage of chips under light and remained unchanged during the same time period if chips were stored in the dark (Lin, 1993) Melton et al. (1993), however, reported that peroxide values of potato chips fried in canola and cottonseed oils and their blends and stored in the dark or under light were not significantly different.

Park et al (1996) studied the effect of storage temperatures on the potato chip quality packaged in laminated edible films They reported that the shelf life of potato chips increased as the storage temperature decreased. Storage at 15, 25 and 35°C and 50% relative humidity kept potato chips acceptable up to 43, 25and 12 da, respectively. Asap and Augustin (1986) also reported that potato chips in transparent jars stored at 60°C had shorter shelf life than those stored at room temperature (27-30°C)

Warner et al (1994) investigated the effects of frying oil composition on potato chip stability. Potato chips fried in a modified canola oil with the highest oleic acid level (78%) had the lowest contents of total polar compounds and total volatile compounds after 4-mo storage. Although the initial quality of the potato chips fried in the oil with the highest oleic level was not the best, the chips had the best flavor stability after 4-mo storage at 25°C in a sealed, metalized foil bag Unmodified canola oil with the highest level of linolenic acid (7.7%) and the lowest level of oleic acid (61.9%) produced chips with lower flavor quality and poorer stability than did the modified canola oils

Lin (1993) also reported that flavor likability and overall acceptability scores of potato chips fried in sunflower oil containing 66% linoleic acid were initially higher than those of potato chips fried in canola, high-oleic sunflower and cottonseed oil containing lower linoleic acid However, the scores of potato chips fried in sunflower oil decreased rapidly after 4-wk storage either under light or in dark The flavor likability and overall acceptability scores of the chips fried in the other oils with lower linoleic acid content and stored 4-wk in dark did not decrease significantly.

Asap and Augustin (1986) studied the effect of frying oil quality and antioxidant tertiarybutyl hydroquinone (TBHQ) on the shelf life of potato chips As the fry number

increased, the quality of frying oil decreased, indicated by increasing total polar compounds, and the shelf life of potato chips fried in it decreased. They also found that initially, the shelf life of potato chips decreased rapidly with an increase in fry number. Beyond the discarded limit (27% total polar compounds), the shelf life of potato chips was only slightly affected by the quality of oil Addition of TBHQ increased the shelf life of potato chips. The effect of TBHQ was more pronounced when added at the beginning of each frying day.

CHAPTER III

MATERIALS AND METHODS

A. MATERIALS

Refined, bleached and deodorized sunflower oil (SFO), palm olein oil (POO)and cottonseed oil (CSO) were obtained from an oil refinery in Tennessee, United States. Enough of each oil was obtained at one time to complete the entire experiment Raw potatoes (Atlantic cultivar, grown in Florida) and chip salt were obtained from Tom's Snack Foods, Knoxville, TN. Each week, enough potatoes were obtained for one replication of each of the four oils. Prior to processing, the potatoes were placed in wooden baskets and stored at 68°C. Wide mouth Mason glass jars (1 9 L) for chip storage were obtained from a local supplier. Solvents, chemicals and other materials necessary for analysis were obtained from Fisher Scientific.

B. EXPERIMENTAL DESIGN

The experiment had three replications A single replication consisted of potato chips fried in four different oils/blends: CSO and SFO and 20:80 and 40 60 w/w blends of POO:SFO and storage of chips fried in each oil/blend for 0, 3 and 6 wk under fluorescent light or the dark at ambient temperatures. For each oil replication, enough potato chips were fried in a single day to complete all chemical and flavor volatile analyses and sensory evaluation of the chips. The order in which the oils/blends were used for frying the potatoes was randomized within each replication. Frying for a single replication was completed in four consecutive days of a week.

C. EXPERIMENTAL PROCEDURES

Frying Oil Handling and Sampling

Prior to the experiment, 12 kg of POO were mixed with 48 kg of SFO to obtain a 20:80 w/w blend and 24 kg of POO were mixed with 36 kg of SFO for a 40:60 w/w blend of POO:SFO. Each oil blend was divided into three parts and each part was used for one replication. All the oils were stored in plastic buckets at ambient temperature Prior to use, CSO and the oil blends were stored at 35°C for 16 hr to provide that all parts were soluble

Prior to being used for frying, each oil/blend (14 kg) was break-in heated in a Gold Medal Fryer (Model FW-12, Gold Medal Products Co., Cincinnati, OH) at 163°C for 3 hr. The temperature was increased from 163 to 194°C approximately 15 min prior to frying chips each day The oil/blend was sampled (200 g) before break-in (fresh), just before the first batch of frying (0 hr) and at the middle (2.5 hr) and end (5 hr) of the frying period. Each oil sample was placed in a 0.45-L glass jar, cooled to ambient temperature, flushed with nitrogen, sealedand stored at –18°C in the dark until analyzed The oil samples were analyzed for fatty acid composition, C18:2/C16:0 concentration ratio, total polar compounds, free fatty acids, conjugated dienoic acids and color to determine deterioration of oils during frying. Fresh oil (500 g) was added to the fryer hourly to bring the level to the full mark to replace oil absorbed dunng frying.

Specific Gravity of Potatoes

Prior to being processed for chips, the specific gravity of potatoes was measured by the following procedures. A metal basket with a metal rod was hung in a barrel (0.75

m diameter x 1 m height) of water with a Potato Hydrometer (Potato Chip Institute International, Cleveland, OH) to tare the reading at 1.07 After removing the piece of metal, the basket was filled with 3.63 kg of potatoes and hung in the barrel of water The specific gravity of the potatoes was recorded directly from the Potato Hydrometer Prior to measurement, the temperature of the water in the barrel was adjusted to 21°C.

Production and Storage of Potato Chips

The potatoes were washed and approximately 4 5 kg were peeled with an abrasive potato peeler (Model 6015P, Hobart Manufacturing Co., Troy, OH) for 70 sec, trimmed of undesirable parts and immediately immersed in tap water until sliced. The peeled potatoes were sliced into 2-mm 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 to remove surface starch, drained, spread in a single layer on a shallow pan and air dried for 8 min under forced air flow at room temperature A batch of 350 g potato slices was placed in a single layer between doughnut frying racks, lowered into the frying oil and fried for 3.5 min. Upon addition of each batch of potato slices, the oil temperature dropped from 194°C to 165-170°C and increased to 180°C after 3.5-min frying The fried chips were drained on paper towels for about 2 min and collected in a plastic container. For each oil replication, 28 batches of potato slices were fried during 5 hr.

After all frying was completed, 400 g of the potato chips were placed in a covered 10-L round plastic container and salted uniformly with 1% (w/w) NaCl by inversion of the container 10 times in different directions All potato chips obtained from 28 batches were placed in a large plastic barrel and mixed thoroughly by inversion and

rotating the barrel 360° in different directions prior to packaging. The chips were sealed in 1.9-L glass jars (128 g chips/jar). Each oil replication required 20 jars: 4 jars each for 0-wk, 3-wk in dark or under light and 6-wk in dark or under light storage. The jars of potato chips for 0-week storage were flushed with nitrogen, sealed, placed in boxes and stored in the dark at –18°C until used for chemical and physical testing (color, moisture and fat levels, color peroxide value and flavor volatiles) or sensory evaluation. Immediately after sealing, the jars for 3- or 6-wk storage in dark were placed in cardboard boxes at ambient temperature The jars for 3- or 6-wk storage under fluorescent light were laid on their side on the tables in the same room where the jars of chips for dark storage were placed. The jars on the table for 3-wk storage were turned 180° at 1 5 wk and those for 6-wk storage were turned 180° at 3 wk so that all the chips received the same light intensity by the end of storage At the end of 3- or 6-wk storage for each oil/blend-replication, the jars of chips stored under light and in dark were opened, flushed with nitrogen, sealed, placed in boxes and stored in the dark at –18°C for physical and chemical analyses, flavor volatile analysis or sensory evaluation.

Chemical and Physical Analysis of Oil

Fatty Acid Composition

The analysis of the fatty acid composition of all oil samples consisted of preparation of fatty acid methyl esters (FAMEs) and chromatographic analysis of FAMEs. FAMEs were prepared according to procedures by AOCS (1993) Method Ce 2-66 To 0.1 g of oil samples in 125-mL T-neck Erlenmeyer flasks were added 4 mL of 0.5N sodium hydroxide in methanol and boiling chips The flasks were attached to

condensers and heated on the hot plates for 10 min until fat globules dispersed. To the solution in the flask were added 5 mL of 14% boron trifluoride in methanol (Supelco, Inc., Bellefonte, PA) through the condenser, and heating was continued for 2 min. After cooling, 5 mL of hexane were added to each flask, and the contents were boiled for 1 min under reflux. After the flask was removed from the condenser, hexane containing the FAMEs was brought into the flask neck by adding saturated sodium chloride solution Approximately 4 mL of the FAME layer was transferred into a vial, and a small amount of sodium sulfate was added to absorb residual water Each vial was flushed with nitrogen, sealed and stored at -18°C until analysis by gas chromatography (GC).

The FAMEs were analyzed by a gas chromatograph (Model GC-9AM, Shimadzu Scientific Instrument, Inc., Columbia, MD) equipped with an automatic injection (Model AOC-0, Shimadzu Scientific Instrument, Inc., Columbia, MD) The methyl esters were separated on a 30-m x 0.25-mm i.d fused silica SP2330 column (Supelco, Inc., Bellefonte, PA) and detected with a flame ionization detector (FID) The temperature of GC injector and detector was 250°C, while the column temperature was programmed from 130°C to 220°C at the rate of 2°C /min. The flow rate of carrier gas helium was 40 mL/min which was split 30:1 before entering the SP2330 column. The peak areas of the separated FAMEs and their relative concentration were recorded with a Shimadzu chromatopac data processor (Model CR-501, Shimadzu Scientific Instrument, Inc., Columbia, MD) interfaced with an IBM personal computer. All chromatograms were stored, using the Chromatopac Data Archive Utility version 3 1 software (Shimadzu Scientific Instrument, Inc., Columbia, MD) Standard solutions containing known percentages of individual FAME were injected into the GC column under the same

conditions as the samples were analyzed. Correction factors for each FAME relative to palmitic acid (C16:0) were determined from analysis of the standard according to AOCS (1993) Method Ce 1-62. Individual FAME found in the samples was identified by matching the retention times of the sample peaks with the corresponding retention times of known standard. The relative concentration of each fatty acid in a sample was calculated as weight percentage of the total FAME present. The concentration ratio of linoleic acid (C18.2) to palmitic acid (C16:0) also was calculated for each oil sample.

Total Polar Compounds

The level of total polar compounds (TPC) of each oil sample was determined according to the procedures of Melton and Sykes (1987). Approximately 0 2 g of each oil sample in 50-mL beaker was dissolved in 4 mL of petroleum ether:diethyl ether (PE.EE) (92 8, v/v) and loaded onto a Mega-Bond Elut silica solid-phase cartridge (Varian SPP, Harbor City, CA) in a vacuum filtration unit. The non-polar compounds (NPC) were eluted with 30 mL of the PE:EE solvent as the following steps. The beaker used to dissolve the oil sample was rinsed with 4 mL of PE:EE solvent three times, and each rinse was poured into the cartridge. An additional 18 mL of the solvent was passed through the cartridge The eluent was collected in a weighed 50-mL beaker placed under the cartridge in a vacuum filtration unit. The solvent was evaporated overnight under the hood, and the beaker was dried in an oven at 100°C for 30 min, cooled in a desiccator and weighed. The percentage of TPC was determined by dividing the weight of the TPC by oil weight and multiplying by 100

Free Fatty Acids

The free fatty acid contents of all oil samples were determined as the percentage of oleic acid according to the AOCS (1993) Method Ca 5a-40 An oil sample of 50 g was dissolved in 50 mL of hot 95% ethyl alcohol plus approximately 2 mL of 1% phenolphthalein in 95% alcohol and titrated with 0.1N sodium hydroxide. Free fatty acids in the oils were calculated based on the amount (milliequivalent) of sodium hydroxide required to titrate the samples.

Conjugated Dienoic Acids

The percentages of conjugated dienoic acids of all oil samples were determined according to AOCS (1993) Method Ti 1a-64. Approximately 0.05 g of sample was dissolved in 100 mL of 2,2,4-trimethylpentane (isooctane) to obtain a final concentration of 0.5 g/L which yielded the required absorbency reading between 0.2 and 0.8. The absorbance of the sample in a 1-cm quartz cuvette was measured at 233 nm against a pure isooctane blank on an UV-VIS spectrophotometer (Model UV-2101, Shimadzu Scientific Instrument, Inc., Columbia, MD).

Color Measurement

Color measurement of all oil samples was performed on a Shimadzu UV-VIS scanning spectrophotometer (Model UV-2101, Shimadzu Scientific Instrument, Inc., Columbia, MD) interfaced with an IBM personal computer The spectra of samples were measured at the wavelength range of 380-800 nm, Illuminant C, and 2°-observer angle The spectrum of each sample was further analyzed using UV-2101/3101PC Optical Color Analysis Software Version 2.0 (Shimadzu Scientific Instrument Inc., 1994) to

obtain Hunter color *L*, *a* and *b* values and color differences (ΔE) between the fresh and used oils.

Evaluation of Potato Chips

Moisture and Fat Contents

For each oil/blend-replication combination, the percentages of moisture and fat in the fresh potato chips (n=12) were analyzed with InfraAnalyzer 450 (Bran-Luebbe, Inc., Buffulo Grove, IL). This instrument also was located at Tom's Foods, Inc. (Knoxville, TN). For the color measurement, approximately 128 g of crushed samples were ground for 25 sec with a food processor (Model FPC-70, Waring Inc., New Hartford, CT). About 8 g of the ground chips were put on a dish that was inserted into an IR instrument. The moisture content of the chips was read immediately from the instrument followed by the reading of the fat content.

Color

The color of the fresh chips for each oil/blend-replication combination (n=12) was measured with an Agtron® Electronics colorimeter (Model E-15-FP, Spark, NV), which is used by the snack food industry to determine potato chip color. The instrument was located at Tom's Foods, Inc. (Knoxville, TN). Before operation, the instrument was calibrated with an orange plate (Pumpkin Disk) and set at reading 52.8. One jar of potato chips (approximately 128 g) of each sample was crushed in a cylindrical metal cup which was then put into the instrument to measure the color The color of the samples in terms of Lightness Index was recorded against a reference of 100 reading.

The cylindrical metal cup containing the sample was rotated to take three measurements

Peroxide Values

The peroxide values (PV) of the oil in the fresh potato chips (0-wk storage) and in potato chips stored in the dark and light for 3 or 6 wk were determined by the method of Mehlenbacher (1960). Approximately 30 g of the potato chips were blended with 250 mL of chloroform in a Waring Blendor for 30 sec and then filtered through Whatman No. 1 filter paper in a Buchner funnel under partial vacuum. Then, each of two 25-mL aliquots of the chloroform extract was transferred into a 50-mL dried, weighed beaker and the chloroform was evaporated on a steam bath under nitrogen stream. The beakers were dried in a vacuum oven at 95°C and 584.2 mm Hg for 30 min and cooled to room temperature in a vacuum desiccator before weighing The average weight of oil in the 25-mL aliquot of the chloroform extract was used as the sample weight for PV calculation

Each of two 25-mL chloroform extract aliquots was placed in a 125-mL flask and 37 mL of glacial acetic acid and 1 mL of saturated potassium iodide solution were added The mixture was placed in the dark for 1 min with occasional swirling every 15 sec. Immediately, 30 mL of distilled water and 1 mL of 1% starch solution were added, and the contents were titrated with approximately 0 01N sodium thiosulfate solution until the blue color disappeared. The volumes required for titration of the duplicate chloroform extracts were averaged for PV calculation of each chip oil sample. The actual normality of the thiosulfate solution was determined according to AOCS (1993) Method Cd 8b-90. A 25-mL aliquot of the chloroform solvent containing no oil was

titrated for a blank The PV of the potato chips were expressed as milliequivalents of peroxide per kg of oil in the chips

Flavor Volatiles

For each oil/blend-replication combination, the headspace flavor volatiles in potato chips stored for 0-, 3- and 6-wk in the light and dark were analyzed by solid phase microextraction (SPME) (Harmon, 1997). For each sample, the potato chips were crushed in a mortar and pestle, and 1.0 g of the material was transferred into a 4-mL vial which was sealed with a PTFE silicone septa (Supelco, Inc., Bellefonte). The vial was heated at 60°C on a SPME sampling stand which fit compactly on a Corning heat/stir plate (Model PC-400/410/ 420, Corning Inc., Corning, NY), and volatiles in the headspace were collected for 15 min on a 50/30 μm Divinylbenzene/Carboxen/ Polydimethylsiloxane fiber (Supelco, Inc., Bellefonte, PA) inserted through the silicon septa The volatiles were desorbed for 3 min by inserting the SPME needle and exposing the SPME fiber directly into the injection port of the same GC used for fatty acid analysis, except the injection port had a special smaller glass liner (Supelco, Inc., Bellefonte, PA) SPME analysis. The absorption was carried out using a split of about 20:1 of a carrier gas flow rate of 40 mL/min. The initial column temperature was 40°C which was increased to 180°C at 4°C/min. Flavor volatiles of potato chips were identified by matching GC retention times of sample peaks with those of standards analyzed under the same conditions The concentration of each volatile in a sample was estimated by its GC peak area.

Sensory Evaluation

Color lightness and flavor characteristics (characteristic potato chip flavor, oxidative rancidity and off-flavor) of chips fried in each oil/blend and stored for 0, 3 and 6 wk in dark and light were evaluated by 26 panelists on 9-point scales (Penfield and Campbell, 1990). The panelists were from the faculty, staff and students at The University of Tennessee who often participate in sensory panels. Sensory evaluation for each replication consisting of chips fried in the four oils/blends was conducted in five sessions, one session at 0-week and two sessions per storage period at 3- and 6-wk storage, respectively. For each storage time of 3 or 6 wk, an incomplete block design was generated so that each of the 26 panelists evaluated each of the eight samples in two sessions.

Each panelist was familiarized with the properties of fresh and oxidized potato chips at the beginning of each session (Appendix A). The fresh chips were those fried in cottonseed oil from Tom's Snack Foods (Knoxville, TN), and the oxidized chips were the same chips stored in 1 9-L sealed jars laid on their sides under fluorescent light for 6 wk at ambient temperature. Enough fresh and oxidized chips were obtained and prepared prior to the start of sensory evaluation sessions to allow for all familiarization sessions. The fresh and oxidized chips were stored in the dark in 1.9-L sealed, nitrogen-filled glass jars at -18°C until used. Prior to being served to panelists, chips were removed from frozen storage and allowed to reach ambient temperature for 2 hr in dark.

At the end of each storage time (0, 3 and 6 wk), the jars of chips assigned for sensory evaluation were opened, flushed with nitrogen, sealed and held in the dark at -

18°C until analysis in the following week Prior to evaluation, chip samples were removed from the frozen storage (-18°C) and allowed to reach ambient temperature for 2 hr Panelists were seated in individual booths and evaluated the four potato chip samples on a paper plate coded with 3-digit random numbers after they were familiarized with the flavor characteristics of the fresh and oxidized potato chips. The four samples were presented individually to the panelists in random order. Each panelist was presented three pieces of potato chips for each sample. Panelists were instructed to check the 9-point scale (Appendix B) at a point that best described their perception of each chip characteristic and to rinse their mouths with water between samples

D. STATISTICAL ANALYSIS

The overall statistical design for the frying oil and the chemical evaluation of the potato chips was a Randomized Block Design (RBD), blocked on week The data of the oil levels of fatty acid composition (FA), total polar compounds (TPC), free fatty acid (FFA), conjugated dienoic acids (CDA), and color from all oil/blend samples (n=48) during frying were analyzed according to a RBD with repeated measure treatment arrangement and three replications Repeated measures occurred due to sampling over time of the oils/blends The effects of fresh oil added during frying of potato chips on FA, TPC, FFA, CDA and color were controlled with covariate analysis The covariate was dropped from the model when it was not significant

The design for the fresh chip samples (n=12) evaluated for color, moisture and fat contents was a RBD with three replications. The data for peroxide value of the oil

extracted from chip samples (n=60) and flavor volatiles of chips (n=60) during storage were analyzed according to RBD with split-plot treatment arrangement The whole plot experiment units were the four oils/blends, while the sub-plot experiment units were storage conditions (dark and light) and storage time (0, 3 and 6 wk)

The data from sensory evaluation of the chips (n=60) were subjected to analysis according to an Incomplete Block Design with a split-plot treatment arrangement, blocked on week and panelists. The order of sample presentation to the panelists was dropped from the model since it was not significant for the sensory attributes tested, except color intensity.

The data were analyzed using the SAS Mixed Procedure (Littell et al., 1996). Significant differences among means were determined by the Least-Squares Means method with PDIFF option For the oil samples, the significant differences among means of FA, TPC, FFA, CDA and color also were analyzed with orthogonal contrasts. All statistical analyses were conducted using SAS Software Release 6.12 (SAS Institute Inc , 1997).

CHAPTER IV

RESULTS AND DISCUSSION

A. CHARACTERISTICS AND PERFORMANCE OF FRYING OILS

Fatty Acid Composition and C18:2/C16:0 Ratio

Fatty acids identified from the frying oils were lauric acid (C12 0), myristic (C14 0), palmitic (C16.0), palmitoleic (C16:1), stearic (C18 0), oleic (C18:1), linoleic (C18 2), linolenic (C18:3), arachidic (C20:0), gadoleic (C20:1)and behenic (C22:0) Frying oils affected ($p<0.01$) concentration of all fatty acids except for C20:1 and the C18·2/C16:0 ratio (Table 1). Sampling or frying time only affected levels of C18:1 ($p<0.01$) and C18:2 ($p<0.05$) (Table 2), while oil x sampling interaction affected only C18.1 concentration ($p<0.05$) (Fig. 1)

Least-squares means of fatty acid concentrations for each frying oil are presented in Table 1. Neither cottonseed (CSO) nor sunflower oil (SFO) contained C12:0, while the concentration of C12:0 acid in the oil blends increased as the amount of palm olein oil (POO) increased. POO contains approximately 0.2% C12 0 (Basiron, 1996). The highest amount of C14 0 was found in CSO followed by the 40% POO and 20% POO blends Increasing the amount of POO to 40% significantly raised the concentration of C16 0 in that oil blend to be similar to that of CSO ($p<0.05$), C16·0 is the major fatty acid (~44%) found in POO (Basiron, 1996)

CSO contained the highest amounts of C16:1, C18:3 and C20:0 and the lowest amount of C18 0, while the levels of these fatty acids in the other oils were not different ($p>0.05$) (Table 1). The levels of C18:1 and C18·2 in SFO were higher ($p<0.05$) than

Table 1 -- Least-squares means[ab] and standard errors (SE) of fatty acid concentrations (%) and C18:2/C16:0 ratio of frying oils averaged across sampling times[c] before and during frying of potato chips

Fatty acids[d]	Frying oils				SE
	Cottonseed	Sunflower	20% POO[e]	40% POO[e]	
C12:0 **	ND[f]	ND[f]	0.18 b	0.34 a	0.01
C14:0 **	0.71 a	0.05 d	0.31 c	0.57 b	0.03
C16:0 **	22.02 a	6.46 c	13.14 b	20.08 a	0.68
C16:1 **	0.49 a	0.08 b	0.06 b	0.04 b	0.03
C18:0 **	2.95 b	4.19 a	4.14 a	4.09 a	0.07
C18:1 **	20.14 d	22.08 c	26.42 b	30.50 a	0.11
C18:2 **	51.68 c	65.78 a	54.58 b	43.33 d	0 62
C18:3 **	1.25 a	0.27 b	0.25 b	0.24 b	0.05
C20:0 **	0.36 a	0.28 b	0.30 b	0.29 b	0.02
C20:1	0.12 a	0.16 a	0.13 a	0.13 a	0.05
C22:0**	0.26 d	0.68 a	0.52 b	0.39 c	0.03
C18:2/C16:0 **	2.83 c	10.19 a	4.16 b	2.16 c	0.34

[a] N = 12.
[b] Least-squares means in a row followed by unlike letters are different ($p<0.05$).
[c] Frying oils were sampled while fresh, after heating at 163°C for 3 hr prior to frying and after frying 2.5 and 5 hr.
[d] Fatty acids followed by ** had a significant F-value at $p<0.01$ for oil effect.
[e] 20 and 40% POO = 20 and 40% (w/w) palm olein in sunflower, respectively.
[f] ND = non detected.

Table 2 -- Least-squares means [ab] and standard errors (SE) of fatty acid concentrations (%) and C18·2/C16 0 ratio of frying oils while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying 2 5 and 5 hr averaged across four different frying oils[c]

Fatty acids[d]	Sampling time				SE
	Fresh	0 hr	2.5 hr	5 hr	
C12·0	0 13	0 13	0.13	0 13	0.01
C14 0	0.35	0 44	0.42	0.42	0 03
C16 0	14 03	15 68	15.92	16.07	0 68
C16 1	0 13	0 18	0 18	0.18	0 03
C18 0	3 83	3 79	3 86	3.89	0 07
C18·1 **	24.53 b	24 58 b	24 90 a	25 13 a	0 11
C18·2 *	55 69 a	53.75 b	53 15 b	52 78 b	0 62
C18.3	0 48	0 55	0 50	0 49	0.05
C20.0	0.30	0 31	0.30	0 32	0.02
C20.1	0.10	0.16	0.13	0 14	0.05
C22 0	0 46	0 43	0 48	0.48	0 03
C18·2/C16 0	5 52	4 73	4 59	4 51	0 34

[a] N = 12

[b] Least-squares means in a row followed by unlike letters are different ($p<0.05$)

[c] Frying oils consisted of cottonseed, sunflower and 20 and 40% (w/w) palm olein in sunflower oil.

[d] Fatty acids followed by ** and * had a significant F-value at $p<0$ 01 and $p<0.05$, respectively, for sampling effect

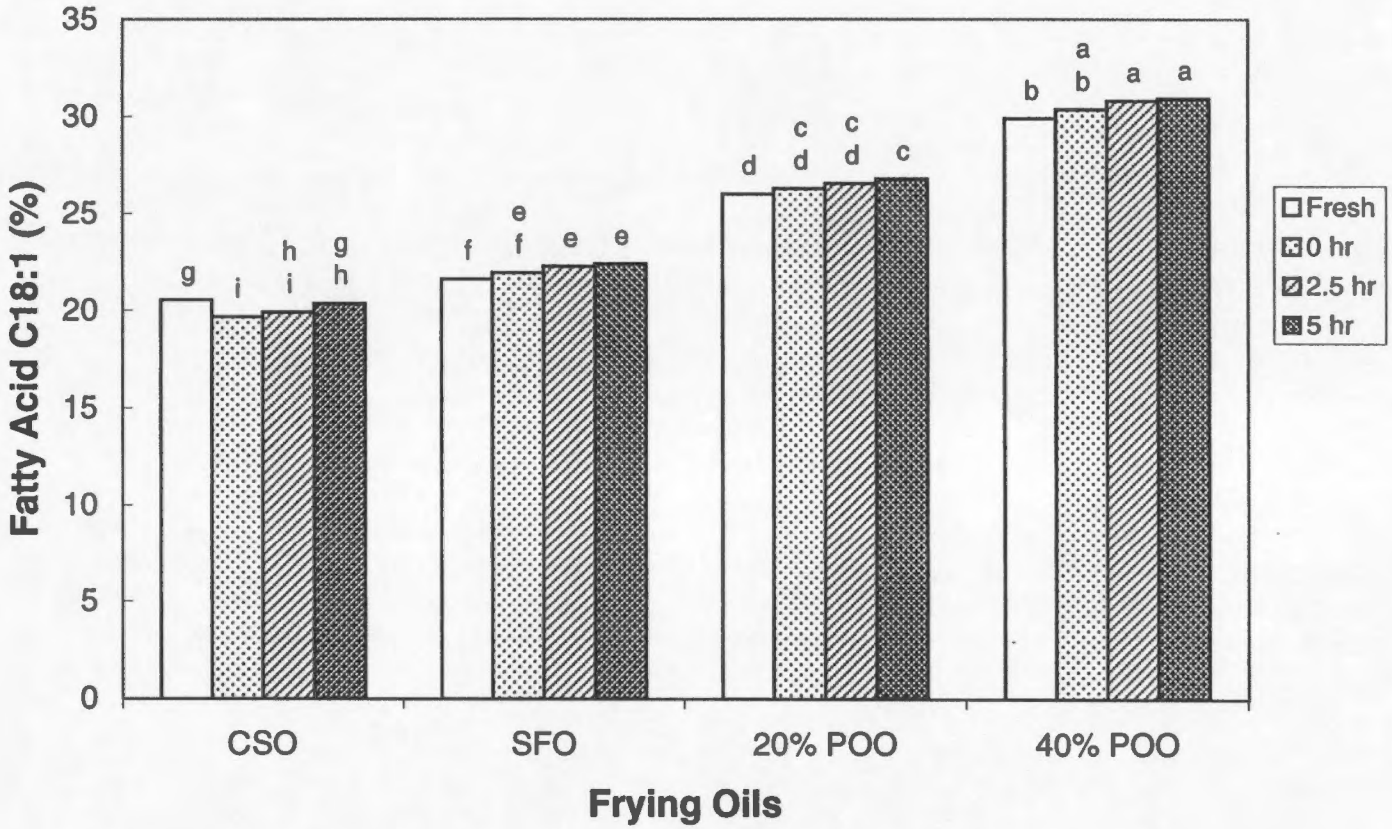

Fig. 1 - Least-squares means (N = 3) of the percentages of fatty acid, C18:1, of frying oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower, respectively) while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

those in CSO These results agreed with those reported by O'Brien (1998). Since C18:1 is the second major fatty acid (~39%) in POO (Basiron, 1996), the levels C18.1 in the oil blends containing 20 or 40% POO were higher than those in the two other oils. The levels of C18:2 in the oil blends decreased significantly from that in SFO with increasing amount of POO. All of the frying oils contained the same amounts of C20:1 ($p>0.05$). The highest level of C22:0 was found in SFO, while the lowest level was found in CSO

The effects of break-in heating and frying time on fatty acid concentrations are presented in Table 2. Least-squares mean analyses indicated that break-in heating and frying time affected only the concentrations of C18:1 and C18:2. However, the results of orthogonal contrast analysis showed that heating or frying also significantly affected C14:0 and C16:0. Concentrations of C14 0 and C16 0 in the fresh oil increased ($p<0$ 01) after break-in heating at 163°C for 3 hr but remained unchanged during 5-hr frying On the other hand, the concentration of C18 2 decreased in the fresh oil during the 3-hr break-in heating period, but also remained the same during the frying period. Therefore, the increased levels of C14 0 and C16:0 could have resulted from thermal oxidation of unsaturated fatty acid C18:2 and its decrease during heating. The level of C18:1 in oil, however, did not significantly change during the 3-hr break-in heating period but did increase by the end of 2 5-hr frying period (Table 2) This might be due to a decreased levels of other fatty acids such as C18 2 Neither least-squares analysis nor orthogonal contrast indicated a significant change of the concentration of C18:2, but it tended to decrease during frying period (Table 2) Since concentrations of fatty acids are expressed on a 100% basis, any degradation of polyunsaturated fatty acids in an oil

will result in a decrease in their percentages and result in an increase in the percentages of the more stable fatty acids

The results that heating the oils without frying resulted in more deterioration in the oils than frying as shown by the significant decrease in C18.2 concentration during break-in heating only agrees with results of other researchers Dobarganes et al. (1993) found that high-oleic SFO, regular SFO and olive oil heated at 180°C for 10 hr deteriorated more than when they were used for frying potatoes for 15 hr. During frying, the steam generated from the moisture of potato slices covers the oil surface in the fryer reducing the hot oil contact with oxygen thus decreasing oxidation. The steam generated during frying also removes volatiles formed by oil oxidation and helps keep the oil in good condition. Addition of fresh make-up oil also keeps the level of free fatty acids (FFA) low and further reduces oxidation during frying (Stevenson et al., 1984; Weiss, 1983).

In contrast to an increase in levels of C18:1 during the first 2.5 hr of frying potatoes and no change in the concentration of C18.2 during 5-hr frying, Tyagi and Vasishtha (1996) reported a gradual decrease in levels of C18.1 and C18·2 during 70-hr frying in soybean oil and an oil blend They found that the concentration loss increased with increasing degree of unsaturation in the fatty acid and with increasing frying temperature

Figs 1 and 2 show the effect of sampling time on C18·1 and C18 2, respectively, in each oil. The least-squares mean levels of C18.1 and C18.2 for each sampling time in each oil are presented in Appendix C After break-in heating the oil 3 hr, C18:1 decreased ($p<0$ 05) in CSO, but not in the other oils/blends. However, during 5-hr

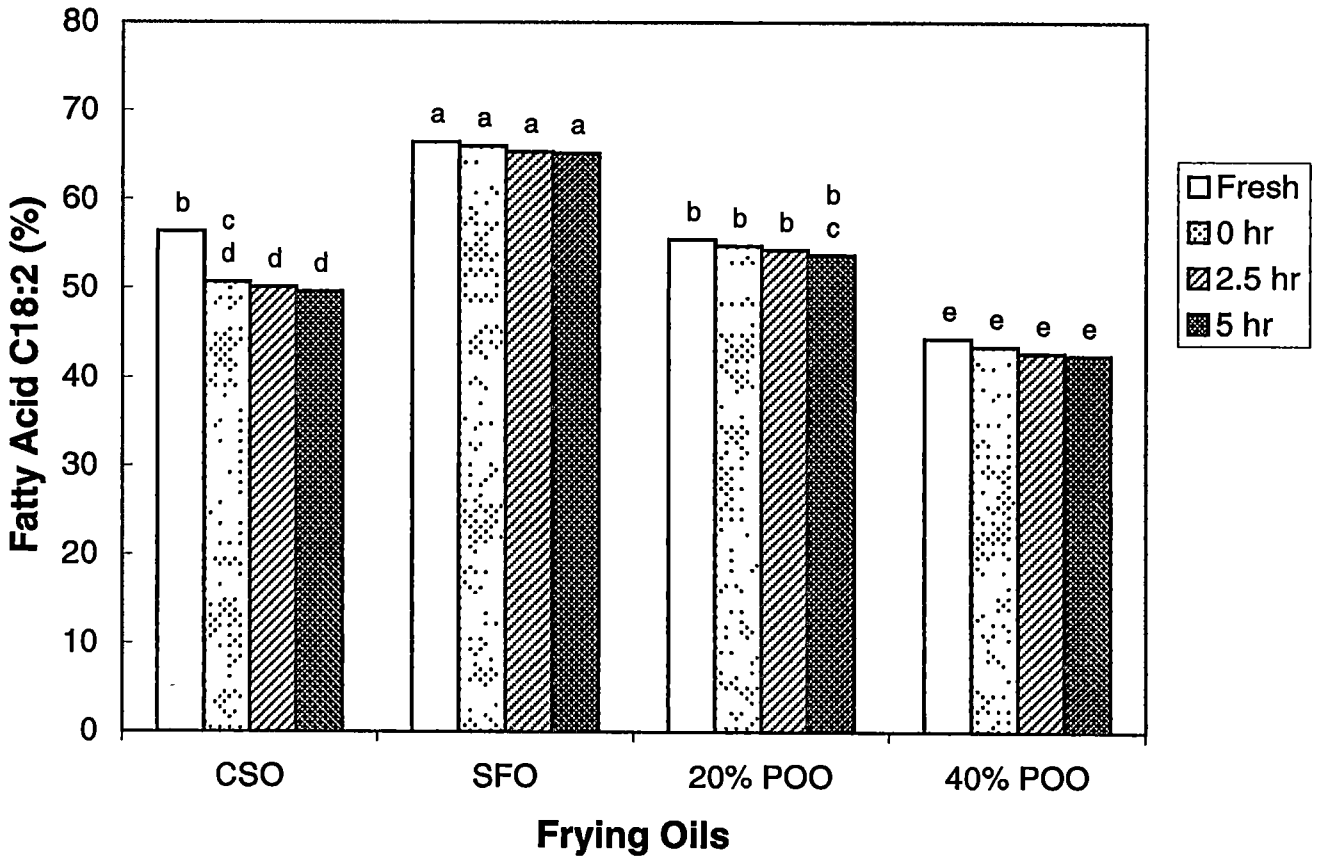

Fig. 2 - Least-squares means (N = 3) of the percentages of fatty acid, C18:2, of frying oils (CSO = cottsonseed, SFO = sunflower and 20 and 40% PO = 20 and 40%, w/w, palm olein in sunflower, respectively) while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

frying, C18:1 level increased in all oils/blends significantly either by 2.5-hr or 5-hr frying time dependent upon oil/blend. In CSO, the level of C18 1 increased to that of its original level after 5-hr frying. These results partially agree with those reported by Lin (1993) who found that C18:1 level in SFO did not change after 3-hr heating at 163°C or during 4-hr frying of potato slices. That researcher found, however, C18:1 level did increase in CSO during 4-hr frying of potato slices

Concentrations of C18·2 in oils/blends did not significantly change after 3-hr break-in heating and 5-hr frying with the exception of CSO (Fig 2). The level of C18 2 in CSO decreased after 3-hr break-in heating ($p<0$ 05), but remained unchanged during frying The higher stability of C18:2 in SFO and 20 and 40% POO blend was due to higher contents of natural antioxidant, tocopherols. Analytical results indicated that the total tocopherol contents of CSO, SFO and the 20 and 40% POO blends were 38 49, 69.33, 60 74 and 51 60 μg/g oil, respectively (Shao, 1999).

The C18.2/C16:0 ratio was different in each frying oil (Tables 1). Neither heating/frying time nor oil x frying time interaction affected the C18:2/C16·0 ratio ($p>0.05$). Averaged across sampling times, the highest C18.2/C16:0 was found in SFO followed by 20% POO oil blend (Table 1). The fatty acid ratio in CSO was not significantly different from that of the 40% POO oil blend Although the analysis of variance did not show an effect of heating/frying time ($p>0.05$) (Table 2), an orthogonal contrast analysis showed that the C18 2/C16·0 ratio significantly decreased after 3-hr break-in heating and then remained unchanged throughout frying (Table 2). This result was consistent with the concentration of C18.2 (Table 2). Contrary to these results,

Silaula (1997) reported that the C18.2/C16 0 ratio decreased throughout frying The magnitude of change was dependent on the initial C18·2 content of the oil

Total Polar Compounds

Total polar compounds (TPC) were significantly different among the types of frying oils and were affected ($p<0.01$) by break-in heating/frying time (Table 3), oil x heating/frying time interaction also affected ($p<0.01$) TPC. Averaged across break-in heating/frying time, CSO had higher TPC levels than other oils and the levels of TPC also increased with increasing amounts of POO in the oil blends (Table 3)

Averaged across frying oils, the quantities of TPC increased progressively during 3-hr break-in heating and 5-hr frying (Table 3) At the end of frying, the average TPC content of the oils was 15.9%, which is lower than the cut-off point of 25-27% that has been suggested for discarding frying oils (Firestone et al., 1991; Melton et al., 1994). The highest level of TPC (15 9%) found indicates that the frying oils probably did not affect the flavor of potato chips' Melton et al. (1994) reported that flavor score of fried food was affected only after the TPC increased above 15%. Also, the oils were not used for frying for a long enough period to become deteriorated. For example, Tseng et al (1996) reported that it took 25-hr frying of tortilla chip dough (55% moisture) in soybean oil for that oil to reach 27% TPC content.

The levels of TPC at each sampling time for each oil are presented in Fig 3 and Appendix D. In the fresh oils, the highest and the lowest amounts of TPC were found in CSO and SFO, respectively (Fig. 3). Addition of 20 and 40% POO increased the initial levels of TPC in the oil blends over that in SFO, yet the initial levels of TPC in the oil blends were not different ($p>0.05$). With the exception for CSO containing ~7% TPC,

Table 3 -- Least-squares means[ab] and standard errors (SE) for levels of total polar compounds (TPC), free fatty acids (FFA) and conjugated dienoic acids (CDA) averaged across sampling times for each type of frying oil and across types of frying oils for each sampling time

Independent variable	TPC** [c] (%)	FFA** [c] (% oleic)	CDA** [c] (%)
Frying oils [d]			
- Cottonseed	12.328 a	0 039 d	0.837 a
- Sunflower	9 713 d	0 043 c	0.731 b
- 20% POO	10.584 c	0 046 b	0 655 c
- 40% POO	11.104 b	0 052 a	0.593 d
SE	0.13	0.002	0.01
Sampling [e]			
- Fresh	5 049 d	0.025 d	0.183 d
- 0 hr	9 756 c	0.036 c	0.604 c
- 2 5 hr	13.047 b	0.050 b	0.909 b
- 5 hr	15 875 a	0 070 a	1.121 a
SE	0.13	0 002	0 01

[a] N = 12.
[b] Least-squares means in a column within an independent variable followed by unlike letters are different ($p<0.05$).
[c] TPC, FFA and CDA followed by ** had significant F-values at $p<0$ 01 for frying oil and sampling effects.
[d] 20 and 40% POO = 20 and 40% (w/w) palm olein oil in sunflower oil, respectively.
[e] Oils were sampled while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying 2 5 and 5 hr

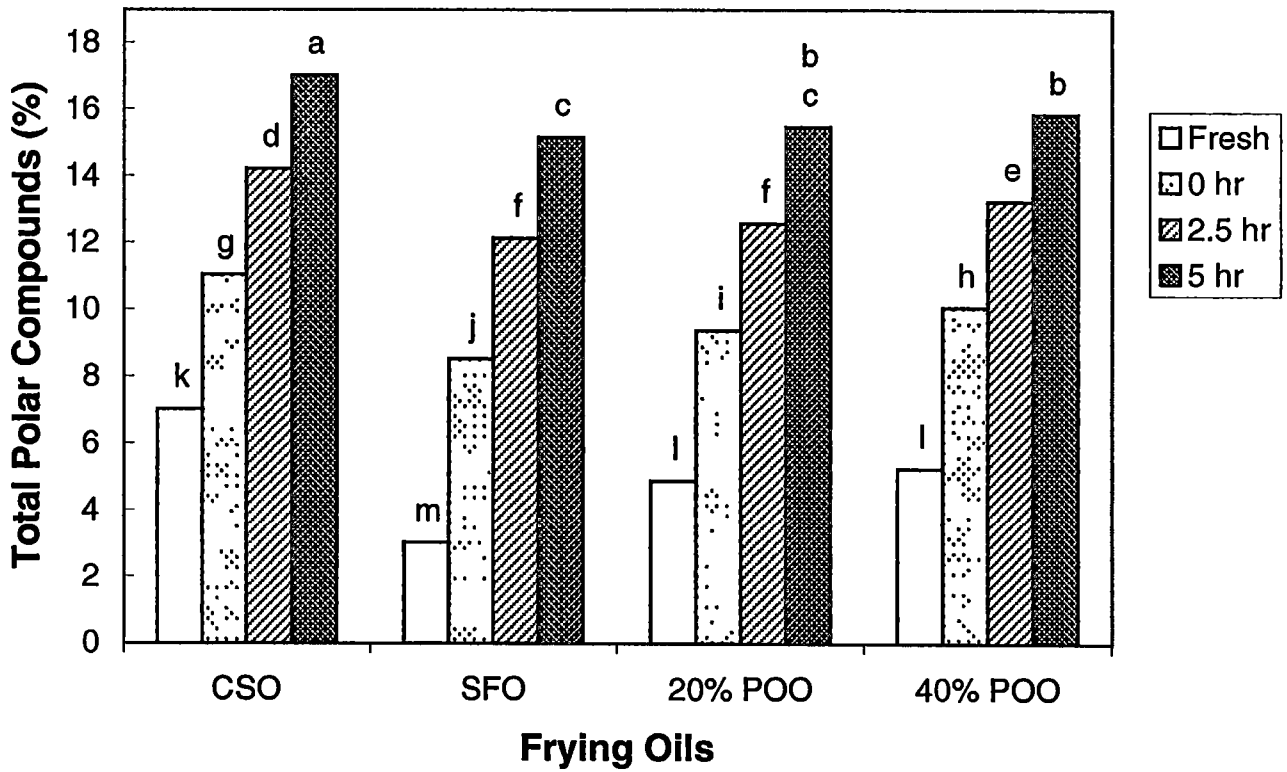

Fig. 3 - Least-squares means (N = 3) of levels of total polar compounds of frying oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower, respectively) while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

the levels of TPC in the fresh oils used in the current study were in the range normally found in fresh oils. According to Stier and Blumenthal (1993), fresh oils typically contain 2-4% nontryacylglycerols, constituents of TPC. The differences in the TPC contents of fresh oils might be due to differences in processing techniques and sources (Dobarganes et al., 1993).

The levels of TPC in all oils increased during 3-hr break-in heating and 5-hr frying. However, the levels of TPC increased at different rates, depending on the type of oils and sampling time (Fig.3 and Appendix D). Generally, TPC in CSO accumulated at a lower rate than TPC in the other oils during break-in heating. During 3-hr heating, TPC in SFO accumulated at the highest rate while that in CSO at the lowest rate In the break-in heating, the levels of TPC increased about 4 0, 5.5, 4.5 and 4.8% in CSO, SFO and 20 and 40% POO blends, respectively (Fig. 3). The highest rate of increase in TPC level also was found in SFO during the first 2.5-hr frying. This high rate increase may have been due to the higher C18:2 content in SFO compared to the other oils (Table 2). These results also indicate that addition of the more saturated POO to the unsaturated SFO tended to delay or retard oil degradation. Accumulation of TPC as a measure of oil degradation during frying is dependent not only on the fatty acid composition or the degree of unsaturation of an oil but also on triacylglycerol distribution (Dobarganes et al., 1993).

Free Fatty Acids

Free fatty acids (FFA) contents were affected ($p<0.01$) by the type of frying oils and heating/frying time (Table 3); FFA also had an oil x heating/frying time interaction ($p<0$ 01) When averaged across heating/frying time, the levels of FFA among oils were

significantly different with the lowest level being found in CSO (Table 3) Adding POO to SFO, which contained higher FFA than CSO, further increased the amounts of FFA in the oil blends. Averaged across frying oils, the levels of FFA increased ($p<0.05$) steadily during heating and frying.

The FFA levels at each sampling period for each oil/blend and the respective least-squares means are presented in Fig. 4 and Appendix E, respectively. The level of FFA in the fresh CSO was lower than those of the other three fresh oils which basically contained the same amount of FFA The fresh oils used in this study contained low levels of FFA, 0.02-0.03%, indicating the oils had been properly refined. Generally, fresh, unused oil contains no more than 0.08% FFA (Stevenson et al , 1984).

Overall, FFA levels in all oils increased ($p<0.05$) during break-in heating and frying of potato chips (Fig 4), indicating the occurrence of oil hydrolysis and oxidation. These results agree with those reported by other researchers (Lin, 1993; Tseng et al., 1996; Silaula, 1997) CSO had the lowest FFA levels of all fresh oils/blends and after break-in heating (Fig 4). While adding POO to SFO did not significantly increase FFA levels initially, it increased FFA levels at an increased rate during potato chips frying when compared with SFO and CSO. The highest FFA level was found in the 40% POO in SFO blend after 5-hr frying (Fig 4) Even after 5-hr frying, the FFA levels in all oils remained lower than the 0.5%, reported to decrease the shelf life of potato chips (Weiss, 1983). According to Stier and Blumenthal (1993), however, FFA level is not a good indicator of oil degradation for several reasons FFA can be changed to oxidized fatty acids and decomposition products. They do not affect frying, good quality foods can be fried in pure FFA. Also FFA can be diluted by replenishment with fresh oil. According to

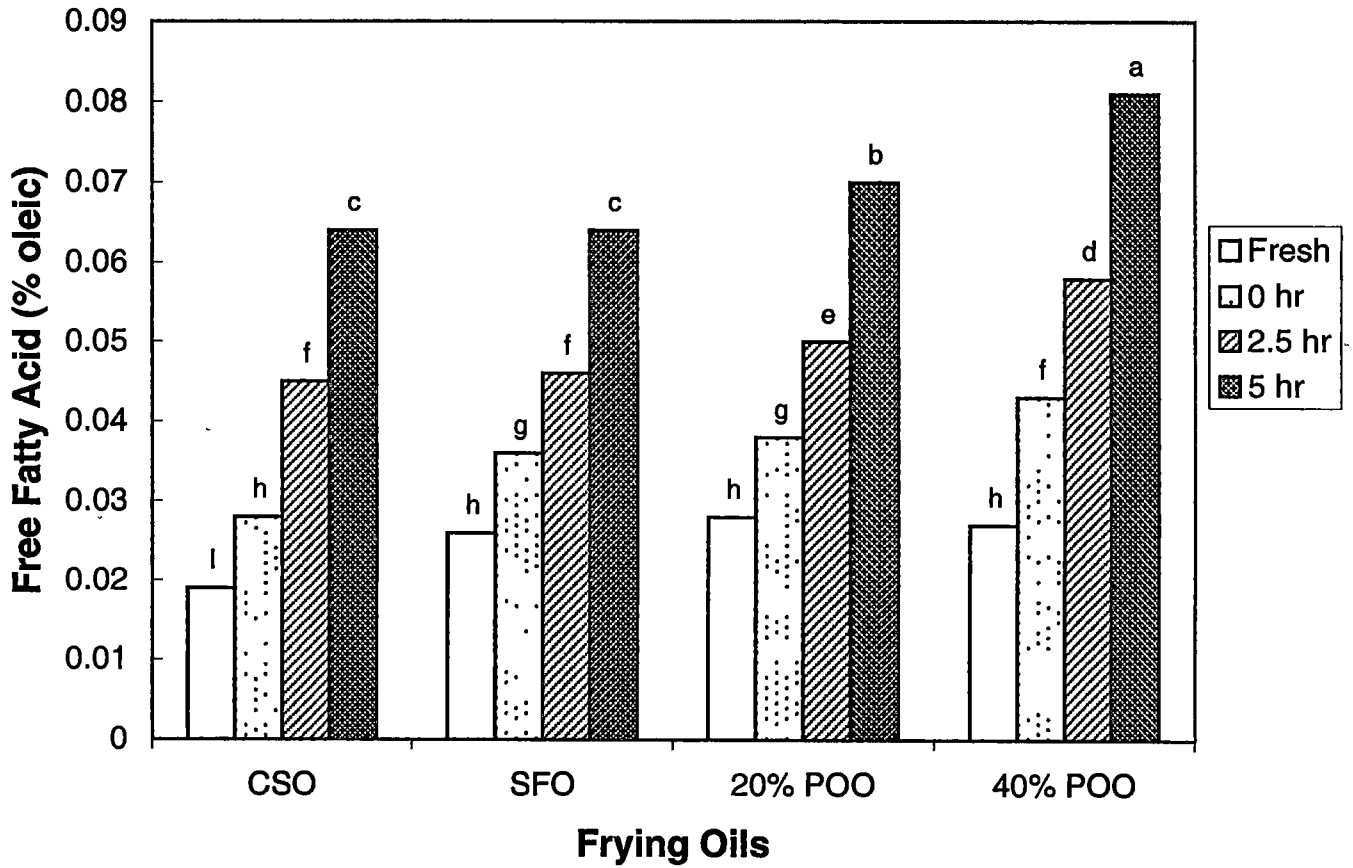

Fig. 4 - Least-squares means ($\bar{N}$ = 3) of free fatty acid levels in frying oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower, respectively) while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

Melton et al (1994), FFA are volatile and can be distilled out by steam; also, they degrade to more volatile compounds or react to form nonvolatile compounds In a study of soybean oil degradation by frying tortilla chips dough, Tseng et al. (1996) found that at the 0 25% FFA level, the frying oil already contained 27% TPC and began to form foam and impart pungent off-flavors However, the level of FFA in the oil on the surface of fried food is useful to predict the shelf life of the food with respect to the development of rancidity (Stier and Blumenthal, 1993).

Conjugated Dienoic Acids

Types of oils and break-in heating/frying time affected ($p<0.01$) the levels of conjugated dienoic acids (CDA) (Table 3), oil x heating/frying time interaction also affected CDA ($p<0.01$) Unexpectedly, CSO contained a higher level of CDA than did SFO (Table 3), although the level of polyunsaturated fatty acids (PUFA) in CSO was lower than that in SFO (Table 1) when averaged across break-in heating/frying time Generally, CDA are produced when oil is oxidized and one of the double bonds in the PUFA shifts position to form a conjugated diene (White, 1991) Therefore, the CDA test is useful to measure heat abuse of polyunsaturated fatty acids (PUFA). Across break-in heating/frying time, addition of POO to SFO decreased the amounts of CDA in the oil blends. POO contains only ~10% PUFA, while SFO contain ~68% (O'Brien, 1998). Break-in heating/ frying progressively increased the levels of CDA across frying oils (Table 3) indicating the occurrence of oxidation Tyagi and Vasishtha (1996) reported a magnitude increase of CDA in different oils after 70-hr frying. They reported that the higher temperature of frying resulted in higher levels of CDA

The CDA levels of each oil at each sampling time are presented in Fig. 5 and Appendix F CDA were initially present in CSO at a higher level ($p<0.05$) compared to the other fresh oils that basically had similar amounts ($p>0.05$) of CDA Silaula (1997) and Tyagi and Vasishtha (1996) also reported the presence of CDA in fresh oils During the 3-hr break-in heating, the level of CDA in CSO, SFO and the 20 and 40% POO blends increased at a greater rate than during frying (Fig. 5). This finding indicates, as was found by others, that heating of oils is more detrimental than frying (Dobarganes et al , 1993). Even though CSO had the highest initial CDA of all oils, it had next to the lowest level of PUFA (Table 1) and that may have been the reason that during frying in SFO, which contained the highest PUFA amounts, formed CDA at levels as high as CSO (Fig. 5). As the POO level increased in the blends, the levels of PUFA decreased from that present in SFO (Table 1). Also, the relative levels of CDA in the blends compared with those in SFO were corresponding less after heating and frying (Fig. 5).

In the second 2.5-hr frying period, the level of CDA increased at a lower rate in each frying oil than during previous heating or the first frying period. The lower rate of CDA increase at the later stage of frying most likely was due to the establishment of an equilibrium between the rate of formation of CDA and the rate of formation of polymers formed by a Diels-Alder reaction involving CDA (White, 1991).

Color

The Hunter color values, *L* (lightness), *-a* (greenness) and *b* (yellowness) and ΔE (color difference) of the frying oils were influenced ($p<0.01$) by the types of frying oils and heating/frying time (Table 4). The oil x heating/frying time interaction also affected ($p<0.01$) all color measurements, except for the lightness. Least-squares means for

Table 4 -- Least-Squares means[ab] and standard errors (SE) of Hunter color *L*, *-a*, *b* and color difference (ΔE) averaged across sampling times for each oil/blend and across oils/blends for each sampling time

Independent variable	*L* ** [c]	*-a* ** [c]	*b* ** [c]	ΔE ** [c]
Frying oils [d]				
- Cottonseed	87.27 c	6 39 d	19.20 a	5.27 c
- Sunflower	91 52 a	3 04 a	8 79 d	6 80 a
- 20% POO	90.69 ab	4 70 b	13 53 c	6 07 b
- 40% POO	89.42 b	5 97 c	18 67 b	6.93 a
SE	1 27	0.03	0.21	0 38
Sampling [e]				
- Fresh	92 64 a	3 98 a	10 07 d	0.00 d
- 0 hr	93 18 a	4.88 b	11 77 c	2.91 c
- 2 5 hr	87.90 b	5 30 c	16.66 b	8.47 b
- 5 hr	85.18 c	5.94 d	21.69 a	13 71 a
SE	1 27	0 03	0.21	0 38

[a] N = 12.

[b] Least-squares means in a column within an independent variable followed by unlike letters are different ($p<0.05$).

[c] Hunter *L*, *-a*, *b* and ΔE followed by ** had significant F-values at $p<0.01$ for frying oils and sampling

[d] 20 and 40% POO = 20 and 40% (w/w) palm olein oil in sunflower oil, respectively.

[e] Oils were sampled while fresh, after heating at 163°C for 3 hr prior to frying (0 hr) and after frying 2.5 and 5 hr.

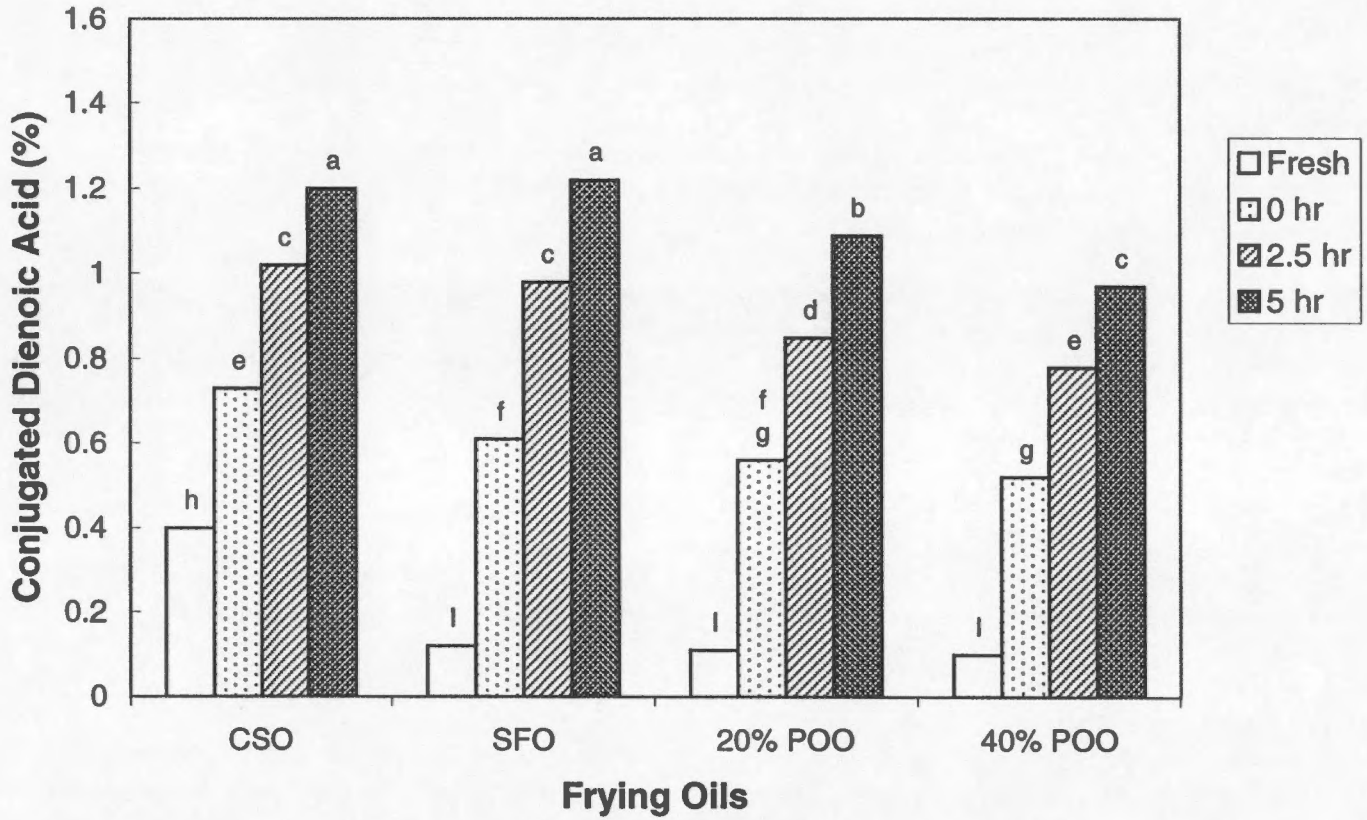

Fig. 5 - Least-squares means (N = 3) of levels of conjugated dienoic acids of frying oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower, respectively) while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

Hunter -*a*, *b* and ΔE of each oil/blend for each sampling time are presented in Figs. 6-8, respectively, and in Appendix G.

CSO was darker (lower *L* value), greener (higher -*a* value) and yellower (higher *b* value) than SFO (Table 4). Addition of POO to SFO decreased lightness (at 40% POO) and increased greenness and yellowness of the oil blends. The differences in color among the frying oils are likely due to the different amounts of color pigments remaining in the different oils after processing (Weiss, 1983) According to Jones and King (1996), most of the red color found in cottonseed oil comes from gossypol and its derivative residues The yellow color in POO is due to carotenoids. Crude palm oil contains 500-700 ppm of carotenoids, mainly α- and β-carotenes (Basiron, 1996). However, most of the color pigments are removed during processing (Weiss, 1983).

The color difference, ΔE, is a measure of overall color change when compared with a standard. In this study, for each oil/blend the standard was the unused, fresh frying oil/blend. Averaged across heating/frying time, the smallest color change was found in CSO, while the greatest color change occurred either in SFO or the 40% POO blend (Table 4).

During break-in heating, the lightness of the frying oils did not change ($p>0.05$), but greenness (-*a* values), yellowness (*b* values) and color differences (ΔE) increased (Table 4). During 5-hr frying, the lightness progressively decreased while greenness, yellowness and color differences increased. Thus, the oils became darker, greener and more yellowand the color differences between fresh and used oils increased Other researchers reported similar color changes in oil during frying (Silaula, 1997; Tseng et al., 1996, Tyagi and Vasishtha, 1996). The color changes during heating and frying

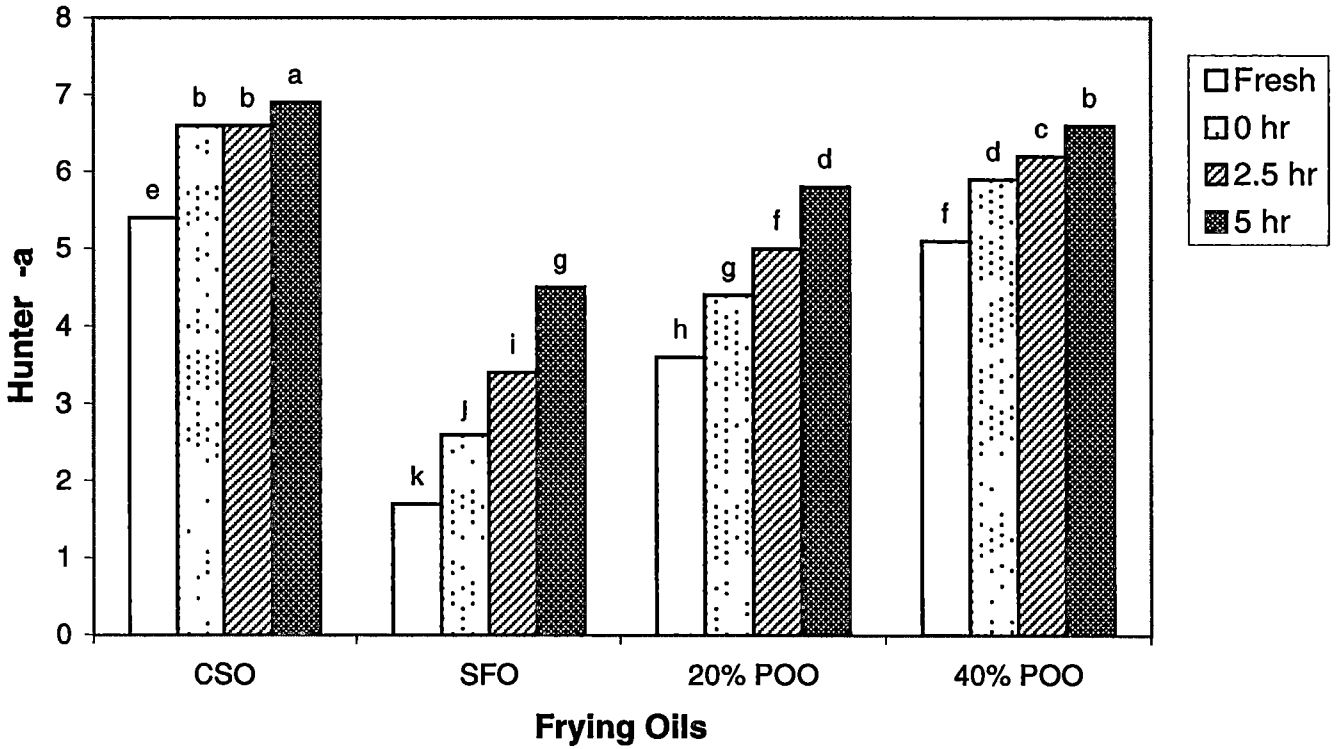

Fig. 6 - Least-squares means (N = 3) of Hunter color -a (greenness) of frying oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower, respectively) while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

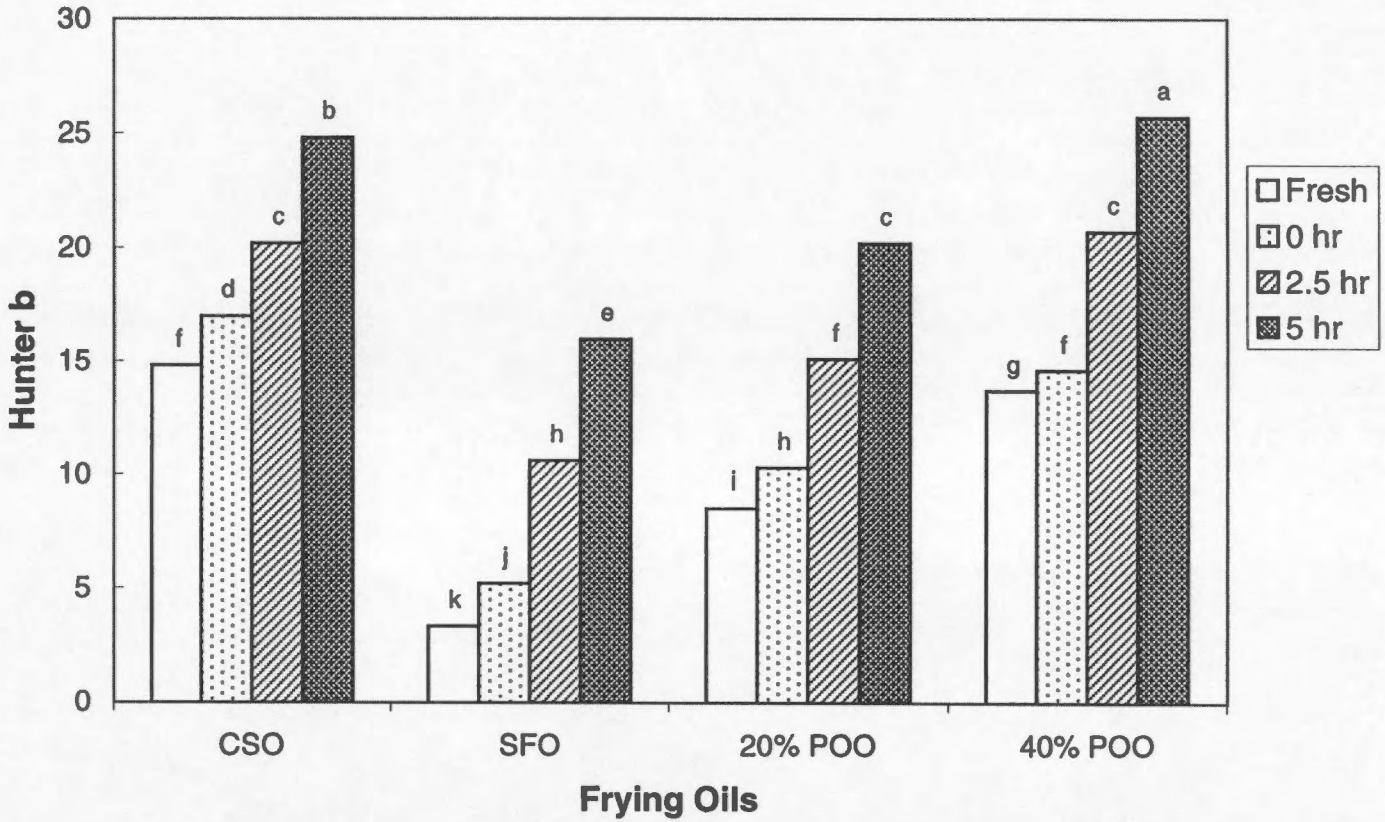

Fig. 7 - Least-Squares means (N = 3) of Hunter color *b* (yellowness) of frying oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower, respectively) while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

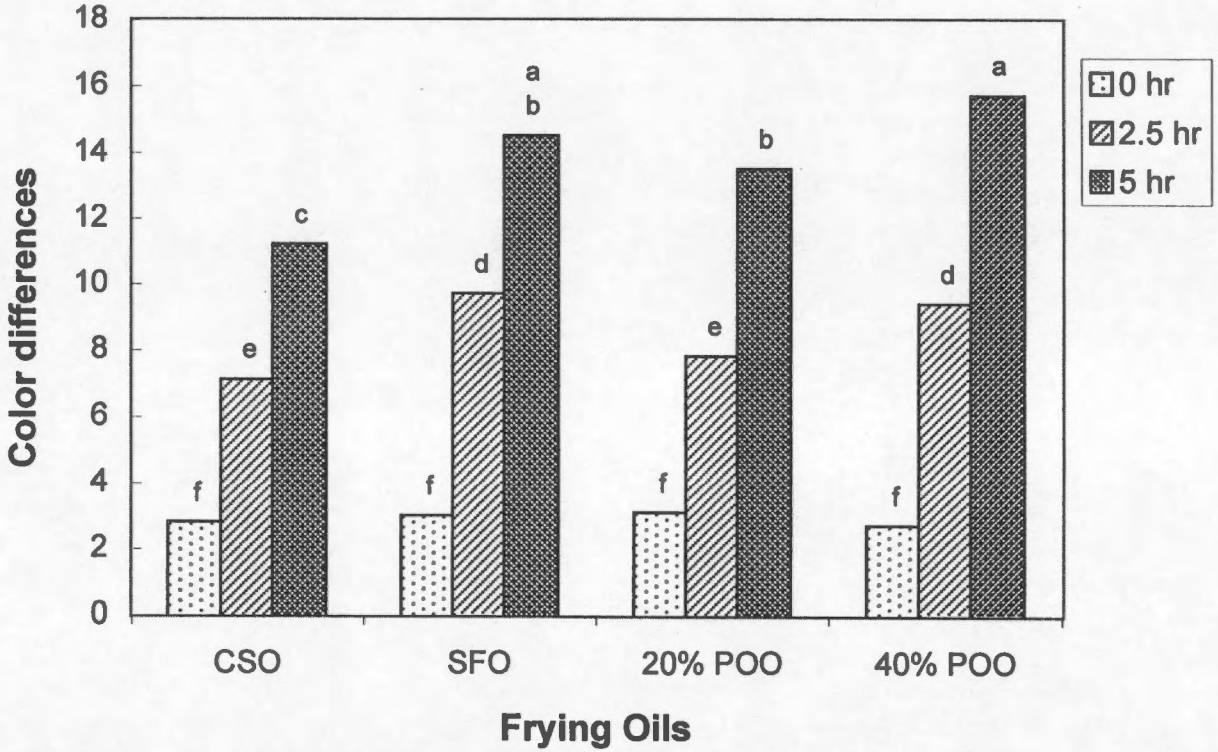

Fig. 8 - Least-squares means of color differences (d*E*) of used frying oils compared to fresh oils; frying oils consisted of cottonseed (CSO), sunflower (SFO) and 20 and 40% (w/w) palm olein in sunflower (20 and 40% POO, respectively); oils were sampled while fresh, after break-in heating at 163°C for 3 hr prior to frying (0 hr) and after frying of potato slices for 2.5 and 5 hr; bars with unlike letters are different ($p<0.05$).

were caused by pigment deterioration and by accumulation of the nonvolatile decomposition products (Stevenson et al , 1984; White, 1991)

The Hunter -*a* values of each oil were affected differently by break-in heating/frying times (Fig. 6 and Appendix G) All the frying oils, either in fresh or used states, had -*a* values, meaning the oils tended to be green in the color dimension system The fresh CSO had the largest -*a value* compared with the other frying oils SFO had the smallest -*a* values. Increasing amounts of POO in the oil blends resulted in more green (larger -*a* values) oils With the exception of CSO, all frying oils gradually increased in -*a* values during break-in heating and frying. During the first 2.5-hr frying period, the -*a* value of CSO did not change, but did increase a slight amount during the next 2.5-hr frying period.

While fresh, CSO was more yellow (higher *b* value) than the other oils (Fig. 7 and Appendix G) Increasing amounts of POO in the oil blends also resulted in increased yellowness Generally, the *b* values of all oils increased during heating and frying, although the rate of the increase differed among the oils The amount of increase in *b* values during break-in heating was less than that during frying. During the first 2.5-hr frying period, the *b* value increased at a lower rate in CSO than in the other oils As a result, the 40% POO blend was more yellow than CSO at the end of frying, although CSO was initially more yellow. However, the *b* values of SFO and the 20% POO blend were lower than those of CSO.

The overall color change (ΔE) for each oil during break-in heating was less than the color change during frying (Fig. 8 and Appendix G). After 2 5-hr frying, a substantial color change was found in SFO and 40% POO blend, which contained the highest and

the lowest amounts of PUFA (Table 1), respectively. At the end of the frying time, greater color changes occurred in SFO and the 20 and 40% POO blends than in CSO. From these results, one may infer that the color changes resulted from food being fried and thermal oxidation of saturated and unsaturated fatty acids.

B. SPECIFIC GRAVITY OF RAW POTATOES

Specific gravity has been used for a long time as a single important indicator for selecting raw potatoes in potato chip production because it affects the quality of the chips (Lisinska and Leszczynski, 1989, Smith, 1987) Therefore, the specific gravities of raw potatoes used in this study were measured prior to the processing for each oil/blend replication. The analysis of variance indicated that the specific gravities of raw potatoes used for production of chips were different among frying oils/blends ($p<0.05$) (Table 5). Chips fried in CSO were from potatoes with the highest specific gravity while those fried in SFO were from potatoes with the lowest specific gravity (Table 5). The specific gravities of potatoes used for production of chips and fried in the 20 and 40% POO blends were in between and not significantly different from those of potatoes for chips fried in CSO and SFO. All potatoes used for production of chips in the present study were from Atlantic cultivar grown in Florida. However, they were obtained from the production line in different weeks. Therefore, the potatoes might have come from different growing areas with different cultural practices, or they might have been harvested at different times. In addition to cultivar, the specific gravity of potatoes is also affected by soil conditions, growing location, cultural practices (Smith, 1987), plant populations and harvest timing (DeBuchananne and Lawson, 1991) The specific

Table 5 -- Least-squares means[ab] of specific gravity for raw potatoes used for production of potato chips, and moisture and fat contents and color of fresh potato chips fried in different oils

Frying oils	Specific gravity * [c]	Moisture (%)	Fat (%)	Color [d] (lightness)
Cottonseed	1 090 a	1 87 a	38.49 a	61 11 a
Sunflower	1 087 b	1.96 a	39 44 a	61.28 a
20% POO[e]	1 089 ab	1.95 a	38 83 a	59 06 a
40% POO[e]	1 089 ab	2 06 a	39 98 a	60.44 a

[a] N = 6, standard error for specific gravity = 0.002, moisture content = 0.12, fat content = 0 57 and color = 1 48
[b] Least-squares means in a column followed by unlike letters are different ($p<0.05$)
[c] Variable followed by * had a significant F-value at $p<0$ 05 for oil effect.
[d] The color of potato chips becomes lighter as the values increase.
[e] 20 and 40% POO = 20 and 40% (w/w) palm olein oil in sunflower oil, respectively.

gravities of all potatoes used in this study were within the acceptable range for potatoes used for chip production in the industry. Tom's Foods, Inc. (Knoxville, TN) uses a specific gravity of 1.070 as the minimum limit for potatoes used for chip production.

C. QUALITY AND STABILITY OF POTATO CHIPS

Proximate Composition

Proximate composition analyzed for fresh potato chips included moisture and fat contents which are usually used as quality parameters for potato chips The analysis of variance indicated that types of oils did not affect the moisture and fat contents of fresh chips ($p>0.30$).

The moisture contents of fresh potato chips fried in four different oils/blends ranged from 1.9-2.1% (Table 5). These results are higher than those reported by Lin (1993). This researcher found that the moisture contents of chips fried in different oils ranged from 1.06 % for those fried in SFO to 1 51% for those fried in high oleic SFO. The moisture differences of potato chips between the two studies were probably due to the different thickness of potato slices. The present study used 2.0-mm thick potato slices while Lin (1993) used 1.27-mm thick slices. Gamble and Rice (1988) reported that the final moisture content of chips increased with increasing thickness of potato slices. They theorized that the thin slices resulted in shorter distances for moisture to diffuse to the surface during frying which led to rapid moisture loss. The moisture contents of potato chips of the current study were still in the acceptable range. According to Gamble and Rice (1988), potato chips may not be crispy if the moisture

content is higher than 2% Other researchers indicated that the crispiness of potato chips was lost only if the moisture content was 3 5% or greater (Kubiak et al., 1982)

The fat content of potato chips fried in different oils ranged from 38.8 to 40% (Table 5), which were lower than those reported by Lin (1993) This likely was due to the differences in the specific gravity of raw potatoes The specific gravity of raw potatoes used in the present study ranged from 1.087 to 1.090, while those of Lin (1993) ranged from 1.073 to 1 081. The oil contents of potato chips generally decrease with increasing specific gravity of the potatoes (Lulai and Orr, 1979; Smith, 1987). Based on the specific gravities of the raw potatoes, the results of the current study agreed with those reported by Lulai and Orr (1979). Another factor that could have effected differences in the oil contents of the potato chips in the present study compared with those of Lin (1993) was the thickness of potato slices. Gamble and Rice (1988) reported that the oil content of the chips decreased almost linearly as the slice thickness was increased.

Color

The analysis of variance indicated that the types of frying oils/blends did not affect the color of potato chips ($p>0.70$). Factors such as chemical composition of potatoes, slice thickness, blanching or washing water temperature and time, frying temperature and time and the quantities of slices in the fryer all may affect the color of potato chips (Lisinska and Leszczinski, 1989, Smith, 1987) unless they are well controlled.

The Agtron color of the potato chips in the present study ranged from 59.1 to 61 3 (Table 5) meaning the potato chips were in the acceptable to excellent color quality

range According to Sinha et al (1992), Agtron chip color above 60 is considered to be excellent, 56-60 is acceptableand 50-55 is marginally acceptable. The Agtron color of potato chips of the present study was lower than that of the same cultivar reported by Sinha et al. (1992) The maturity of potato tubers also affected the color of chips, generally, the more mature potatoes produce lighter colored (higher Agtron color) chips (DeBuchananne and Lawson, 1991; Sinha et al , 1992; Smith, 1987).

Peroxide Values

Analyses of variance indicated that types of oils, storage and their interaction affected ($p<0.001$) the peroxide values (PV) of oils extracted from chips Least-squares means of the PV of chips fried in different oils, stored under different conditions and for each oil at each sampling time are presented in Appendix H. Averaged across storage conditions and time, the chips fried in SFO contained oil with the highest level of PV (29.2 meq peroxide/kg oil), while those fried in the 40% POO blend contained oil with the PV (16 9 meq peroxide/kg oil) at the lowest level. SFO contained the highest level of the total unsaturated fatty acids (Table 1) and, therefore, chips fried in it underwent the most oxidation during storage On the other hand, the 40% POO blend contained the lowest level of total unsaturated fatty acids and produced chips that were more stable to oxidation during storage The oxidation rate of fat is roughly proportional to the degree of unsaturation; the greater the degree of unsaturation, the higher the oxidation rate (Melton et al , 1994). Further, increasing amounts of POO in the oil blends reduced the degree of fatty acid unsaturation and, therefore, reduced the level of the PV from that of oil extracted from chips fried in SEO However, the potato chips fried in CSO had higher levels of PV (24 5 versus 20.7 meq peroxide/kg oil) than did those fried in the

20% POO blend even though the CSO contained lower amounts of unsaturated fatty acids (Table 1) Perhaps this was due to other factors that retarded oxidation

The PV progressively increased during storage (Appendix H), indicating occurrence of oxidation. Without consideration of the type of oil, potato chips stored in the dark oxidized at a much slower rate than did those stored under fluorescent light. After 3- and 6-wk storage in dark, the PV of chips increased from 2.9 to 4.9 and 13.4 meq peroxide/kg oil, respectively, while those of chips stored under light for 3 and 6 wk increased to 29.0 and 64.0 meq peroxide/kg oil, respectively. These results indicate that both autoxidation and photooxidation occurred in the potato chips during storage. The potato chips stored under light experienced photooxidation as well as autoxidation resulting in the greater increase in PV. According to Nawar (1996), singlet oxygen which is the active species involved in photooxidation can react 1500 times faster than triple oxygen with unsaturated fatty acids. The findings in the present study agreed with those reported by Lin (1993) who found similar trends in chips fried in different oils and stored in dark and light.

Fig. 9 and Appendix H present the PV of oils extracted from the chips fried in each oil and stored in dark or light 3 or 6 wk. All chips fried in different oils experienced oxidation during storage. The extent of oxidation, however, was dependent upon the type of oils and storage time and conditions When stored in the dark, the PV of potato chips fried in CSO or 20 and 40% POO did not significantly increase. The PV of the chips fried in SFO progressively increased during storage in the dark for 0 to 6 wk, but was only significant from that in fresh chips after 6-wk storage in the dark These findings agreed with Lin (1993) who reported that the PV of chips fried in CSO did not

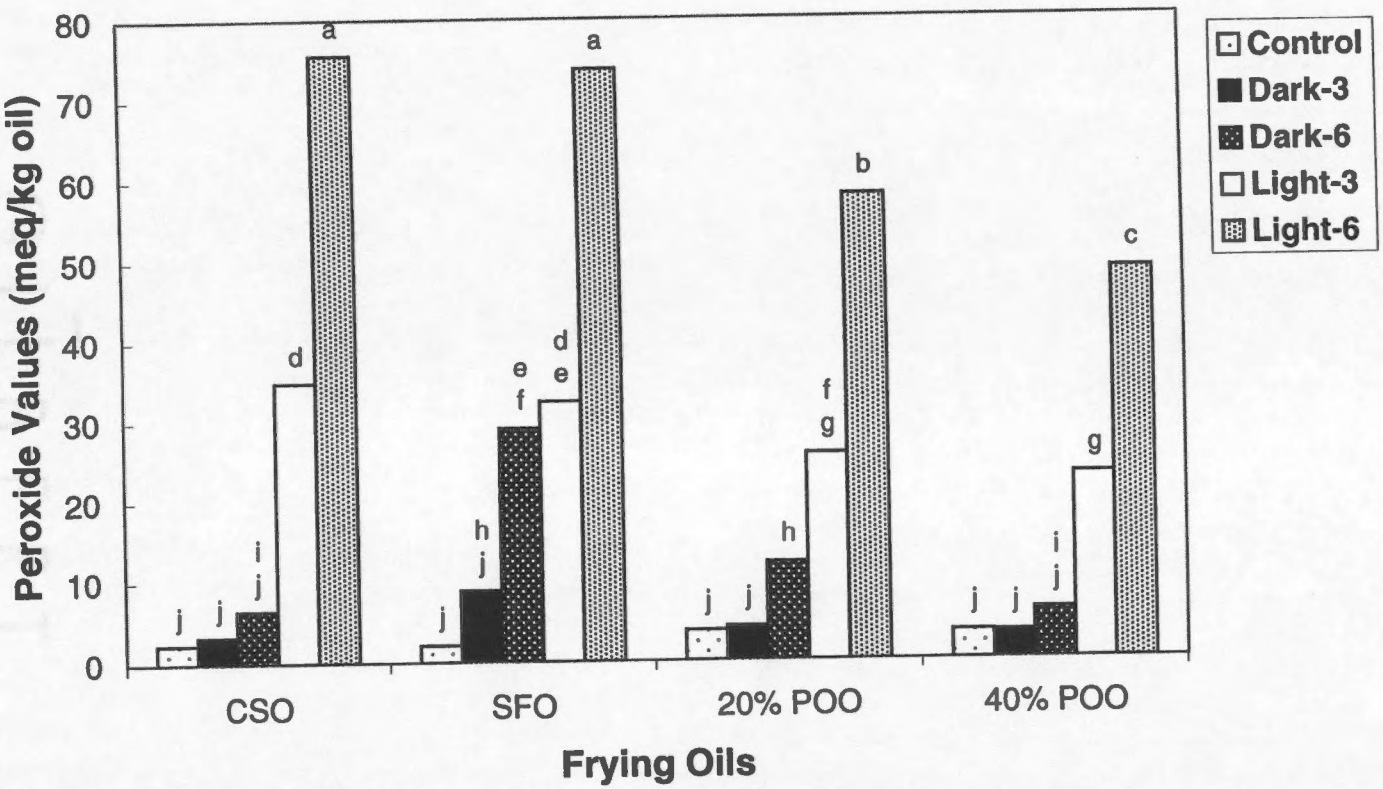

Fig. 9 -Least-squares means (N=3) of the peroxide values of oil extracted from potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored for 0 wk (control) or 3 or 6 wk in dark (dark-3, dark-6) or under light (light-3 and light-6); bars with unlike letters are different ($p<0.05$).

significantly change after 4-wk storage in the dark This researcher, however, found that the PV of chips fried in SFO significantly increased after 2-wk storage in dark Fig 9 shows that adding POO to SFO produced chips that were more stable during storage than those fried in SFO Addition of 40% POO to SFO produced chips that were as stable as those fried in CSO when they were stored in dark.

When stored under light, potato chips fried in CSO and SFO oxidized at the same rate, producing the same level of PV at 3- and 6-wk storage (Fig. 9). Under the same storage condition, the chips fried in the oil blends containing POO had lower levels of PV, showing they oxidized at slower rates The oxidation rate of chips stored in light decreased with increasing amount of POO in the frying oil At the end of 6-wk storage under light, the chips fried in the 40% POO blend contained the lowest level of PV compared to the chips fried in the other oils/blend and stored under the same conditions. This was probably due to the presence of β-carotene in POO that quenched singlet oxygen and reduced the photooxidation rate during storage under light. Crude palm oil contains high amount of carotenoids, mainly β-carotene (Basiron, 1996). Some of the carotene might remain in the oil after processing. According to Nawar (1996), β-carotene is one of the sensitive quenchers that prevent photooxidation of fat containing foods

Flavor Volatiles

Volatiles identified from the potato chips fried in different oils/blends and stored for up to 6 wk consisted of 10 known compounds and 7 unknowns (Table 6). The analyses of variance indicated that frying oils significantly affected concentrations of nonanal, benzaldehyde, trans-2-decenal and unknowns 2 and 7 (Table 6) Storage

Table 6 -- Least-squares means[ab] and standard errors (SE) of concentrations[c] of volatiles isolated from potato chips fried in four different oils averaged across storage treatments

Volatiles[d]	Retention Time (min)	Oils				SE
		Cottonseed	Sunflower	20% POO[e]	40% POO[e]	
		peak area				
Unknown 1	4 5	470 a	395 a	404 a	493 a	48
Hexanal	5.6	1548 a	1870 a	1899 a	2240 a	213
Unknown 2 **	6 2	8898 a	0 b	0 b	79 b	800
Unknown 3	7 5	180 a	99 a	8 a	186 a	96
Heptanal	7.8	60 a	84 a	120 a	137 a	27
Unknown 4	12 4	1419 a	1618 a	1582 a	1657 a	167
Nonanal **	13 4	706 bc	633 c	875 b	1116 a	184
2-Furaldehyde	15.3	674 a	661 a	675 a	752 a	70
Decanal	16 1	22 a	24 a	24 a	3 a	15
Benzaldehyde **	17 2	61 a	0 b	0 b	7 b	13
t,t,-2,4-Heptadienal	17.4	68 a	7 a	0 a	7 a	30
Unknown 5	17.7	111 a	82 a	115 a	104 a	31
t,2-Nonenal	18 2	85 a	71 a	114 a	119 a	24
t,2-Decenal **	21 1	374 c	402 c	539 b	739 a	40
Unknown 6	23 8	38 a	60 a	58 a	69 a	16
t,t-2,4-Decadienal	25.8	6176 a	7143 a	6969 a	7444 a	833
Unknown 7 **	27.0	257 b	349 a	362 a	396 a	37

[a] N = 15

[b] Least-squares mean concentrations in a row for any volatile followed by unlike letters are different ($p<0.05$).

[c] Expressed in peak areas from gas chromatographic analysis

[d] Volatiles followed by ** had significant F-values at $p<0.01$ for oil effect

[e] 20% and 40% POO are 20 and 40% (w/w) palm olein oil in sunflower oil, respectively

affected concentration of several of the volatiles, but not those of decanal, benzaldehyde, t,t-2,4-heptadienal, t,2-nonenal, t,2-decenal, t,t-2,4-decadienal and unknown 3 and 5 (Table 7). Oil x storage condition interaction only affected ($p<0.01$) concentration of unknown 2. However, all volatiles, except unknown 2, significantly affected by storage are presented in bar graphs (Figs 10-17) to show trends in volatile concentration for each oil/blend during storage of chips. The least-squares means of these volatiles for each oil/blend and storage time are presented in Appendix I

Least-squares means of concentrations of volatiles (in terms of GC peak areas) identified from potato chips fried in different oils are presented in Table 6 Basically, unknown 2 and appreciable amounts of benzaldehyde and t,t-2,4-heptadienal were found only in potato chips fried in CSO. Benzaldehyde and t,t-2,4-heptadienal are produced from oxidation of linolenic acid, C18 3, (deMan, 1999) which was found in appreciable amounts only in CSO (Table 1). Averaged across storage, potato chips fried in the 20 and 40% POO oil blends contained higher ($p<0.05$) levels of nonanal and t,2-decenal than the other oils The concentrations of the latter two compounds increased ($p<0.05$) with increasing amounts of POO in the blends. Nonanal and t,2-decenal are formed during oxidation of oleic acid (deMan, 1999) which had higher levels in the 20 and 40% POO blends than that in CSO and SFO (Table 1). The level of unknown 7 in the CSO fried chips was lower ($p<0.05$) than those in the chips fried in the other oils/blends which basically contained the volatile at the same levels ($p>0.05$). All potato chips fried in the four different oils/blends contained abundant and similar amounts of hexanal, unknown 4 and t,t-2,4-decadienal Hexanal and t,t-2,4-decadienal are formed during oxidation of linoleic acid (deMan, 1999), the most abundant fatty acid

Table 7 -- Least-squares means[ab] and standard errors (SE) of concentrations[c] of volatiles isolated from potato chips stored for 0 wk (control) or 3 or 6 wk in dark (dark-3 and dark-6) or under light (light-3 and light-6) averaged across frying oils[d]

Volatiles[e]	Storage					SE
	Control	Dark-3	Dark-6	Light-3	Light-6	
	peak area					
Unknown 1 **	199 c	238 c	434 b	466 b	866 a	52
Hexanal **	592 d	1048 cd	2228 b	1467 c	4112 a	239
Unknown 2 **	20 c	10 c	23 c	4419 b	6751 a	876
Unknown 3	196 a	138 a	75 a	65 a	119 a	105
Heptanal *	77 abc	46 c	162 a	70 bc	147 ab	30
Unknown 4 **	1565 b	1255 b	1353 b	1518 b	2155 a	175
Nonanal *	953 a	920 a	878 a	588 b	822 ab	188
2-Furaldehyde **	509 c	553 bc	757 b	580 bc	1056 a	78
Decanal	14 a	9 a	29 a	22 a	19 a	16
Benzaldehyde	12 a	23 a	0 a	19 a	31 a	13
t,t,-2,4-Heptadienal	53 a	0 a	0 a	33 a	19 a	30
Unknown 5	167 a	57 a	157 a	57 a	78 a	35
t,2-Nonenal	90 a	101 a	137 a	58 a	104 a	26
t,2-Decenal	492 a	496 a	600 a	453 a	427 a	45
Unknown 6 **	3 b	44 b	124 a	11 b	100 a	16
t,t-2,4-Decadienal	6799 a	7583 a	7241 a	6409 a	6633 a	894
Unknown 7 **	68 d	316 c	596 a	277 c	449 b	39

[a] N = 12

[b] Least-squares means concentration in a row for any volatile followed by unlike letters are different (p<0 05).

[c] Expressed in peak areas from gas chromatographic analysis.

[d] Frying oils consisted of cottonseed, sunflower and 20 and 40% (w/w) palm olein in sunflower oils

[e] Volatiles followed by ** and * had significant F-values at p<0 01 and p<0 05, respectively, for storage effect.

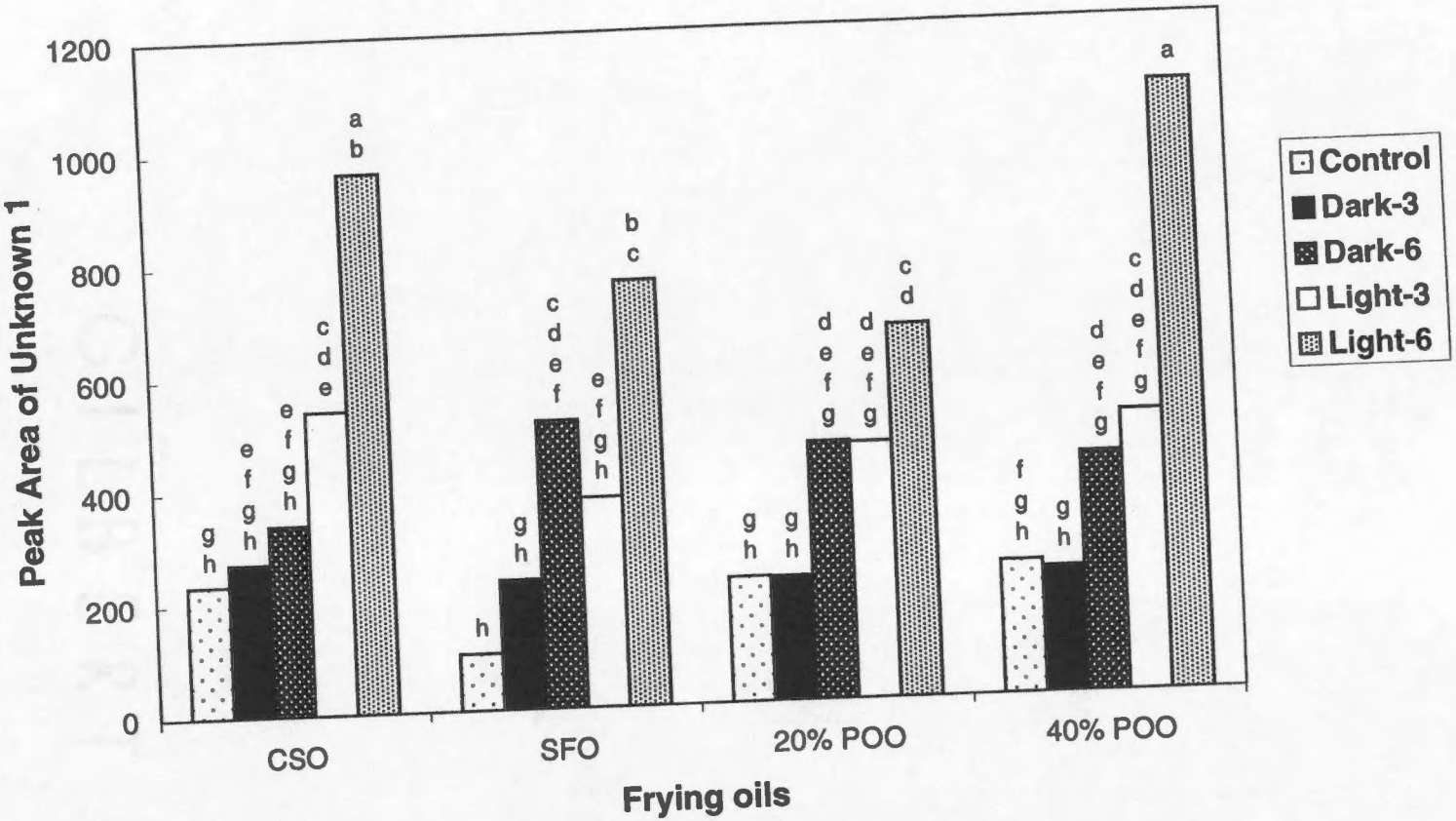

Fig. 10 - Least-squares means (N = 3) of the concentrations of unknown 1 in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

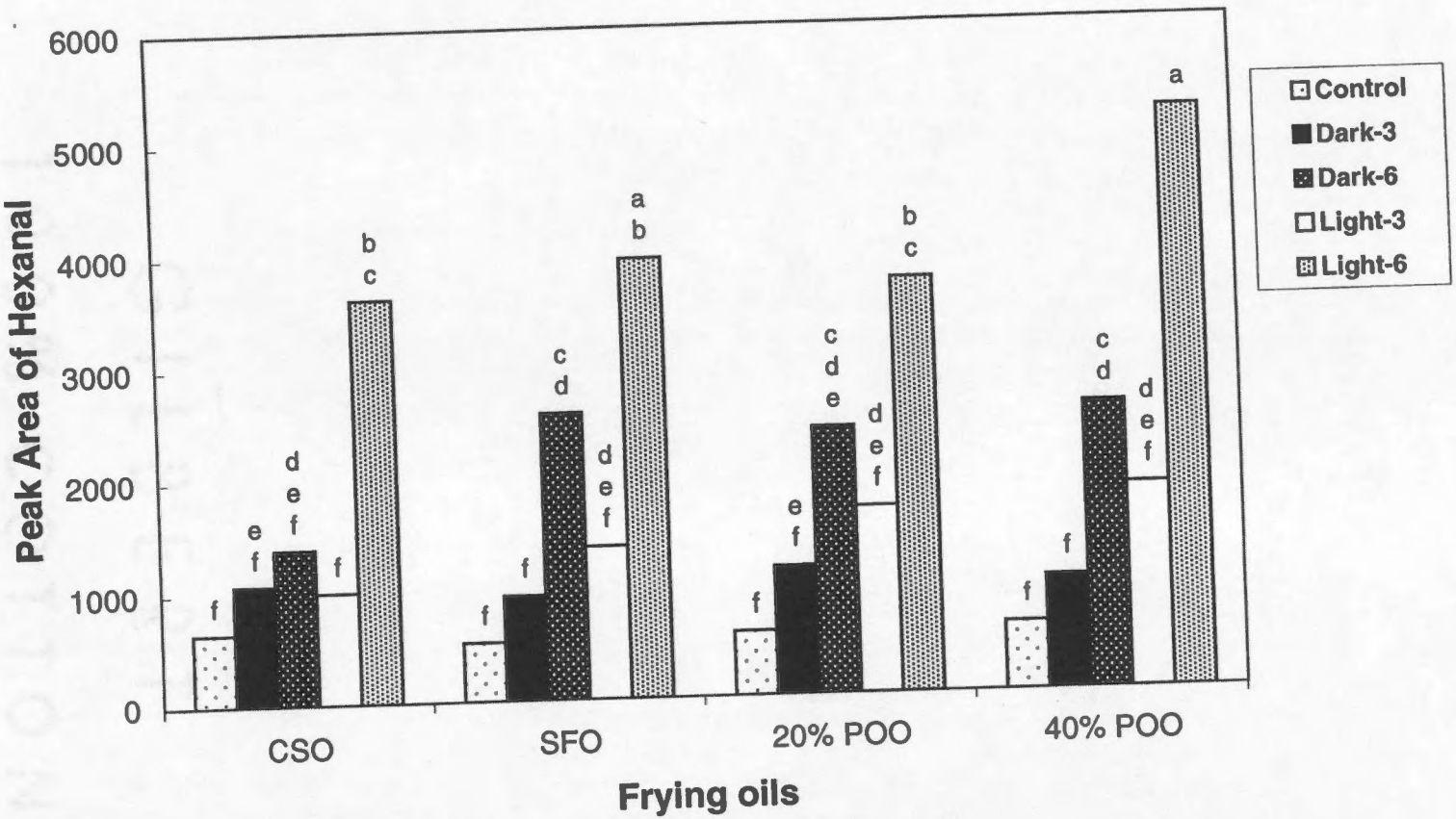

Fig. 11- Least-squares means (N = 3) of the concentrations of hexanal in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

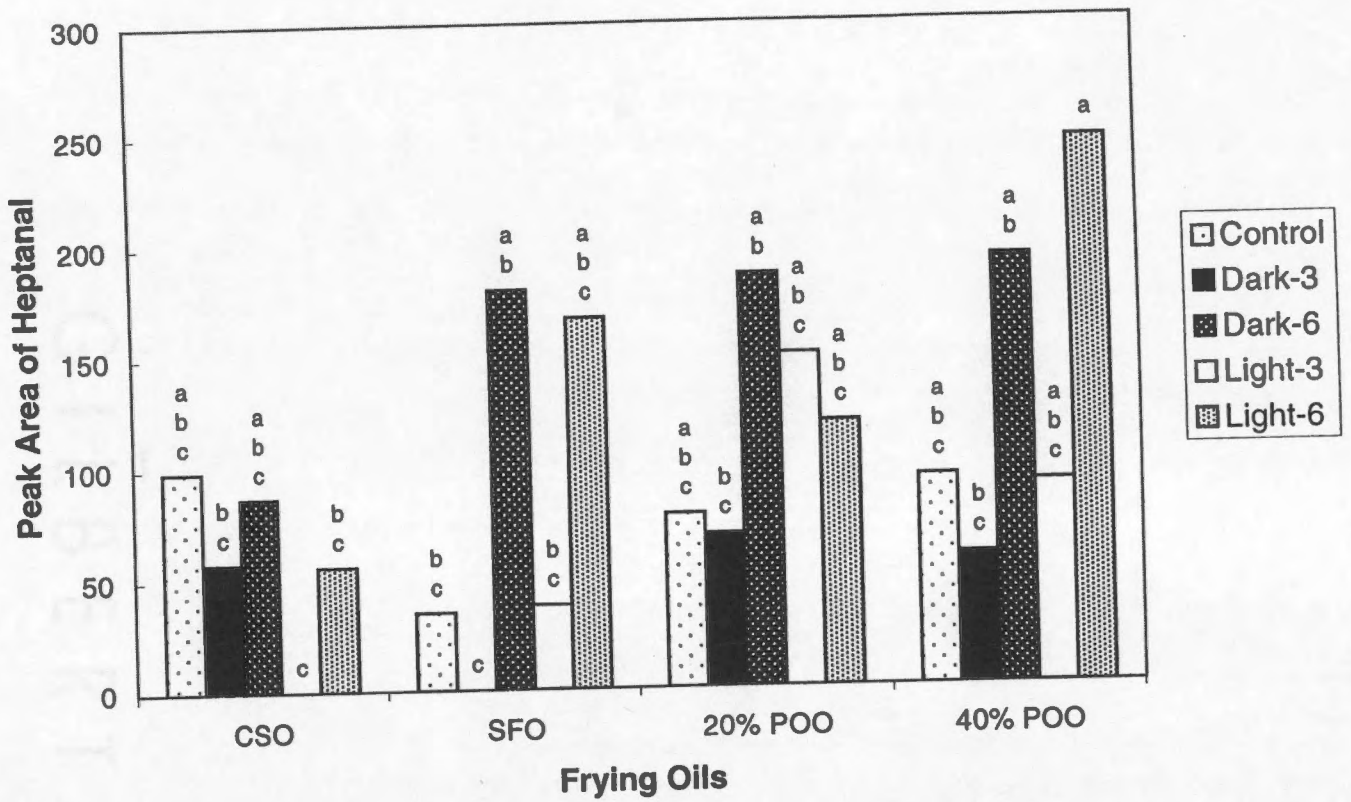

Fig. 12 - Least-squares means (N = 3) of the concentrations of heptanal in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

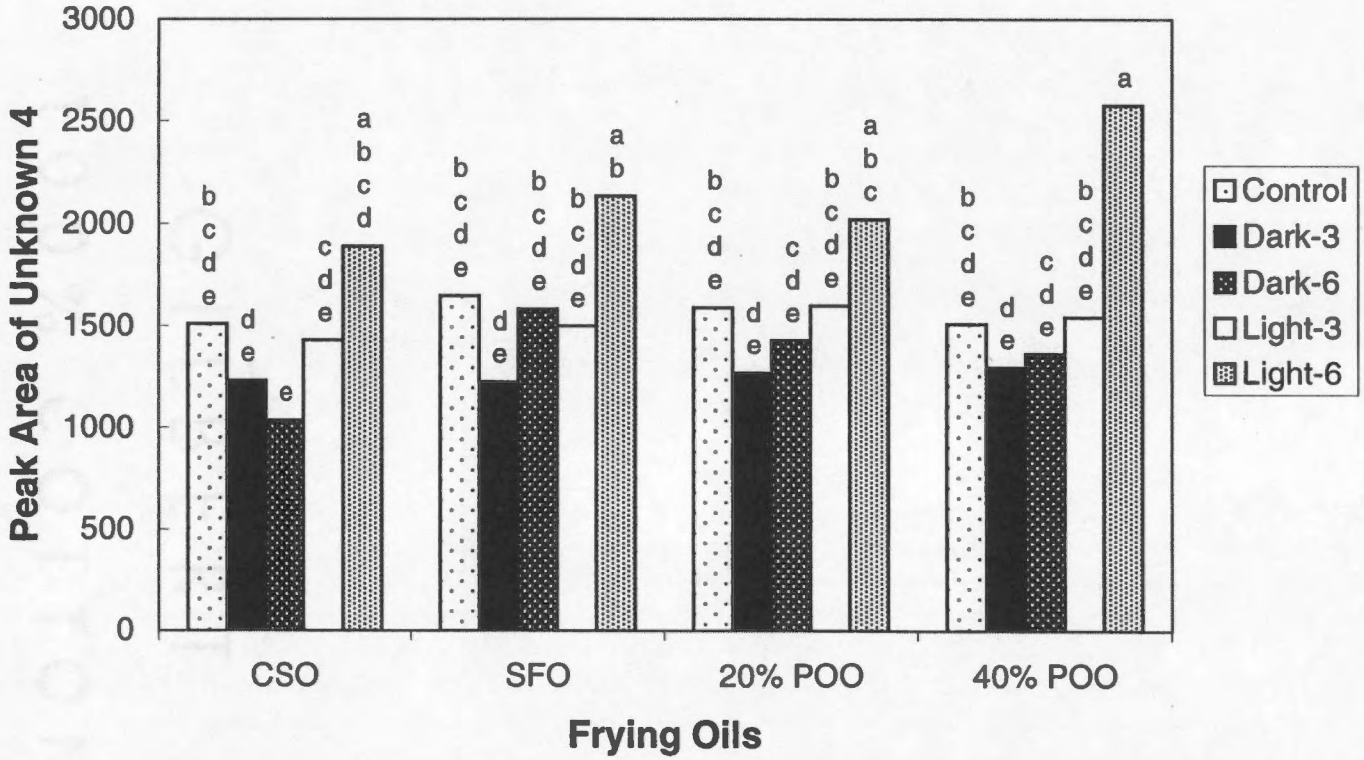

Fig. 13 - Least-squares means (N = 3) of the concentrations of unknown 4 in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

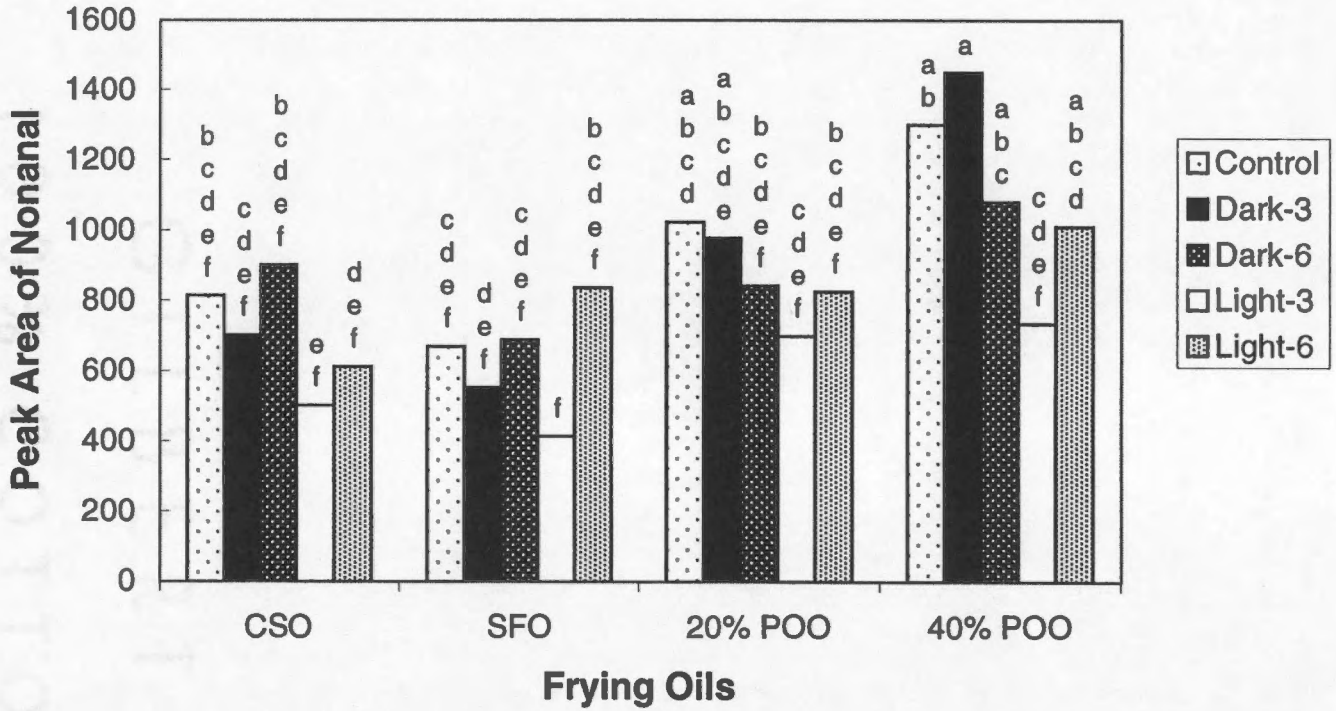

Fig.14 - Least-squares means (N = 3) of the concentrations of nonanal in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

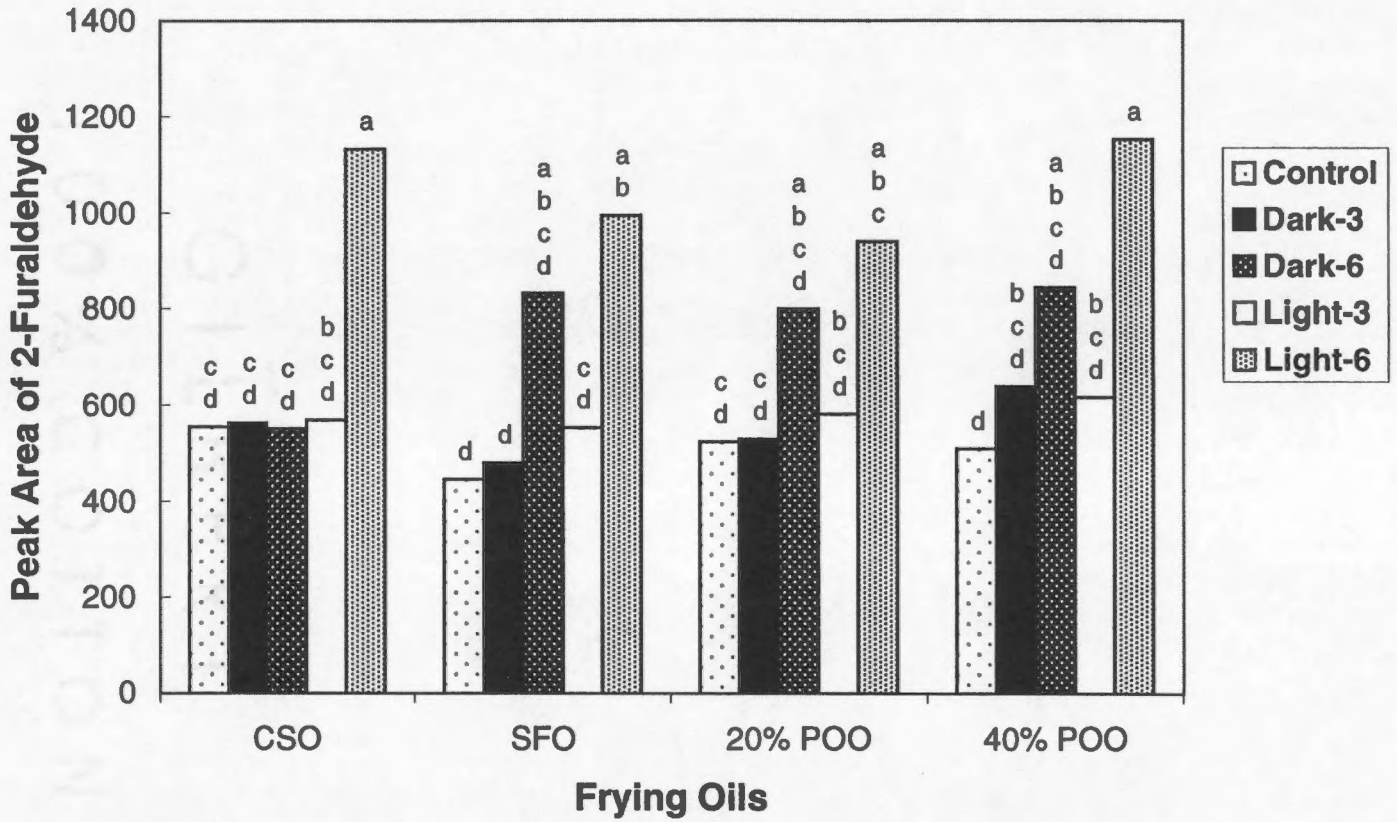

Fig. 15 - Least-squares means (N = 3) of the concentrations of 2-furaldehyde in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

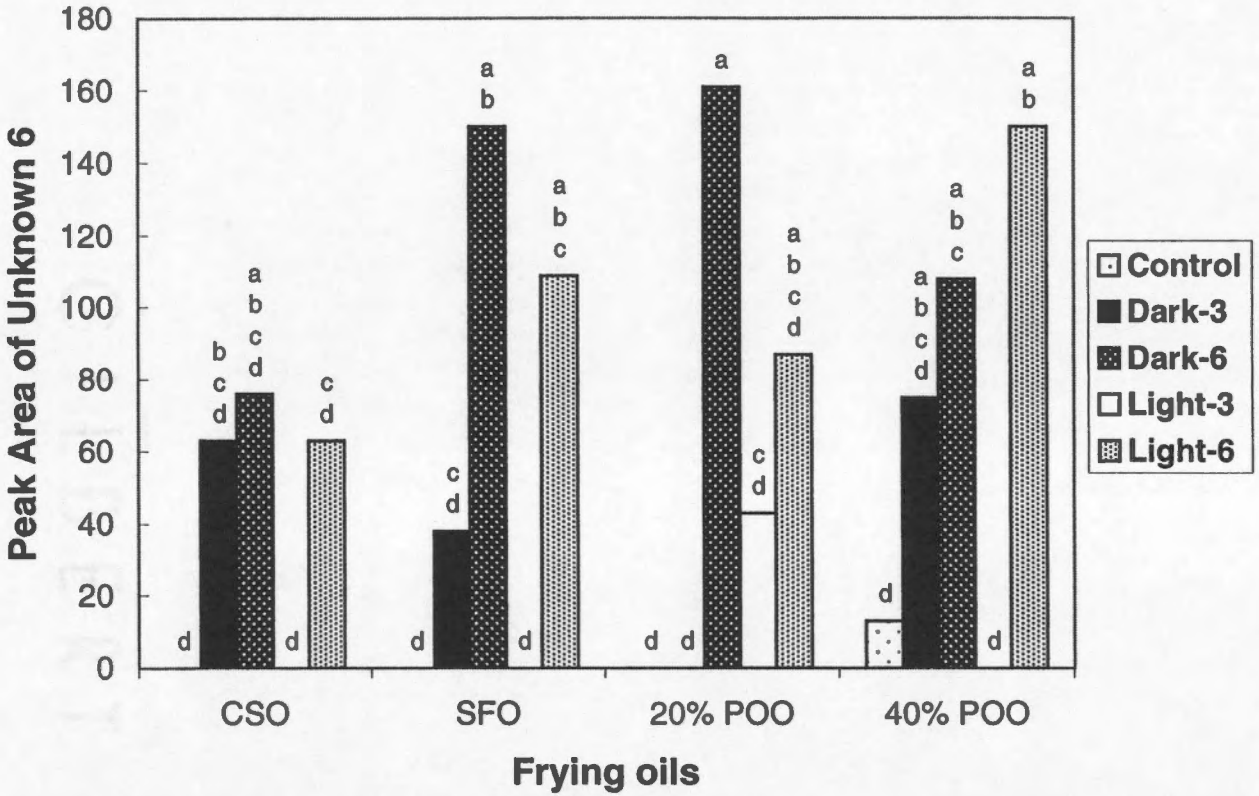

Fig. 16 - Least-squares means (N = 3) of the concentrations of unknown 6 in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

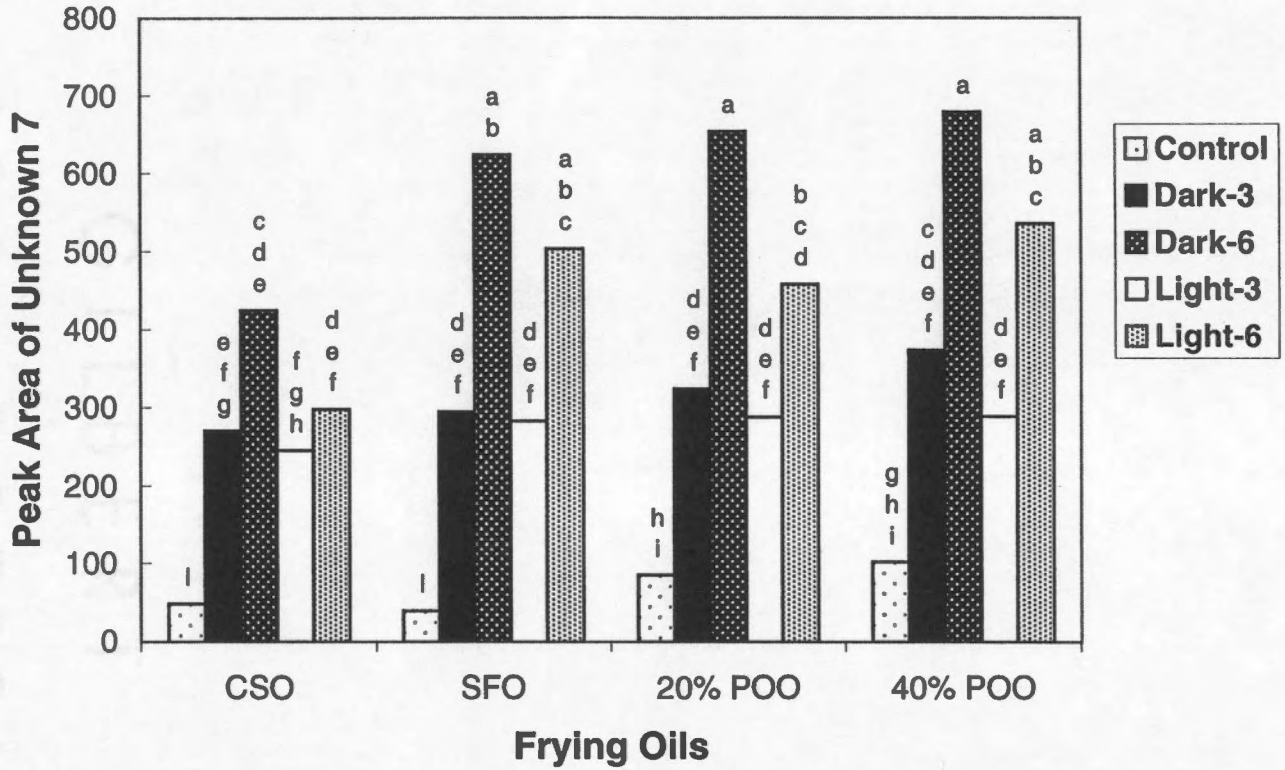

Fig. 17 - Least-squares means (N = 3) of the concentrations of unknown 7 in the head space of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

found in the frying oils (Table 1). The other volatiles such as heptanal, 2-furaldehyde, decanal, t,2-nonenal and unknown 1, 3, 5 and 6 were found in relatively small amounts. Heptanal and t,2-nonenal are oxidation products of C18 1 and C18:2, respectively, (Mookherjee et al., 1965). The volatile, 2-furaldehyde, can be formed by dehydration of a pentose and may be a Maillard reaction product of a sugar in the potato chips (Heath and Reineccius, 1986).

Least-squares means of concentration of volatiles identified from potato chips during storage up to 6 wk are presented in Table 7. All volatiles measured in control (fresh) chips either already existed in the frying oils due to thermal oxidation and were absorbed by the potato chips or were formed from reactions in the chips during frying. With the exception of 2-furaldehyde, the most abundant identified volatiles in the headspace of control chips were oxidation products of unsaturated fatty acids, oleic and linoleic acids, the most abundant fatty acids in the frying oils as discussed previously Generally, concentrations of volatiles that were significantly affected by storage changed at lower rates when the chips were stored in dark. This was due to the low rate of oxidation of oils in the chips stored in dark as evidenced by the PV presented in Fig. 9 and Appendix H. Hexanal progressively increased during storage. Heptanal level tended to decrease at 3-wk storage and then increased again by 6-wk storage either in dark or under light. The concentration of nonanal in chips was significantly lower at 3-wk storage under light than in fresh chips, but it tended to increase at 6-wk storage compared with 3-wk storage The volatile 2-furaldehyde increased in concentration steadily during storage of potato chips, but level increased faster in the chips stored under light, especially from 3- to 6-wk storage. Lin (1993) also reported the increase

level of 2-furaldehyde in potato chips during 4-wk storage. This researcher postulated that malonaldehyde, a lipid oxidation product, reacts with amino acids in potato chips to form 2-furaldehyde Thus, increasing concentration of malonaldehyde during storage of potato chips could have increased the level of 2-furaldehyde. The volatile t,t-2,4-decadienal that imparts desirable flavor to fresh potato chips (Pokorny, 1989) did not significantly change during 6-wk storage in the dark or under light. The latter results disagreed with those of Lin (1993) who reported that the volatile significantly increased after 4-wk storage of potato chips under light. Han (1989) reported that the level of t,t-2,4-decadienal significantly decreased after 4-wk storage of potato chips in dark, however, the decrease was not significant when potato chips were stored under light.

Volatiles from oxidation of oils during storage of the chips are being formed constantly, as well as, degrading and reacting with other volatiles. Only when the rate of formation is greater than the rate of disappearance due to their degradation and other reactions will the concentration of the volatile increase in the headspace of fried foods such as potato chips. This may explain the pattern of heptanal, nonanal and t,t-2,4-decadienal changes during storage.

During 6-wk storage of chips in the dark, the concentration of Unknown 1 did not change significantly, except for the chips fried in SFO (Fig. 10). When the chips were stored under light, the concentration of unknown 1 significantly increased in all chips by 6 wk, but at 3 wk, it was not significantly different from that of fresh chips except for those fried CSO.

The concentration of hexanal, an oxidation product of C18:2, did not significantly change during 3-wk storage in the dark of any of the chips but did increase by 6-wk

storage of all chips except those fried in CSO (Fig 11). When the chips were stored under light, the levels of hexanal increased at the same rate from 3- to 6-wk storage of all chips except those fried in the 40% POO blend. Chips fried in 40% POO increased at a higher rate in hexanal level than those fried in CSO or 20% POO. These changes may be due to different levels of natural antioxidants in the oils, as well as, different levels of polyunsaturated fatty acids. Analyses done by Shao (1999) showed that fresh CSO, SFO and 20% and 40% POO blends contained α–, γ–, and δ–tocopherols at total concentrations of 38.5, 69 3, 60.7 and 51.6 μg/g oil, respectively. However, these levels of antioxidants must be considered in view of the degree of unsaturated fatty acids in each oil/blend. SFO, which had the highest level of tocopherols and the highest concentration of C18·2 (Table 1), produced chips with one of the highest levels of hexanal after 6-wk storage in the light (Fig 11). Contrary to these results, the 40% POO blend which contained the lowest levels of C18 2 of all frying oils (Table 1) and one of the lower levels of total tocopherols produced chips with the highest level of hexanal after 6-wk storage in the light In addition, CSO with a higher level of C18 2 than 40% POO (Table 1), but a lower level of total tocopherols, produced chips which had one of the lower levels of hexanal after 6-wk storage in the light. However, CSO also contained higher levels of C18 3 than the other oils/blends (Table 1). C18.3 oxidizes at a much faster rate than C18·2, and the products produced could have interacted with hexanal resulting in its destruction. According to Heath and Reineccius (1986), hexanal is a secondary reaction product of lipid oxidation that can react to form other products Also, it should be noted that chips fried in CSO had a much higher level of PV at 6-wk storage under light than did those fried in 40% POO (Fig 9). Hexanal is a product of the

degradation of the fatty acid C18 2 hydroperoxide This PV difference possibly was related to the difference in hexanal concentration in chips fried in these oils and after 6-wk storage in the light.

Basically, unknown 2 volatile was found only in potato chips fried in CSO and after they were stored in light (Appendix I) The volatile increased in concentration rapidly during storage of CSO fried chips under light up to 6 wk Efforts are continuing to identify this unknown volatile.

Concentrations of heptanal in the potato chips fried in any oil/blend had only a few significant differences during 0- to 6-wk storage in the light or dark (Fig. 12). CSO-fried chips stored 3 wk in the light and SFO-fried chips stored 3 wk in the dark had lower levels ($p<0.05$) of heptanal than the chips fried in SFO or 20% POO and stored 6 wk in the dark or chips fried in 40% POO and stored 6 wk in the dark or light. The manner in which the headspace concentrations of heptanal changed across storage, however, was dependent upon the frying oil/blend. For example, when looking at chips stored in the light, heptanal had an increasing trend in concentration from control through 6-wk storage in chips fried in SFO or 40% POO but not in CSO or 20% POO (Fig 12) CSO-fried chips first appeared to decrease in heptanal concentration from 0- to 3-wk storage in light before increasing again from 3- to 6-wk, but the level of heptanal in the 6-wk light stored chips appeared to be less than that in the control CSO-fried chips Chips fried in 20% POO appeared to increase in heptanal level between 0- and 3-wk storage in the light and decrease between 3- and 6-wk storage (Fig. 12). Heptanal is an oxidation product of oleic acid (Mookherjee et al., 1965) which was an abundant fatty acid in the frying oils/blends used to fry potato chips (Table 1). The formation of heptanal is due to

unusual double bond shifts to form more stable compounds before or after hydroperoxide decomposition or to the presence of unknown precursors (Mookherjee et al., 1965) The formation of heptanal and other higher molecular weight carbonyls have been reported to be responsible for flavor changes of potato chips during storage (Dornseifer and Powers, 1965).

Volatile unknown 4 significantly increased in potato chips fried in 40% POO blend after 6-wk storage in the light (Fig. 14). However, this latter concentration was not different ($p>0.05$) from levels in chips which were fried in any of the other oils/blends and stored under identical conditions and time. Concentrations of unknown 4 across storage conditions had different trends among oils (Fig. 13). For example, the level of unknown 4 has a decreasing trend across 0- to 6-wk storage in the dark for chips fried in CSO, but this trend is not found in the chips fried in the other oils.

Nonanal, an oxidation production of C18 1 (deMan, 1999; Mooherjee et al , 1965), appeared to be more abundant in chips fried in 40% POO (Fig. 14). Chips fried in 40% POO and stored 3 wk in the dark had higher nonanal levels than in any chips fried in CSO or SFO Control chips fried in 40% POO had higher levels of nonanal than did CSO-fried chips stored in dark or light for 3 wk or in light for 6 wk or all of SFO-fried chips except those stored in the light for 6 wk (Fig 14) However, the nonanal concentration pattern across control and storage in dark differed between chips fried in 20% POO and those fried in 40% POO. Among chips fried in 20% POO, the control chips appeared to have the highest nonanal level, whereas, among chips fried in 40% POO, the chips stored for 3 wk in the dark appeared to have the highest level (Fig. 14)

Nonanal, which is an important flavor volatile reminiscent of orange flavor, is suspected to cause flavor changes in stored potato chips (Dornseifer and Power, 1965).

Chips fried in any oil and stored in the light for 6 wk appeared to have the higher levels of 2-furaldehyde (Fig. 15) In CSO-fried chips, 2-furaldehyde did not change much in concentration until after 6-wk storage in the light, whereas, in chips fried in the other oils there was a trend toward increasing levels of 2-furaldehyde with increasing storage time in dark or light.

The concentrations in peak area for volatile unknowns 6 and 7 are given for each storage treatment and each frying oil/blend in Figs. 16 and 17, respectively Unknown 7 was present at more abundant levels than unknown 6. Unknown 6 formed during storage in the dark in chips fried in all oils/blends, and, for the same length of storage, tended to have higher levels in chips stored in the dark than in the light, except for those fried in 20% POO and stored 3 wk and in 40% POO (Fig. 16) and stored 6 wk. This trend of dark stored chips having higher levels than light stored chips was also found for unknown 7, except it was true for chips fried in any oil/blend and stored either 3 or 6 wk (Fig 17). Also, for any one storage condition, chips fried in CSO tended to have lower levels of both unknown 6 and 7 than chips fried in the other oils/blends.

The volatile unknowns 1 through 7 need to be identified before their significance to chip flavor or oxidation during storage can be assessed Efforts are continuing to identify the more abundant of these volatiles

Sensory Properties

The analyses of variance indicated that types of frying oils (Table 8) and storage (Table 9) affected ($p<0.01$) all sensory attributes studied, except for the characteristic potato chip flavor. The oil x storage interaction affected oxidative rancidity ($p<0.05$) and off-flavors (0.01) of potato chips.

Averaged across storage conditions and time, color lightness of potato chips differed among oils/blends (Table 8). Panelists rated the color lightness of the potato chips fried in CSO, SFO or the 40% POO blend as the same. The potato chips fried in the 20% POO had the darkest color but not significantly different from that chips fried in SFO. Instrumental measurements using Agtron indicated that color lightness values were not significantly different among the fresh potato chips fried in the different frying oils (Table 5). There is a lack of agreement among researchers on the extent to which different frying oils affect chip color. It may depend upon whether color lightness is determined sensorially or instrumentally. Hawrysh et al. (1996) reported that panelists detected no differences in color intensity of potato chips fried in canola, partially hydrogenated canola, soybean and cottonseed oils during storage. On the other hand, Han (1989) found that potato chips fried in CSO were lighter than those fried in POO or soybean oil based on the Hunter *L* values. The results of the current study are different from those of Hawrysh et al. (1996) and Han (1989) in that instrumental analysis showed no significant differences in chip color lightness values among chips fried in different oils while sensory evaluation did show differences.

The intensities of the characteristic potato chip flavor of the chips fried in four different oils/blends were not different ($p<0.05$) when averaged across storage

Table 8 -- Least-squares means[ab] and standard errors (SE) for scores of sensory characteristics of potato chips fried in different oils averaged across panelists and storage conditions and times

Sensory attribute[c]	Oils				SE
	Cottonseed	Sunflower	20% POO[d]	40% POO[d]	
Color lightness[e] **	3 61 b	3 71 ab	3 86 a	3 57 b	0.29
Characteristic potato chip flavor[f]	4.84 a	4.97 a	5.05 a	4 95 a	0 24
Oxidative rancidity[f] **	4 60 a	3 95 bc	3 89 c	4 22 b	0 28
Off flavors[f] **	4 69 a	4 24 bc	4 10 c	4 44 ab	0 30

[a] N = 390
[b] Least-squares means in a row for any sensory attribute followed by unlike letters are different ($p<0.05$)
[c] Sensory attribute followed by ** had significant F-values at $p<0.01$ for oil effect
[d] 20 and 40% POO are 20 and 40% (w/w) palm olein oil in sunflower oil, respectively
[e] 1 = light; 9 = dark.
[f] 1 = not at all; 9 = intense.

Table 9 -- Least-squares means [ab] and standard errors (SE) of the scores for sensory characteristics of potato chips stored for 0 wk (control), 3 or 6 wk in dark (dark-3 or dark-6) or light (light-3 or light-6) and averaged across panelists[c] and frying oils[d]

Sensory attribute[e]	Storage					SE
	Control	Dark-3	Dark-6	Light-3	Light-6	
Color lightness [f] **	4.00 a	3 89 a	3.86 a	3.30 b	3 39 ab	0 29
Characteristic potato chip flavor [g]	5.11 a	5.00 a	4 93 a	4.94 a	4.78 a	0 26
Oxidative rancidity [g] **	3 98 b	3.90 b	3 98 b	4 21 b	4 77 a	0.28
Off flavors [fg] **	4.25 bc	4 15 c	4.17 bc	4.49 ab	4.79 a	0 31

[a] N = 312
[b] Least-squares means in a row for any sensory attribute followed by unlike letters are different ($p<0.05$).
[c] Potato chips were evaluated by 26 panelists
[d] Frying oils consisted of cottonseed, sunflower and 20 and 40% (w/w) palm olein in sunflower.
[e] Sensory attribute followed by ** had significant F-values at $p<0.01$ for storage effect
[f] 1 = light, 9 = dark.
[g] 1 = not at all, 9 = intense.

conditions and times (Table 8). Panelists rated the characteristic potato chip flavor of all the samples the midway of "not at all" to "intense" range categories These results agree with results found for levels of t,t-2,4-decadienal in the potato chips (Table 6) which also were not different among the frying oils when averaged across storage conditions and times. The volatile t,t-2,4-decadienal imparts desirable flavor in potato chips and other fried foods (Mookherjee et al , 1965, Pokorny, 1989) According to Deck et al. (1973), 2,5-dimethyl pyrazine formed through Maillard reaction also imparts strong characteristic potato chip flavor; however, this volatile was not identified in the headspace of any of the potato chips.

When averaged across storage conditions and times, the intensity of oxidative rancidity of potato chips was significantly different among the frying oils (Table 8). Potato chips fried in CSO had the most intense oxidative rancidity. This more intense oxidative rancidity may have been due to the significantly higher amount of C18:3 in CSO (Table 1) and the lowest level of tocopherols (Shao, 1999) when compared to the other oils/blends. The higher the degree of unsaturation, the more susceptible the fatty acids to the oxidation (Melton et al., 1994). Warner et al. (1994) reported that the quality score of potato chips decreased with increasing levels of C18:3 in frying oils. Panelists rated the intensity of the oxidative rancidity of the chips fried in SFO similar ($p>0.05$) to that of potato chips fried in the oil blends. Unexpectedly, however, the potato chips fried in the 40% POO blend were more rancid than those fried in the 20% POO blend. The 40% POO blend contained the lowest level of PUFA (Table 1) but it also contained lower levels of tocopherols than the 20% POO blend (51.6 versus 60.7 µg/ g oil) as determined by Shao (1999). Overall, the oxidative rancidity scores of the

potato chips ranged from 3.89 to 4 60. Thus, panelists rated the intensity of the oxidative rancidity of the potato chips just below the midway of the 9-point scales that ranged from "not at all" rancid (1) to "intense" rancid (9)

The off-flavors of potato chips fried in CSO were more intense ($p<0.05$) than were those fried in SFO or the 20% POO blend, but were similar in intensity to that of chips fried in the 40% POO blend (Table 8) Intensities of off-flavors detected in the chips fried in SFO were similar to that of chips fried in the 20% POO blend. Generally, the intensities of the off-flavors of potato chips fried in different oils/blends reflected the same pattern as the intensities of the oxidative rancidity (Table 8). Off-flavors detected in potato chips were due to the formation of hexanal and pentanal (Jeon and Bassette, 1984). Warner et al (1994) also reported that fishy flavor in potato chips was due to the presence of C18:3 in frying oil at level of 3% or above

During storage, the scores for the color lightness of potato chips tended to decrease (Table 9), thus the color of the potato chips became lighter. However, the color lightness did not significantly change when the potato chips were stored in dark up to 6 wk. The rate of color change increased when the potato chips were stored under light. The color lightness scores of the potato chips significantly decreased after 3-wk storage under light, but remained unchanged up to 6-wk storage These findings may be due to the deterioration of color pigments in the potato chips by oxidation during storage. Contrary to these results, Han (1989) reported that the lightness (Hunter *L* values) of potato chips fried in CSO, soybean oil and POO did not significantly change during 4-wk storage in dark or under light.

The intensity of characteristic potato chip flavor tended to decrease during storage either in dark or under light, but it was not significant (Table 9). These results may be because of the lack of change ($p>0.05$) in t,t-2,4-decadienal contents of the potato chips during storage (Table 7). As previously stated, this particular aldehyde imparts acceptable flavor to fried foods such as chips (Pokorny, 1989) Hawrysh et al. (1996) reported that the intensity of characteristic potato chip flavor of chips fried in different oils significantly decreased after 6-da storage at 60°C in a modified Schaal Oven Test or after 18-wk storage in dark at ambient temperature

Averaged across frying oils, the intensity of the oxidative rancidity of the potato chips did not change during 6-wk storage in dark (Table 9) Panelists rated the oxidative rancidity of the fresh potato chips just below the midpoint of the 9-point scales of the descriptive analysis The oxidative rancidity detected in the fresh potato chips may have come from thermally oxidized oil during frying which was absorbed by the potato chips. When the potato chips were stored under light, the intensity of the oxidative rancidity steadily increased from 0- to 6-wk storage, but it was significantly greater only after 6-wk storage. The levels of peroxide values in these same chips also increased at a high rate when the potato chips were stored under light (Appendix H). These results for oxidative rancidity agreed with those reported by Kubiak et al. (1982). They found that the oxidative flavor intensity of potato chips stored in light barrier pouches was stable during 10-wk storage at ambient temperature, but potato chips stored in the clear pouches oxidized rapidly

Off-flavors intensity scores of the potato chips had the same pattern as the intensity scores of oxidative rancidity across storage (Table 9) The intensity of the off-

flavors did not change significantly when potato chips were stored in dark. Storage of the potato chips under light, however, induced the development of the off-flavors steadily the intensity of which became significantly greater by 6-wk storage. Hawrysh et al. (1996) also found development of off-flavors in potato chips after 6-da storage at 60°C or 18-wk in dark at ambient temperature Off-flavors in potato chips are caused by increased levels of pentanal and hexanal according to Jeon and Bassette (1984) The concentrations of hexanal in potato chips of the current study did increase ($p<0.05$) during 0- to 6-wk storage in the dark, but at a greater rate when stored under light (Table 7). Perhaps, these increased levels of hexanal in the chips stored in the light did contribute to the increased intensity of the off-flavors in the chips.

Fig 18 and Appendix J present the color lightness scores of the potato chips fried in each oil and stored in dark or under light for 3 and 6 wk. With the exception of the scores of potato chips fried in SFO, the color lightness scores of all potato chips did not change significantly during 6-wk storage in the dark, but significantly decreased when the potato chips were stored under light for 3 wk and remained unchanged until 6-wk storage. Thus, panelists generally scored potato chips stored under light for 3 and 6 wk as lighter than fresh potato chips or those stored in dark The color lightness scores of potato chips fried in SFO significantly decreased after 3-wk storage under light, but after 6-wk storage under light scores were at a similar level as those of fresh potato chips or chips fried in other oils and stored in the dark However, the trend still existed for light-stored, SFO-fried chips to have lighter color than control or dark-stored, SFO-fried chips. Perhaps, since light increased oxidation in chips compared to control or those stored in the dark (Fig 9), the oxidation also caused bleaching of the potato chips

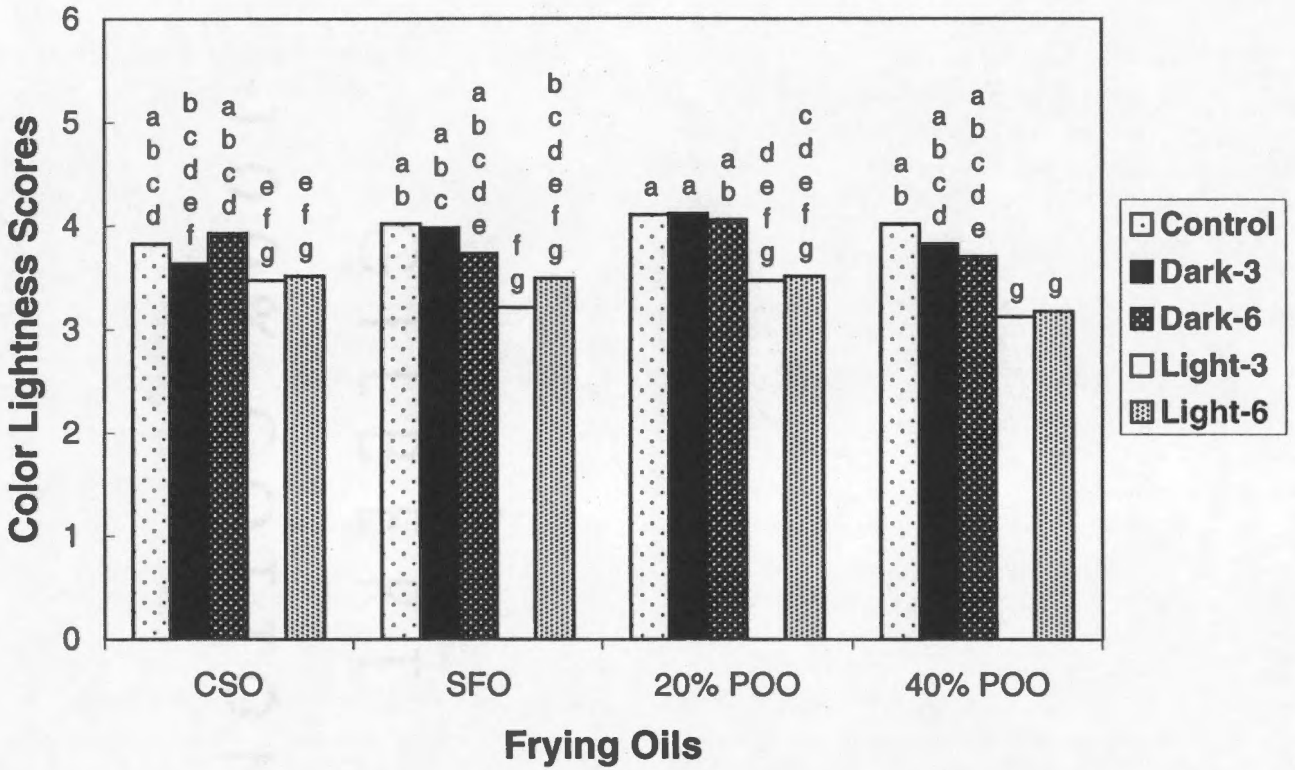

Fig. 18 - Least-squares means (N = 78) of the color lightness scores (1 = light, 9 = dark) of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

Development of oxidative rancidity in potato chips during storage was dependent upon frying oils and storage conditions (Fig. 19 and Appendix J). With the exception of chips fried in the CSO or the 40% POO blend, storage of potato chips fried in the other oils did not affect ($p>0.05$) the oxidative rancidity The potato chips that had the most intense oxidative rancidity flavor were those fried in CSO and stored under light for 6 wk. The significant increase in oxidative rancidity of potato chips fried in CSO may have been due to the significantly high amounts of C18:3 (Table 1) and low level of the total tocopherols in CSO as discussed earlier Also, the peroxide values (35 to 78 meq/kg oil) of chips fried in CSO and stored 3 and 6 wk in the light (Fig 9) indicated that significant oxidation occurred during storage Peroxides, which are primary, unstable products of oxidation, degrade to form volatile compounds and the headspace volatile compounds from the chips were analyzed. In the CSO-fried, light-stored chips, oxidation also produced significant amounts of hexanal (Fig. 11) and unknown 2 volatile (Appendix I) and one of the higher levels of 2-furaldehyde (Fig 15) Unknown 2 was not found in any of the other chips in this experiment at significant concentration, and efforts to identify this volatile are continuing The extent to which this volatile contributed to the higher levels of oxidative rancidity in these chips has not been assessed.

The intensity of off-flavors significantly increased mainly in potato chips fried in CSO and stored for 3 or 6 wk under light (Fig. 20 and Appendix J). Basically, storage did not affect ($p>0$ 05) the off-flavors of chips fried in SFO and the 20 and 40% POO blends. The intensity of off-flavors of chips fried in the 40% POO blend only increased ($p<0$ 05) after 3-wk storage in the light, but it decreased to the level similar to that of control chips after 6-wk storage in the light Panelists detected the most intense off-

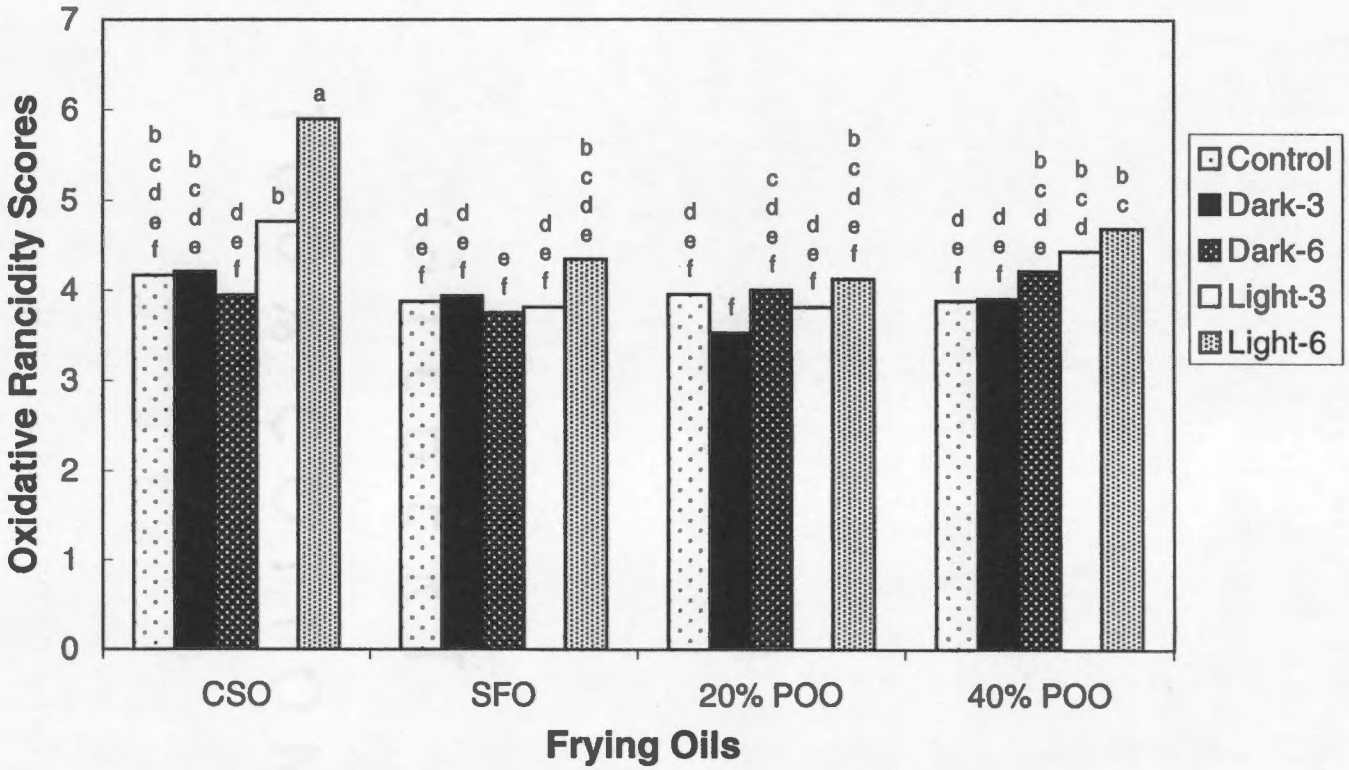

Fig. 19 -Least-squares means (N = 78) of the oxidative rancidity scores (1 = not at all, 9 = intense) of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

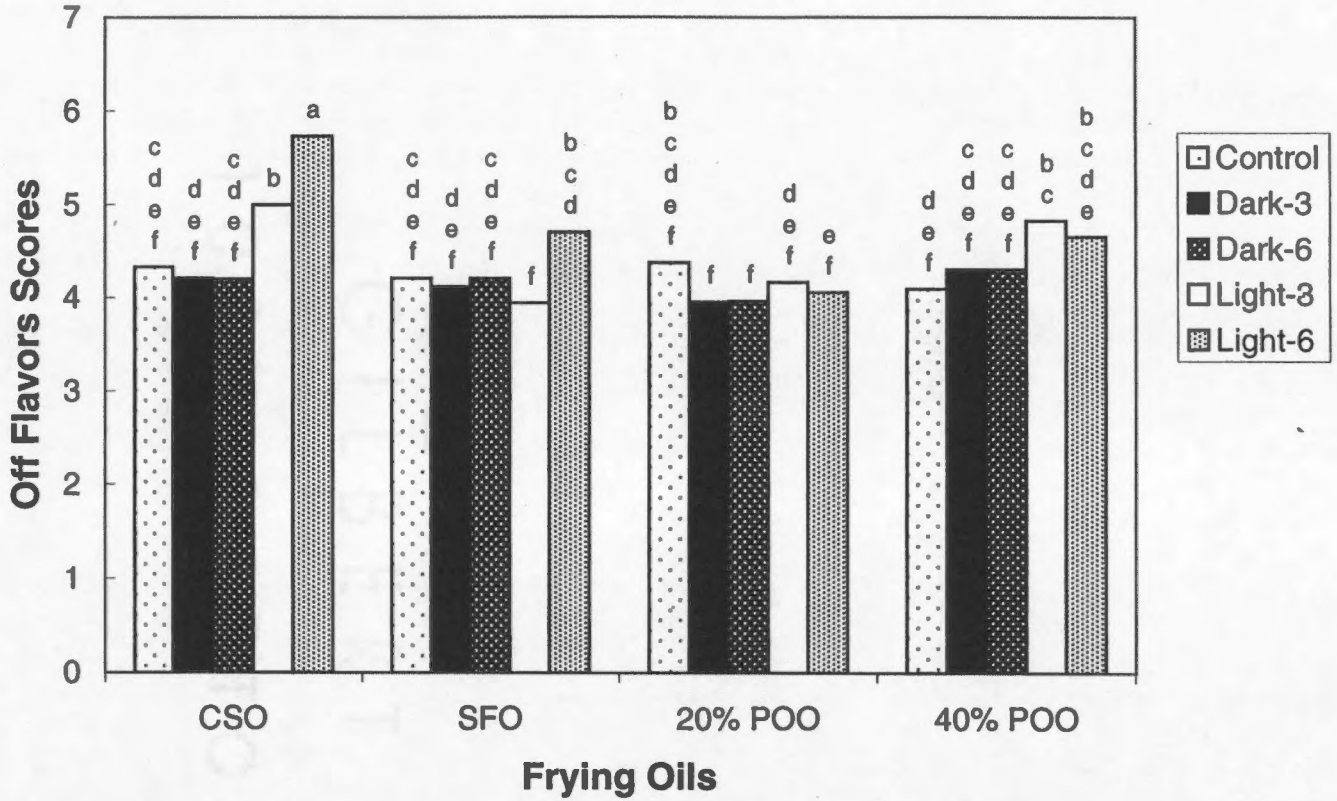

Fig. 20 - Least-squares means (N = 78) of the off-flavors scores (1 = not at all, 9 = intense) of potato chips fried in different oils (CSO = cottonseed, SFO = sunflower and 20 and 40% POO = 20 and 40%, w/w, palm olein in sunflower oil) and stored 0 wk (control) or 3 and 6 wk in dark (dark-3 or dark-6) or under light (light-3 or light-6); bars with unlike letters are different ($p<0.05$).

flavors in the chips fried in CSO and stored under light for 6 wk After storage under light for 3 or 6 wk, unknown 2 volatile compound was found in chips fried in CSO but not found in any other samples (Appendix I). Thus, the most intense off-flavors detected in the CSO fried chips may have been due to this unknown volatile. These off-flavors or an increase in such an unknown 2 volatile of CSO-fried chips stored in the light were not found by other researchers using SCO from the same source earlier to fry potato chips (Han, 1989; Lin, 1993).

CHAPTER V

SUMMARY

The objectives of this study were (1) to determine the degradation of cottonseed oil (CSO) and regular sunflower oil (SFO) and 20 and 40% palm oil olein (POO) blends with SFO during break-in heating and 5-hr frying of potato slices and (2) to determine the quality and flavor stability of the fried potato chips during storage The purpose of adding POO to SFO was to improve the stability of the highly polyunsaturated SFO during frying and to improve the flavor of chips fried in SFO during storage with altering the flavor of the fresh SFO-fried chips CSO, the oil of choice for producing potato chips in the southeastern U.S., served as a control.

Addition of 20 and 40% POO to SFO decreased the unsaturation of SFO to be closer to that of CSO. The predominant polyunsaturated fatty acid in all oils/blends was linoleic acid (C18:2); the concentration of C18 2 in SFO was 65 8% compared with 51 7, 54 6 and 43.3% in CSO, 20% POO and 40% POO, respectively. Based on C18:2 concentrations of the respective oils used in this study, addition of 25 2% POO to SFO would give the same C18 2 concentration present in the CSO.

During 3-hr break-in heating and 5-hr frying of potato slices, all oils/blends increased in levels of degradation measurements, including total polar components (TPC) and free fatty acids (FFA) levels. However, the average contents of TPC (15.9%) and FFA (0.07%) at the end of frying indicate that all oils/blends were still in excellent condition for producing potato chips During break-in heating and frying, the levels of TPC increased by the greatest amount in SFO Addition of 20 or 40% POO to SFO decreased the rate of TPC formation to be similar to that of CSO. These results indicate

that addition of POO increased the stability of SFO to that of CSO during production of the potato chips.

Storage in the dark up to 6 wk increased ($p<0.05$) the peroxide values (PV) in SFO-fried chips the most but did not increase ($p>0.05$) PV in CSO- or 40% POO-fried chips. Also, during storage in the dark, the rate of PV increase was decreased in 20% POO-fried chips compared with that of SFO-fried chips. While the rate of PV increase was greatest in both CSO-fried and SFO-fried chips during 6-wk storage in the light, the rate was decreased ($p<0.05$) progressively by addition of 20 and 40% POO to SFO Addition of POO to SFO increased stability of potato chips to be the same as that of CSO-fried chips during storage in the dark and to be greater than that of CSO-fried chips during storage in the light.

Seventeen volatile compounds, ten of which were identified, were isolated from the headspace of the potato chips by solid phase microextraction. Hexanal was the only known volatile to increase ($p<0.05$%) in concentration progressively during light or dark storage from 0 to 6 wk. However, 2-furaldehyde had maximum concentration ($p<0.05$) in chips fried in any oil/blend by 6-wk storage in the light An unknown volatile, with a retention time close to that of hexanal, was found in significant amounts only in CSO-fried chips stored in light for 3 or 6 wk The level of a desirable fried flavor volatile, t,t,-2,4-decadienal, did not differ ($p>0.05$) in the headspace of chips fried in the different oils/blends and remained the same throughout their storage in the light or dark

Characteristic potato chip flavor did not change ($p>0.05$) in intensity during 0- to 6-wk storage in dark or light in chips fried in any oil/blend Oxidative rancidity increased ($p<0.05$) in intensity only in CSO fried chips after 3- and 6-wk storage in the light, but did

not change in any of the other chips during storage Off-flavors also increased ($p<0.05$) in intensity in CSO-fried chips after 3- and 6-wk storage in the light and were significantly lower in intensity after 6-wk storage in the light in 20% POO-fried chips than in SFO-fried chips.

Results of this study indicate that addition of at least 20% POO to SFO can produce a more stable oil during limited frying and a chip more stable to oxidation during storage than SFO-fried chips. It is especially important to note that the stability was increased without any change in the intensity of the characteristic potato chip flavor, and at the 20% POO level, without loss of polyunsaturation compared to CSO. These results indicate snack food processors could replace CSO or SFO with a 20% POO blend with SFO, perhaps at a savings since POO is a low-cost oil, and produce chips with as high quality and flavor but more stability. However, more research is needed to test the stability of SFO versus the POO blends during a longer frying period, and to determine the acceptability of fresh and stored chips fried in the different oils/blends.

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Appendices

Appendix A – Instructions to familiarize panelists with the properties of fresh and oxidized potato chips at the beginning of each session of sensory evaluation

Please smell/taste the two references in front of you to recognize characteristics fresh potato chip and oxidized potato chips flavors One of these references is marked "fresh" and the other one "oxidized."

After evaluating the references, open the hatch and you will be given your first sample. A total of four samples will be presented in this session

Thank you for participating in this sensory panel. Treats are in the laboratory today.

Appendix B – Sensory score card for descriptive analysis of potato chips

Potato Chip Score Card

Judge: _____ Order _____ Sample _____

You will receive 4 (four) samples in this session one at a time. Please evaluate the color of each sample of chips for color lightness by checking the box that best describes this color characteristic. After color evaluation, taste the chips and evaluate the flavor characteristics listed by marking the intensity of each characteristic in the appropriate box. You may expectorate in the cup provided, but please rinse your mouth with water between tasting samples.

Color lightness

Light ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ dark

Flavor

Characteristic potato chip

Not at all ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ intense

Oxidative rancidity

Not at all ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ intense

Off flavors:

Not at all ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ intense

Comments _____

_____

_____

Appendix C – Least-Squares means[a] for fatty acids C18:1 and C18:2 affected by the oil x heating/frying time interaction

---------- _ADJUST_=LSD(05) BYGROUP=18 Effect=OIL*SAMP ----------

FA[b]	OIL[c]	SAMP[d]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
181	1	0	20 56666667	0 20766560	30	99.04	0 0001	G
181	1	1	19.70000000	0.20766560	30	94.86	0 0001	I
181	1	2	19.93333333	0.20766560	30	95 99	0 0001	HI
181	1	3	20.36666667	0 20766560	30	98 07	0 0001	GH
181	2	0	21.63333333	0.20766560	30	104 17	0 0001	F
181	2	1	21.96666667	0.20766560	30	105 78	0 0001	EF
181	2	2	22.30000000	0 20766560	30	107 38	0.0001	E
181	2	3	22 43333333	0 20766560	30	108 03	0 0001	E
181	3	0	26 00000000	0 20766560	30	125.20	0 0001	D
181	3	1	26 30000000	0 20766560	30	126.65	0 0001	CD
181	3	2	26.56666667	0 20766560	30	127.93	0 0001	CD
181	3	3	26 80000000	0.20766560	30	129 05	0 0001	C
181	4	0	29.90000000	0.20766560	30	143 98	0 0001	B
181	4	1	30 36666667	0.20766560	30	146 23	0 0001	AB
181	4	2	30.80000000	0 20766560	30	148 32	0 0001	A
181	4	3	30.93333333	0 20766560	30	148 96	0 0001	A

---------- _ADJUST_=LSD(.05) BYGROUP=21 Effect=OIL*SAMP ----------

FA	OIL	SAMP	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
182	1	0	56.36666667	1.23667902	30	45.58	0 0001	B
182	1	1	50.66666667	1.23667902	30	40 97	0 0001	CD
182	1	2	50.10000000	1.23667902	30	40 51	0.0001	D
182	1	3	49 60000000	1 23667902	30	40.11	0 0001	D
182	2	0	66.46666667	1 23667902	30	53.75	0 0001	A
182	2	1	66.03333333	1.23667902	30	53 40	0.0001	A
182	2	2	65.36666667	1.23667902	30	52 86	0.0001	A
182	2	3	65 23333333	1 23667902	30	52.75	0 0001	A
182	3	0	55 50000000	1 23667902	30	44.88	0 0001	B
182	3	1	54 76666667	1 23667902	30	44 29	0.0001	B
182	3	2	54 33333333	1.23667902	30	43 93	0.0001	B
182	3	3	53 73333333	1 23667902	30	43 45	0 0001	BC
182	4	0	44 43333333	1.23667902	30	35.93	0 0001	E
182	4	1	43 53333333	1 23667902	30	35 20	0 0001	E
182	4	2	42.80000000	1 23667902	30	34.61	0.0001	E
182	4	3	42 53333333	1.23667902	30	34.39	0 0001	E

[a] Least-Squares means of the same fatty acid followed by unlike letters at the end of the row are different (p<0 05).

[b] FA 181 and 182 = C18 1 and C18.2, respectively

[c] Oil 1, 2, 3, and 4 = cottonseed, sunflower, and 20 and 40% palm olein oil in sunflower oil

[d] Samp 0, 1, 2, 3 = sampling while fresh, after heating at 163°C for 3 hr prior to frying, after frying 2 5 hr, and after frying 5 hr, respectively

Appendix D – Least-squares means[a] of total polar compounds (TPC) contents affected by the oil x heating/frying time interaction

------- _ADJUST_=LSD(05) BYGROUP=3 Effect=OIL*SAMP -------

OIL[b]	SAMP[c]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	0	7 03000000	0.22541904	76	31.19	0.0001	K
1	1	11 05333333	0.22541904	76	49.03	0.0001	G
1	2	14 20666667	0.22541904	76	63.02	0 0001	D
1	3	17.02000000	0.22541904	76	75.50	0.0001	A
2	0	3.02333333	0.22541904	76	13.41	0.0001	M
2	1	8 52500000	0 22541904	76	37.82	0.0001	J
2	2	12.14377967	0.24528582	76	49.51	0.0001	F
2	3	15.16000000	0.22541904	76	67.25	0 0001	C
3	0	4 88500000	0.22541904	76	21.67	0 0001	L
3	1	9.37777967	0.24528582	76	38.23	0.0001	I
3	2	12.59166667	0.22541904	76	55.86	0.0001	F
3	3	15.48166667	0.22541904	76	68.68	0.0001	BC
4	0	5.25833333	0.22541904	76	23.33	0.0001	L
4	1	10.06833333	0.22541904	76	44.66	0 0001	H
4	2	13.24666667	0.22541904	76	58.76	0 0001	E
4	3	15.84166667	0.22541904	76	70.28	0.0001	B

[a] Least-squares means followed by unlike letters at the end of therow are different (p<0 05)
[b] Oil 1, 2, 3, and 4 = cottonseed, sunflower, and 20 and 40% (w/w) palm olein in sunflower oil, respectively
[c] Samp 0, 1, 2, and 3 = oils were sampled while fresh, after heating at 163°C for 3 hr, and after frying 2.5 and 5 hr, respectively

Appendix E – Least-squares means[a] of free fatty acids (FFA) levels affected by the oil x heating/frying time interaction

------- _ADJUST_=LSD(.05) BYGROUP=3 Effect=OIL*SAMP -------

OIL[b]	SAMP[c]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	0	0.01923333	0.00212160	78	9.07	0 0001	I
1	1	0 02846667	0.00212160	78	13 42	0.0001	H
1	2	0.04520000	0 00212160	78	21 30	0 0001	F
1	3	0.06360000	0.00212160	78	29 98	0 0001	C
2	0	0.02593333	0 00212160	78	12.22	0.0001	H
2	1	0.03598333	0.00212160	78	16.96	0.0001	G
2	2	0.04603333	0.00212160	78	21 70	0.0001	F
2	3	0 06445000	0.00212160	78	30 38	0.0001	C
3	0	0.02761667	0.00212160	78	13.02	0.0001	H
3	1	0.03768333	0.00212160	78	17.76	0.0001	G
3	2	0.05023333	0.00212160	78	23 68	0 0001	E
3	3	0.06950000	0 00212160	78	32.76	0.0001	B
4	0	0.02686667	0.00212160	78	12.66	0.0001	H
4	1	0.04280000	0 00212160	78	20.17	0.0001	F
4	2	0 05790000	0.00212160	78	27.29	0.0001	D
4	3	0.08053333	0.00212160	78	37 96	0.0001	A

[a] Least-squares means followed by unlike letters at the end of the row are different ($p<0.05$)
[b] Oil 1, 2, 3, and 4 = cottonseed, sunflower, and 20 and 40% (w/w) palm olein in sunflower oil, respectively
[c] Samp 0, 1, 2, and 3 = oils were sampled while fresh, after heating at 163°C for 3 hr, and after frying 2.5 and 5 hr, respectively

Appendix F – Least-squares means[a] (lsmeans) of levels of conjugated dienoic acids as affected by the oil x heating/frying time interaction

-------- _ADJUST_=LSD(.05) BYGROUP=3 Effect=OIL*SAMP --------

OIL[b]	SAMP[c]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	0	0.39840000	0 02087408	30	19.09	0.0001	H
1	1	0 72963333	0 02087408	30	34.95	0.0001	E
1	2	1.01890000	0.02087408	30	48.81	0 0001	C
1	3	1 20296667	0.02087408	30	57.63	0 0001	A
2	0	0.11520000	0.02087408	30	5.52	0 0001	I
2	1	0 60846667	0.02087408	30	29.15	0.0001	F
2	2	0 97863333	0 02087408	30	46.88	0.0001	C
2	3	1 22173333	0 02087408	30	58.53	0.0001	A
3	0	0.11456667	0.02087408	30	5.49	0 0001	I
3	1	0.55906667	0.02087408	30	26.78	0.0001	FG
3	2	0 85390000	0.02087408	30	40.91	0.0001	D
3	3	1.09200000	0.02087408	30	52.31	0.0001	B
4	0	0 10253333	0.02087408	30	4.91	0.0001	I
4	1	0.51856667	0 02087408	30	24.84	0.0001	G
4	2	0.78443333	0.02087408	30	37.58	0.0001	E
4	3	0.96550000	0 02087408	30	46.25	0 0001	C

[a] Least-squares means followed by unlike letters at the of the row are different (p<0 05)
[b] Oil 1, 2, 3, and 4 = cottonseed, sunflower, and 20 and 40% (w/w) palm olein in sunflower oil, respectively
[c] Samp 0, 1, 2, and 3 = oils were sampled while fresh, after heating at 163°C for 3 hr, and after frying 2.5 and 5 hr, respectively

Appendix G – Least-squares means[a] of Hunter color *a* and *b*, and color differences (ΔE) affected by the oils x heating/frying time interaction

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——— _ADJUST_=LSD(05) BYGROUP=3 Effect=OIL*SAMP ———

——— Hunter color *a* ———

OIL[b]	SAMP[c]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	0	-5.44714286	0 06463167	94	-84 28	0.0001	G
1	1	-6.56428571	0 06463167	94	-101.6	0.0001	J
1	2	-6 63857143	0.06463167	94	-102 7	0 0001	J
1	3	-6 90571429	0.06463167	94	-106 8	0.0001	K
2	0	-1 71285714	0.06463167	94	-26.50	0 0001	A
2	1	-2 60428571	0.06463167	94	-40.29	0 0001	B
2	2	-3.35714286	0 06463167	94	-51 94	0 0001	C
2	3	-4 48571429	0.06463167	94	-69.40	0.0001	E
3	0	-3 61285714	0.06463167	94	-55 90	0.0001	D
3	1	-4.43285714	0.06463167	94	-68 59	0.0001	E
3	2	-4 97142857	0.06463167	94	-76 92	0.0001	F
3	3	-5 79857143	0.06463167	94	-89.72	0 0001	H
4	0	-5 13714286	0 06463167	94	-79.48	0.0001	F
4	1	-5 93571429	0 06463167	94	-91.84	0.0001	H
4	2	-6 24571429	0 06463167	94	-96 64	0.0001	I
4	3	-6 57571429	0.06463167	94	-101 7	0 0001	J

——— Hunter color *b* ———

OIL	SAMP	LSMEAN	Std Error	DF	t	Pr > |t|	Le
1	0	14.76405544	0.29955646	29	49.29	0 0001	F
1	1	17 02738878	0.29955646	29	56 84	0 0001	D
1	2	20.18242438	0 27647658	29	73 00	0 0001	C
1	3	24.80913852	0 36291025	29	68 36	0 0001	B
2	0	3.31738878	0.29955646	29	11 07	0 0001	K
2	1	5.21738878	0.29955646	29	17.42	0.0001	J
2	2	10.62792557	0.27713581	29	38.35	0.0001	H
2	3	15.98461597	0.30830502	29	51 85	0.0001	E
3	0	8 53072211	0.29955646	29	28.48	0 0001	I
3	1	10.26405544	0.29955646	29	34 26	0.0001	H
3	2	15.09293743	0.28865429	29	52.29	0.0001	F
3	3	20.23794930	0.30830502	29	65.64	0.0001	C
4	0	13.66072211	0.29955646	29	45 60	0.0001	G
4	1	14 55738878	0.29955646	29	48 60	0.0001	F
4	2	20.72843862	0 29027531	29	71 41	0 0001	C
4	3	25 74079332	0 33176386	29	77.59	0 0001	A

Continued

Appendix G – (continued)

——— _ADJUST_=LSD(05) BYGROUP=3 Effect=OIL*SAMP ———

——— Color differences (ΔE)———

OIL[b]	SAMP[c]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	0	-0.01988786	0 56873681	94	-0 03	0.9722	G
1	1	2.78725499	0 56873681	94	4.90	0 0001	F
1	2	7.06154071	0 56873681	94	12 42	0 0001	E
1	3	11.23725499	0 56873681	94	19 76	0 0001	C
2	0	-0 01988786	0.56873681	94	-0 03	0 9722	G
2	1	3.04868357	0 56873681	94	5 36	0 0001	F
2	2	9 68725499	0 56873681	94	17.03	0 0001	D
2	3	14.47582642	0 56873681	94	25 45	0 0001	AB
3	0	-0 01988786	0 56873681	94	-0 03	0 9722	G
3	1	3 05725499	0.56873681	94	5 38	0 0001	F
3	2	7 75154071	0.56873681	94	13 63	0 0001	E
3	3	13 48725499	0.56873681	94	23 71	0 0001	B
4	0	-0.01988786	0 56873681	94	-0 03	0 9722	G
4	1	2 72725499	0 56873681	94	4 80	0 0001	F
4	2	9.36582642	0 56873681	94	16 47	0 0001	D
4	3	15 65582642	0 56873681	94	27.53	0 0001	A

[a] Least-squares means followed by unlike letters at the end of the row are different (p<0 05)
[b] Oil 1, 2, 3, and 4 = cottonseed, sunflower, and 20 and 40% (w/w) palm olein in sunflower oil, respectively.
[c] Samp 0, 1, 2, and 3 = oils were sampled while fresh, after heating at 163°C for 3 hr, and after frying 2 5 and 5 hr, respectively.

Appendix H – Least-squares means[a] of peroxide values of of oil extracted from potato chips fried in cottonseed (1) and sunflower (2) oils and oil blends of 20% palm olein oil (3) and 40% palm olein oil (4) in sunflower oil, and stored for 0-wk (c) or 3- and 6-wk in dark (d) or under fluorescent light (l)

---------- _ADJUST_=LSD(.05) BYGROUP=1 Effect=OIL ----------

OIL	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	24 54800000	0 69773880	38	35 18	0.0001	B
2	29 23266667	0 69773880	38	41.90	0 0001	A
3	20 71666667	0 69773880	38	29 69	0 0001	C
4	16 88733333	0 69773880	38	24 20	0 0001	D

---------- _ADJUST_=LSD(.05) BYGROUP=2 Effect=STORE*WEEK ----------

STORE	WEEK	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
c	0	2 92000000	0 77757901	38	3 76	0 0006	D
d	3	4 93666667	0 77757901	38	6 35	0 0001	D
d	6	13 42083333	0.77757901	38	17.26	0 0001	C
l	3	28.97166667	0 77757901	38	37 26	0.0001	B
l	6	63.98166667	0 77757901	38	82 28	0.0001	A

---------- _ADJUST_=LSD(05) BYGROUP=3 Effect=OIL*STORE*WEEK ----------

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	c	0	2.39333333	1 53995923	38	1 55	0 1284	J
1	d	3	3 34000000	1 53995923	38	2 17	0 0364	J
1	d	6	6 48000000	1`53995923	38	4 21	0 0002	IJ
1	l	3	34 89666667	1 53995923	38	22 66	0 0001	D
1	l	6	75 63000000	1 53995923	38	49 11	0 0001	A
2	c	0	2.09666667	1 53995923	38	1.36	0 1814	J
2	d	3	8 82333333	1 53995923	38	5 73	0 0001	HI
2	d	6	29 06333333	1 53995923	38	18 87	0 0001	EF
2	l	3	32.40000000	1.53995923	38	21 04	0 0001	DE
2	l	6	73 78000000	1 53995923	38	47 91	0 0001	A
3	c	0	3 74666667	1.53995923	38	2 43	0.0198	J
3	d	3	4 20000000	1.53995923	38	2 73	0 0096	J
3	d	6	12 05666667	1 53995923	38	7 83	0.0001	H
3	l	3	25.65000000	1 53995923	38	16 66	0 0001	FG
3	l	6	57 93000000	1 53995923	38	37 62	0 0001	B
4	c	0	3 44333333	1 53995923	38	2 24	0 0313	J
4	d	3	3 38333333	1 53995923	38	2 20	0 0342	J
4	d	6	6.08333333	1.53995923	38	3 95	0 0003	IJ
4	l	3	22 94000000	1 53995923	38	4 90	0 0001	G
4	l	6	48 58666667	1.53995923	38	31 55	0 0001	C

[a] Least-squares means in a group followed by unlike letters in the same row are different ($p<0.05$)

Appendix I -- Least-squares means[a] of levels and standard errors of volatiles isolated from potato chips affected by oil x storage interaction

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------- _ADJUST_=LSD(05) BYGROUP=3 Effect=OIL*STORE*WEEK ---------

---------- Unknown 1 ----------

OIL[b]	STORE[c]	WEEK[d]	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	235.33333333	98 33610166	38	2 39 0.0217	GH
1	2	3	539 33333333	98 33610166	38	5 48 0 0001	CDE
1	2	6	960 66666667	98 33610166	38	9 77 0 0001	AB
1	3	3	273 00000000	98 33610166	38	2 78 0 0085	EFGH
1	3	6	339 66666667	98 33610166	38	3 45 0 0014	EFGH
2	1	0	101.00000000	98.33610166	38	1.03 0 3109	H
2	2	3	373 33333333	98 33610166	38	3 80 0 0005	EFGH
2	2	6	757 33333333	98.33610166	38	7 70 0 0001	BC
2	3	3	231 66666667	98 33610166	38	2.36 0 0237	GH
2	3	6	511.00000000	98.33610166	38	5.20 0.0001	CDEF
3	1	0	223.33333333	98.33610166	38	2.27 0 0289	GH
3	2	3	455 00000000	98.33610166	38	4 63 0 0001	DEFG
3	2	6	662.66666667	98 33610166	38	6 74 0 0001	CD
3	3	3	222 00000000	98 33610166	38	2.26 0 0298	GH
3	3	6	458 66666667	98 33610166	38	4.66 0.0001	DEFG
4	1	0	237 00000000	98 33610166	38	2 41 0.0209	FGH
4	2	3	496 33333333	98 33610166	38	5 05 0 0001	CDEFG
4	2	6	1082.3333333	98 33610166	38	11 01 0 0001	A
4	3	3	224 33333333	98 33610166	38	2 28 0 0282	GH
4	3	6	425.00000000	98 33610166	38	4 32 0 0001	DEFG

------- _Hexanal ---------

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	652 33333333	477 32649553	38	1 37 0 1798	F
1	2	3	1002.6666667	477 32649553	38	2 10 0 0424	F
1	2	6	3614 0000000	477 32649553	38	7.57 0 0001	BC
1	3	3	1075 6666667	477 32649553	38	2 25 0 0301	EF
1	3	6	1395 6666667	477 32649553	38	2 92 0 0058	DEF
2	1	0	529 33333333	477 32649553	38	1 11 0 2744	F
2	2	3	1371 6666667	477 32649553	38	2 87 0 0066	DEF
2	2	6	3936 0000000	477 32649553	38	8 25 0 0001	AB
2	3	3	944 33333333	477 32649553	38	1.98 0 0552	F
2	3	6	2569.0000000	477 32649553	38	5 38 0 0001	CD
3	1	0	577.00000000	477 32649553	38	1 21 0 2342	F
3	2	3	1668 0000000	477 32649553	38	3 49 0 0012	DEF
3	2	6	3712 3333333	477 32649553	38	7 78 0 0001	BC
3	3	3	1151 6666667	477 32649553	38	2 41 0 0208	EF
3	3	6	2386 6666667	477 32649553	38	5 00 0 0001	CDE
4	1	0	609 00000000	477 32649553	38	1 28 0 2098	F
4	2	3	1824 0000000	477 32649553	38	3 82 0 0005	DEF
4	2	6	5186 0000000	477 32649553	38	10 86 0 0001	A
4	3	3	1018 3333333	477 32649553	38	2.13 0 0394	F
4	3	6	2561 6666667	477 32649553	38	5 37 0 0001	CD

Continued

Appendix I -- (continued)

_____ _ADJUST_=LSD(05) BYGROUP=6 Effect=OIL*STORE*WEEK _____

_____ Unknown 2 _____

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	81 33333333	1637 7354640	38	0 05 0.9607	C
1	2	3	17569.000000	1637.7354640	38	10.73 0 0001	B
1	2	6	26711 333333	1637.7354640	38	16 31 0 0001	A
1	3	3	38 33333333	1637.7354640	38	0 02 0.9814	C
1	3	6	90 66666667	1637 7354640	38	0 06 0 9561	C
2	1	0	-0 00000000	1637 7354640	38	-0 00 1 0000	C
2	2	3	-0 00000000	1637 7354640	38	-0 00 1 0000	C
2	2	6	-0 00000000	1637.7354640	38	-0 00 1 0000	C
2	3	3	-0 00000000	1637 7354640	38	-0 00 1.0000	C
2	3	6	-0 00000000	1637.7354640	38	-0.00 1 0000	C
3	1	0	-0.00000000	1637.7354640	38	-0.00 1 0000	C
3	2	3	-0.00000000	1637.7354640	38	-0 00 1 0000	C
3	2	6	-0 00000000	1637.7354640	38	-0 00 1 0000	C
3	3	3	-0 00000000	1637.7354640	38	-0.00 1 0000	C
3	3	6	-0.00000000	1637.7354640	38	-0.00 1 0000	C
4	1	0	0.00000000	1637 7354640	38	0 00 1 0000	C
4	2	3	105.33333333	1637 7354640	38	0.06 0 9491	C
4	2	6	291.66666667	1637 7354640	38	0.18 0.8596	C
4	3	3	-0.00000000	1637 7354640	38	-0 00 1 0000	C
4	3	6	0.00000000	1637 7354640	38	0 00 1 0000	C

_____ Unknown 3 _____

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	389.00000000	193 54495602	38	2 01 0 0516	A
1	2	3	261 66666667	193 54495602	38	1 35 0 1844	A
1	2	6	-0 00000000	193 54495602	38	-0 00 1 0000	A
1	3	3	-0.00000000	193 54495602	38	-0 00 1 0000	A
1	3	6	250 66666667	193 54495602	38	1 30 0 2031	A
2	1	0	46.00000000	193.54495602	38	0 24 0 8134	A
2	2	3	0.00000000	193 54495602	38	0 00 1.0000	A
2	2	6	382.33333333	193 54495602	38	1 98 0.0555	A
2	3	3	71.33333333	193 54495602	38	0 37 0.7145	A
2	3	6	-0 00000000	193 54495602	38	-0 00 1 0000	A
3	1	0	41 00000000	193 54495602	38	0 21 0 8334	A
3	2	3	-0 00000000	193 54495602	38	-0 00 1.0000	A
3	2	6	-0.00000000	193 54495602	38	-0 00 1.0000	A
3	3	3	0 00000000	193 54495602	38	0 00 1.0000	A
3	3	6	-0 00000000	193 54495602	38	-0 00 1 0000	A
4	1	0	307 33333333	193.54495602	38	1 59 0.1206	A
4	2	3	-0 00000000	193.54495602	38	-0 00 1 0000	A
4	2	6	94.00000000	193 54495602	38	0 49 0 6300	A
4	3	3	481 33333333	193 54495602	38	2 49 0 0174	A
4	3	6	49 00000000	193.54495602	38	0 25 0.8015	A

Continued

Appendix I -- (continued)

------ _ADJUST_=LSD(05) BYGROUP=27 Effect=OIL*STORE*WEEK --------

---------- Heptanal ----------

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	99 00000000	60 48764796	38	1 64 0 1100	ABC
1	2	3	0.00000000	60.48764796	38	0 00 1 0000	C
1	2	6	56 66666667	60 48764796	38	0 94 0 3548	BC
1	3	3	58 00000000	60 48764796	38	0 96 0 3437	BC
1	3	6	87.00000000	60.48764796	38	1 44 0 1585	ABC
2	1	0	35 33333333	60 48764796	38	0 58 0 5626	BC
2	2	3	38 00000000	60 48764796	38	0 63 0 5336	BC
2	2	6	167.33333333	60.48764796	38	2 77 0 0087	ABC
2	3	3	0.00000000	60.48764796	38	0 00 1 0000	C
2	3	6	180 66666667	60.48764796	38	2.99 0 0049	AB
3	1	0	78.00000000	60 48764796	38	1 29 0 2050	ABC
3	2	3	149.66666667	60 48764796	38	2 47 0.0179	ABC
3	2	6	118 66666667	60.48764796	38	1 96 0 0571	ABC
3	3	3	68.66666667	60 48764796	38	1 14 0.2634	BC
3	3	6	186 00000000	60 48764796	38	3 08 0.0039	AB
4	1	0	94 00000000	60.48764796	38	1.55 0.1285	ABC
4	2	3	91 00000000	60 48764796	38	1.50 0.1407	ABC
4	2	6	246 33333333	60 48764796	38	4 07 0.0002	A
4	3	3	58 66666667	60 48764796	38	0 97 0 3382	BC
4	3	6	193.33333333	60.48764796	38	3 20 0.0028	AB

---------- Unknown 4 ----------

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	1509 6666667	272 89468868	38	5 53 0 0001	BCDE
1	2	3	1429 0000000	272.89468868	38	5.24 0 0001	CDE
1	2	6	1889.0000000	272.89468868	38	6.92 0 0001	ABCD
1	3	3	1231.3333333	272 89468868	38	4.51 0 0001	DE
1	3	6	1036 3333333	272 89468868	38	3 80 0.0005	E
2	1	0	1649.6666667	272 89468868	38	6 05 0.0001	BCDE
2	2	3	1500 0000000	272 89468868	38	5 50 0.0001	BCDE
2	2	6	2134 3333333	272 89468868	38	7.82 0 0001	AB
2	3	3	1224 3333333	272 89468868	38	4.49 0.0001	DE
2	3	6	1583 6666667	272 89468868	38	5 80 0.0001	BCDE
3	1	0	1592 3333333	272 89468868	38	5 83 0 0001	BCDE
3	2	3	1601 0000000	272 89468868	38	5 87 0.0001	BCDE
3	2	6	2020 6666667	272.89468868	38	7.40 0 0001	ABC
3	3	3	1268 0000000	272 89468868	38	4.65 0 0001	DE
3	3	6	1428 6666667	272 89468868	38	5 24 0 0001	CDE
4	1	0	1509 6666667	272 89468868	38	5 53 0.0001	BCDE
4	2	3	1543 6666667	272 89468868	38	5.66 0.0001	BCDE
4	2	6	2576 6666667	272 89468868	38	9.44 0 0001	A
4	3	3	1297 0000000	272 89468868	38	4.75 0 0001	DE
4	3	6	1361 6666667	272 89468868	38	4.99 0 0001	CDE

Continued

Appendix I -- (continued)

------ _ADJUST_=LSD(05) BYGROUP=30 Effect=OIL*STORE*WEEK ---------

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

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	814 00000000	241 40010269	40	3 37	0.0017 BCDEF
1	2	3	502 33333333	241 40010269	40	2 08	0 0439 EF
1	2	6	612 00000000	241 40010269	40	2 54	0 0153 DEF
1	3	3	701.33333333	241 40010269	40	2 91	0 0060 CDEF
1	3	6	901 33333333	241 40010269	40	3 73	0 0006 BCDEF
2	1	0	670 33333333	241.40010269	40	2.78	0 0083 CDEF
2	2	3	414 33333333	241 40010269	40	1.72	0.0938 F
2	2	6	837 33333333	241.40010269	40	3 47	0 0013 BCDEF
2	3	3	553 33333333	241.40010269	40	2 29	0 0272 DEF
2	3	6	689 00000000	241 40010269	40	2 85	0.0068 CDEF
3	1	0	1025.6666667	241.40010269	40	4 25	0 0001 ABCD
3	2	3	700 00000000	241 40010269	40	2 90	0.0060 CDEF
3	2	6	826.33333333	241 40010269	40	3 42	0 0014 BCDEF
3	3	3	978 66666667	241 40010269	40	4 05	0.0002 ABCDE
3	3	6	842 58090641	225 52263243	40	3 74	0 0006 BCDEF
4	1	0	1301.3333333	241 40010269	40	5 39	0 0001 AB
4	2	3	735.33333333	241.40010269	40	3 05	0 0041 CDEF
4	2	6	1012 0000000	241 40010269	40	4 19	0 0001 ABCD
4	3	3	1450 0000000	241.40010269	40	6 01	0 0001 A
4	3	6	1080 8309064	225.52263243	40	4 79	0 0001 ABC

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

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	555 33333333	150 94426860	38	3.68	0 0007 CD
1	2	3	569 33333333	150 94426860	38	3 77	0 0006 BCD
1	2	6	1133.0000000	150 94426860	38	7 51	0 0001 A
1	3	3	562 66666667	150 94426860	38	3 73	0 0006 CD
1	3	6	551 00000000	150.94426860	38	3 65	0 0008 CD
2	1	0	446 00000000	150.94426860	38	2 95	0 0053 D
2	2	3	553 33333333	150 94426860	38	3 67	0 0008 CD
2	2	6	995 33333333	150 94426860	38	6 59	0.0001 AB
2	3	3	480 00000000	150 94426860	38	3 18	0 0029 D
2	3	6	832.33333333	150 94426860	38	5 51	0 0001 ABCD
3	1	0	524 00000000	150 94426860	38	3 47	0.0013 CD
3	2	3	582 33333333	150 94426860	38	3 86	0 0004 BCD
3	2	6	940 66666667	150 94426860	38	6 23	0 0001 ABC
3	3	3	529 66666667	150 94426860	38	3 51	0 0012 CD
3	3	6	800 00000000	150 94426860	38	5 30	0 0001 ABCD
4	1	0	510 00000000	150 94426860	38	3 38	0 0017 D
4	2	3	616 66666667	150 94426860	38	4 09	0.0002 BCD
4	2	6	1153 3333333	150 94426860	38	7 64	0 0001 A
4	3	3	638 66666667	150 94426860	38	4 23	0 0001 BCD
4	3	6	843 66666667	150 94426860	38	5 59	0.0001 ABCD

Continued

Appendix I -- (continued)

------ _ADJUST_=LSD(05) BYGROUP=36 Effect=OIL*STORE*WEEK ---------

---------- Decanal ----------

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	39.33333333	31 32366872	38	1 26 0 2169	A
1	2	3	-0 00000000	31 32366872	38	-0 00 1 0000	A
1	2	6	-0 00000000	31.32366872	38	-0 00 1 0000	A
1	3	3	35 00000000	31 32366872	38	1 12 0 2709	A
1	3	6	37.66666667	31 32366872	38	1 20 0 2366	A
2	1	0	0 00000000	31.32366872	38	0 00 1 0000	A
2	2	3	43 00000000	31 32366872	38	1 37 0 1779	A
2	2	6	0 00000000	31 32366872	38	0 00 1.0000	A
2	3	3	0 00000000	31 32366872	38	0 00 1.0000	A
2	3	6	76.33333333	31.32366872	38	2 44 0 0196	A
3	1	0	0.00000000	31.32366872	38	0.00 1.0000	A
3	2	3	43.66666667	31 32366872	38	1 39 0.1714	A
3	2	6	75 00000000	31 32366872	38	2 39 0 0217	A
3	3	3	-0.00000000	31.32366872	38	-0.00 1.0000	A
3	3	6	0.00000000	31 32366872	38	0.00 1 0000	A
4	1	0	15 00000000	31 32366872	38	0 48 0 6348	A
4	2	3	-0.00000000	31 32366872	38	-0.00 1 0000	A
4	2	6	-0 00000000	31.32366872	38	-0 00 1 0000	A
4	3	3	-0 00000000	31 32366872	38	-0 00 1 0000	A
4	3	6	0 00000000	31 32366872	38	0 00 1 0000	A

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

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	46 00000000	22.91578786	38	2.01 0 0519	BC
1	2	3	77 00000000	22 91578786	38	3 36 0 0018	AB
1	2	6	125 33333333	22 91578786	38	5 47 0 0001	A
1	3	3	57 33333333	22 91578786	38	2 50 0 0168	BC
1	3	6	-0 00000000	22 91578786	38	-0 00 1 0000	C
2	1	0	0 00000000	22.91578786	38	0.00 1 0000	C
2	2	3	0 00000000	22.91578786	38	0.00 1 0000	C
2	2	6	0 00000000	22 91578786	38	0 00 1 0000	C
2	3	3	0 00000000	22.91578786	38	0 00 1.0000	C
2	3	6	-0 00000000	22 91578786	38	-0 00 1 0000	C
3	1	0	0 00000000	22.91578786	38	0 00 1.0000	C
3	2	3	0 00000000	22.91578786	38	0 00 1.0000	C
3	2	6	0 00000000	22.91578786	38	0 00 1 0000	C
3	3	3	0 00000000	22.91578786	38	0.00 1 0000	C
3	3	6	-0 00000000	22 91578786	38	-0.00 1 0000	C
4	1	0	-0.00000000	22 91578786	38	-0.00 1 0000	C
4	2	3	0 00000000	22 91578786	38	0 00 1 0000	C
4	2	6	-0 00000000	22 91578786	38	-0 00 1 0000	C
4	3	3	36 33333333	22 91578786	38	1 59 0.1211	BC
4	3	6	0 00000000	22.91578786	38	0 00 1.0000	C

Continued

Appendix I -- (continued)

------ _ADJUST_=LSD(05) BYGROUP=42 Effect=OIL*STORE*WEEK ----------

t,t-2,4-Heptadienal

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	212 00000000	56 89610414	38	3 73 0 0006	A
1	2	3	130 33333333	56 89610414	38	2.29 0 0276	AB
1	2	6	-0 00000000	56 89610414	38	-0 00 1 0000	B
1	3	3	-0 00000000	56 89610414	38	-0 00 1 0000	B
1	3	6	0 00000000	56 89610414	38	0 00 1 0000	B
2	1	0	0 00000000	56 89610414	38	0.00 1 0000	B
2	2	3	-0 00000000	56.89610414	38	-0.00 1 0000	B
2	2	6	37 33333333	56 89610414	38	0.66 0.5157	B
2	3	3	0 00000000	56.89610414	38	0.00 1 0000	B
2	3	6	0 00000000	56 89610414	38	0 00 1 0000	B
3	1	0	0 00000000	56 89610414	38	0 00 1 0000	B
3	2	3	-0 00000000	56 89610414	38	-0 00 1 0000	B
3	2	6	-0 00000000	56 89610414	38	-0 00 1 0000	B
3	3	3	0 00000000	56 89610414	38	0 00 1 0000	B
3	3	6	0 00000000	56 89610414	38	0 00 1 0000	B
4	1	0	0 00000000	56.89610414	38	0 00 1 0000	B
4	2	3	-0 00000000	56 89610414	38	-0 00 1 0000	B
4	2	6	37 66666667	56.89610414	38	0 66 0 5120	B
4	3	3	0 00000000	56 89610414	38	0 00 1 0000	B
4	3	6	-0 00000000	56 89610414	38	-0.00 1 0000	B

Unknown 5

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	359 00000000	69 36777990	38	5 18 0 0001	A
1	2	3	-0 00000000	69.36777990	38	-0 00 1 0000	B
1	2	6	-0 00000000	69.36777990	38	-0 00 1 0000	B
1	3	3	11 00000000	69 36777990	38	0 16 0 8748	B
1	3	6	187.00000000	69 36777990	38	2 70 0 0104	AB
2	1	0	51 00000000	69.36777990	38	0 74 0 4667	B
2	2	3	46 00000000	69.36777990	38	0 66 0 5112	B
2	2	6	115 00000000	69.36777990	38	1 66 0 1056	B
2	3	3	95 66666667	69 36777990	38	1 38 0 1759	B
2	3	6	103 66666667	69.36777990	38	1 49 0 1433	B
3	1	0	127.00000000	69 36777990	38	1 83 0 0750	B
3	2	3	87 33333333	69 36777990	38	1 26 0 2157	B
3	2	6	113 33333333	69.36777990	38	1 63 0 1106	B
3	3	3	69 66666667	69.36777990	38	1 00 0 3216	B
3	3	6	179 00000000	69.36777990	38	2 58 0 0139	AB
4	1	0	132 00000000	69 36777990	38	1.90 0 0647	B
4	2	3	95 33333333	69 36777990	38	1 37 0.1774	B
4	2	6	84 33333333	69 36777990	38	1 22 0 2316	B
4	3	3	52 00000000	69.36777990	38	0 75 0 4581	B
4	3	6	160 00000000	69 36777990	38	2 31 0 0266	B

Continued

Appendix I -- (continued)

------ _ADJUST_=LSD(05) BYGROUP=45 Effect=OIL*STORE*WEEK ---------

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

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	83 00000000	44 68531949	38	1 86 0 0710	AB
1	2	3	77 33333333	44 68531949	38	1 73 0 0916	AB
1	2	6	46 00000000	44 68531949	38	1 03 0 3098	B
1	3	3	121 33333333	44 68531949	38	2 72 0 0099	AB
1	3	6	99.66666667	44 68531949	38	2 23 0 0317	AB
2	1	0	52 00000000	44 68531949	38	1 16 0 2518	B
2	2	3	39 00000000	44 68531949	38	0 87 0 3883	B
2	2	6	90 33333333	44 68531949	38	2.02 0 0503	AB
2	3	3	84 33333333	44.68531949	38	1 89 0 0668	AB
2	3	6	91.33333333	44 68531949	38	2 04 0 0479	AB
3	1	0	114 33333333	44 68531949	38	2 56 0 0146	AB
3	2	3	77.33333333	44.68531949	38	1 73 0 0916	AB
3	2	6	132.00000000	44.68531949	38	2 95 0.0054	AB
3	3	3	76.66666667	44 68531949	38	1 72 0 0944	AB
3	3	6	173.66666667	44 68531949	38	3 89 0 0004	A
4	1	0	109 66666667	44 68531949	38	2 45 0 0188	AB
4	2	3	39 33333333	44 68531949	38	0 88 0 3843	B
4	2	6	147.00000000	44 68531949	38	3 29 0 0022	AB
4	3	3	119.66666667	44 68531949	38	2 68 0 0109	AB
4	3	6	181.66666667	44 68531949	38	4 07 0 0002	A

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

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	385 00000000	90 28095037	38	4.26 0.0001	DE
1	2	3	364.33333333	90 28095037	38	4 04 0.0003	DE
1	2	6	365.66666667	90 28095037	38	4 05 0 0002	DE
1	3	3	388 33333333	90 28095037	38	4 30 0 0001	DE
1	3	6	367 00000000	90 28095037	38	4 07 0.0002	DE
2	1	0	356 00000000	90.28095037	38	3 94 0 0003	E
2	2	3	347 66666667	90 28095037	38	3.85 0.0004	E
2	2	6	452 66666667	90 28095037	38	5 01 0 0001	CDE
2	3	3	347 66666667	90 28095037	38	3 85 0 0004	E
2	3	6	505 00000000	90 28095037	38	5 59 0.0001	CDE
3	1	0	556 00000000	90 28095037	38	6 16 0 0001	BCDE
3	2	3	482 33333333	90 28095037	38	5 34 0.0001	CDE
3	2	6	522 66666667	90 28095037	38	5 79 0.0001	BCDE
3	3	3	482 66666667	90.28095037	38	5 35 0 0001	CDE
3	3	6	652 66666667	90 28095037	38	7.23 0 0001	ABC
4	1	0	669 00000000	90 28095037	38	7 41 0 0001	ABC
4	2	3	616 33333333	90 28095037	38	6 83 0 0001	BCD
4	2	6	766 00000000	90 28095037	38	8 48 0 0001	AB
4	3	3	766 66666667	90 28095037	38	8 49 0.0001	AB
4	3	6	877 00000000	90 28095037	38	9 71 0 0001	A

Continued

Appendix I -- (continued)

------ _ADJUST_=LSD(.05) BYGROUP=18 Effect=OIL*STORE*WEEK ------

---------- Unknown 6 ----------

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	1	0	0 00000000	32 85540713	38	0 00	1 0000	D
1	2	3	0.00000000	32 85540713	38	0 00	1.0000	D
1	2	6	51.66666667	32 85540713	38	1 57	0 1241	CD
1	3	3	3.33333333	32 85540713	38	1 93	0.0614	BCD
1	3	6	75 66666667	32 85540713	38	2 30	0 0268	ABCD
2	1	0	0.00000000	32 85540713	38	0 00	1 0000	D
2	2	3	0 00000000	32 85540713	38	0 00	1 0000	D
2	2	6	109 33333333	32 85540713	38	3.33	0 0020	ABC
2	3	3	38 33333333	32 85540713	38	1 17	0.2506	CD
2	3	6	150 33333333	32 85540713	38	4 58	0.0001	AB
3	1	0	0.00000000	32.85540713	38	0 00	1 0000	D
3	2	3	43.00000000	32 85540713	38	1.31	0 1985	CD
3	2	6	87.66666667	32 85540713	38	2.67	0.0111	ABCD
3	3	3	0 00000000	32 85540713	38	0 00	1 0000	D
3	3	6	161 00000000	32 85540713	38	4 90	0 0001	A
4	1	0	13 33333333	32 85540713	38	0 41	0 6872	D
4	2	3	0 00000000	32.85540713	38	0 00	1 0000	D
4	2	6	150 66666667	32 85540713	38	4 59	0 0001	AB
4	3	3	75 33333333	32.85540713	38	2.29	0.0275	ABCD
4	3	6	107.66666667	32.85540713	38	3 28	0 0022	ABC

---------- t,t-2,4-Decadienal ----------

OIL	STORE	WEEK	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
1	1	0	6168 6666667	1536 5677119	38	4 01	0 0003	AB
1	2	3	5776.0000000	1536 5677119	38	3.76	0 0006	AB
1	2	6	5851 3333333	1536 5677119	38	3 81	0.0005	AB
1	3	3	6663.3333333	1536 5677119	38	4 34	0 0001	AB
1	3	6	6422.6666667	1536 5677119	38	4 18	0 0002	AB
2	1	0	7518 0000000	1536 5677119	38	4 89	0 0001	AB
2	2	3	7267 3333333	1536 5677119	38	4 73	0 0001	AB
2	2	6	5284 6666667	1536 5677119	38	3 44	0 0014	B
2	3	3	8265 6666667	1536 5677119	38	5 38	0 0001	AB
2	3	6	7379 6666667	1536 5677119	38	4 80	0 0001	AB
3	1	0	7323 3333333	1536 5677119	38	4 77	0 0001	AB
3	2	3	6668 6666667	1536 5677119	38	4 34	0 0001	AB
3	2	6	7932.6666667	1536 5677119	38	5.16	0 0001	AB
3	3	3	7357.0000000	1536 5677119	38	4.79	0 0001	AB
3	3	6	5561.6666667	1536 5677119	38	3 62	0 0009	AB
4	1	0	6184 3333333	1536 5677119	38	4 02	0 0003	AB
4	2	3	5925.0000000	1536 5677119	38	3 86	0 0004	AB
4	2	6	7462.0000000	1536 5677119	38	4 86	0 0001	AB
4	3	3	8046 6666667	1536 5677119	38	5 24	0 0001	AB
4	3	6	9601.3333333	1536 5677119	38	6 25	0 0001	A

Continued

Appendix I -- (continued)

------ _ADJUST_=LSD(05) BYGROUP=21 Effect=OIL*STORE*WEEK --------

---------- Unknown 7 ----------

OIL[b]	STORE[c]	WEEK[d]	LSMEAN	Std Error	DF	t Pr > |t|	LetGrp
1	1	0	48 00000000	66.56976291	38	0 72	0.4753	I
1	2	3	245 66666667	66.56976291	38	3 69	0 0007	FGH
1	2	6	298 00000000	66 56976291	38	4 48	0.0001	DEF
1	3	3	270 00000000	66.56976291	38	4 06	0 0002	EFG
1	3	6	425 66666667	66.56976291	38	6.39	0 0001	CDE
2	1	0	39.00000000	66.56976291	38	0 59	0.5614	I
2	2	3	283.33333333	66.56976291	38	4 26	0.0001	DEF
2	2	6	503.66666667	66.56976291	38	7 57	0 0001	ABC
2	3	3	295 33333333	66 56976291	38	4 44	0.0001	DEF
2	3	6	623 66666667	66 56976291	38	9 37	0 0001	AB
3	1	0	84 66666667	66 56976291	38	1.27	0 2112	HI
3	2	3	288.33333333	66.56976291	38	4.33	0 0001	DEF
3	2	6	458 00000000	66.56976291	38	6.88	0.0001	BCD
3	3	3	324.33333333	66 56976291	38	4 87	0 0001	DEF
3	3	6	654 00000000	66.56976291	38	9 82	0.0001	A
4	1	0	101 66666667	66.56976291	38	1 53	0 1350	GHI
4	2	3	289 33333333	66.56976291	38	4 35	0.0001	DEF
4	2	6	536 00000000	66 56976291	38	8 05	0 0001	ABC
4	3	3	374 00000000	66.56976291	38	5.62	0.0001	CDEF
4	3	6	679 33333333	66.56976291	38	10 20	0 0001	A

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[a] Least-squares means of the same volatile followed by unlike letters at the end of the row are different ($p<0.05$)

[b] Oil 1, 2, 3, and 4 = cottonseed, sunflower, and 20 and 40% (w/w) palm olein oil in sunflower oil, respectively

[c] Store 1, 2, 3, and 4 = stored for 0 wk, stored under light, and stored in dark, respectively.

[d] Week = length of time in wk chips were stored in dark or light

Appendix J – Least-squares means [a] of color lightness, oxidative rancidity, and off flavors scores of potato chips affected by oil x storage interaction

---------- _ADJUST_=LSD(05) BYGROUP=3 Effect=OIL*STORE*WEEKS ----------

----------COLOR lightness ----------

OIL[b]	STORE[c]	WEEKS[d]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
B6	C	0	4.02417277	0.32316949	1353	12.45	0.0001	AB
B6	D	3	3.83289442	0.32317076	1353	11.86	0.0001	ABCD
B6	D	6	3.70672642	0.32812576	1353	11.30	0.0001	ABCDE
B6	L	3	3 12864166	0.32373093	1353	9.66	0.0001	G
B6	L	6	3.17642339	0.32812576	1353	9 68	0.0001	G
B8	C	0	4.10525385	0.32316949	1353	12.70	0.0001	A
B8	D	3	4.12083319	0.32373032	1353	12.73	0.0001	A
B8	D	6	4.05521127	0.32812576	1353	12.36	0.0001	AB
B8	L	3	3.47699757	0.32373032	1353	10.74	0.0001	DEFG
B8	L	6	3.52490824	0.32812576	1353	10.74	0.0001	CDEFG
CS	C	0	3.83498358	0.32316949	1353	11.87	0.0001	ABCD
CS	D	3	3.64138113	0.32373032	1353	11.25	0.0001	BCDEF
CS	D	6	3.93399915	0.32812576	1353	11.99	0.0001	ABCD
CS	L	3	3.36740853	0.32373032	1353	10.40	0.0001	EFG
CS	L	6	3.28248400	0.32812576	1353	10.00	0.0001	EFG
SF	C	0	4.02417277	0.32316949	1353	12.45	0.0001	AB
SF	D	3	3.98154307	0.32317076	1353	12.32	0.0001	ABC
SF	D	6	3.73702945	0.32812576	1353	11.39	0.0001	ABCDE
SF	L	3	3.22478631	0.32317076	1353	9.98	0.0001	FG
SF	L	6	3.59143042	0.32882496	1353	10 92	0.0001	BCDEFG

---------- Oxidative rancidity ----------

OIL	STORE	WEEKS	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
B6	C	0	3.89069056	0.34457197	1353	11.29	0.0001	DEF
B6	D	3	3.90972978	0.34457446	1353	11.35	0.0001	DEF
B6	D	6	4.21979436	0.35408101	1353	11.92	0.0001	BCDE
B6	L	3	4 43675681	0.34457446	1353	12.88	0.0001	BCD
B6	L	6	4.68949133	0.35408101	1353	13.24	0.0001	BC
B8	C	0	3 95825813	0.34457197	1353	11.49	0.0001	DEF
B8	D	3	3 53509896	0.34565910	1353	10.23	0.0001	F
B8	D	6	4 00767315	0.35408101	1353	11.32	0.0001	CDEF
B8	L	3	3.82277019	0.34565910	1353	11.06	0.0001	DEF
B8	L	6	4 12888527	0.35408101	1353	11.66	0.0001	BCDEF
CS	C	0	4.17447434	0.34457197	1353	12.11	0.0001	BCDEF
CS	D	3	4.20633183	0.34565910	1353	12.17	0.0001	BCDE
CS	D	6	3.94706709	0.35408101	1353	11.15	0.0001	DEF
CS	L	3	4 76797567	0.34565910	1353	13.79	0.0001	B
CS	L	6	5.90161254	0.35408101	1353	16.67	0.0001	A
SF	C	0	3.87717705	0.34457197	1353	11.25	0.0001	DEF
SF	D	3	3.93675681	0.34457446	1353	11.42	0.0001	DEF
SF	D	6	3.75996083	0.35539779	1353	10.58	0.0001	EF
SF	L	3	3.81513519	0.34457446	1353	11.07	0.0001	DEF
SF	L	6	4.34994165	0.35539819	1353	12.24	0.0001	BCDE

continued

Appendix J – (continued)

---------- _ADJUST_=LSD(.05) BYGROUP=3 Effect=OIL*STORE*WEEKS ----------

---------- Off flavors ----------

OIL[b]	STORE[c]	WEEKS[d]	LSMEAN	Std Error	DF	t	Pr > |t|	LetGrp
B6	C	0	4.10479084	0.36725291	1350	11.18	0.0001	DEF
B6	D	3	4.30764963	0.36247403	1350	11.88	0.0001	CDEF
B6	D	6	4.31265045	0.37068998	1350	11.63	0 0001	CDEF
B6	L	3	4.82525454	0.36259770	1350	13 31	0 0001	BC
B6	L	6	4 66287138	0.37070761	1350	12.58	0.0001	BCDE
B8	C	0	4.37506111	0.36725291	1350	11.91	0.0001	BCDEF
B8	D	3	3.95753140	0.36342153	1350	10.89	0 0001	F
B8	D	6	3.96629388	0.37074695	1350	10 70	0.0001	F
B8	L	3	4.16776247	0.36356788	1350	11 46	0.0001	DEF
B8	L	6	4.05797701	0.37067284	1350	10.95	0 0001	EF
CS	C	0	4.32600075	0.36910025	1350	11.72	0 0001	CDEF
CS	D	3	4.20967756	0.36386757	1350	11.57	0.0001	DEF
CS	D	6	4.19523920	0.37084081	1350	11.31	0.0001	CDEF
CS	L	3	4.99974126	0.36340933	1350	13 76	0.0001	B
CS	L	6	5.72926413	0.37063025	1350	15 46	0.0001	A
SF	C	0	4.21400284	0.36817190	1350	11 45	0.0001	CDEF
SF	D	3	4.12385689	0.36251542	1350	11.38	0.0001	DEF
SF	D	6	4.20715962	0.37192339	1350	11.31	0.0001	CDEF
SF	L	3	3.95151179	0.36245424	1350	10.90	0.0001	F
SF	L	6	4.70719988	0.37178542	1350	12.66	0.0001	BCD

[a] Least-squares means of the same sensory properties followed by unlike letters at the end of the row are different (p<0 05)

[b] Oil B6, B8, CS, and SF = 40 and 20% (w/w) palm olein in sunflower, cottonseed, sunflower oil, respectively

[c] Store C, D, and L = stored for 0 wk, stored in dark, and under light, respectively.

[d] Week = length of time in weeks chips were stored in dark or under light

VITA

Philipus Pangloli was born in Tana Toraja, South Sulawesi, Indonesia on December 31, 1958. In December 1977, he received the high school diploma from a high school in Tana Toraja, Indonesia. He graduated from Bogor Agricultural University, Bogor, Indonesia, in 1982 with a Bachelor of Science degree in Agricultural Product Technology.

In 1982, he worked with the Research Institute or Agro-Based Industry, Department of Industry of the Republic of Indonesia. In 1983, he worked with the Department of Agriculture of the Republic of Indonesia In 1984, he began working with the Agency for the Assessment and Application of Technology of the Republic of Indonesia as research assistant

In 1991, under scholarship of the Indonesian Government, he began his studies toward the Master of Science degree in Food Science and Technology at the University of Tennessee, Knoxville. After graduation in May 1993, he went back to Indonesia to assume his former job and serve as research associate In 1997, under another scholarship of the Indonesian Government, he returned to the US to pursue a doctoral program at the University of Tennessee, Knoxville and received the degree in December 1999 in the College of Agricultural Sciences and Natural Resources with a major in Food Science and Technology. He is a member of the Institute of Food Technologists (IFT) and American Oil Chemists Society (AOCS)