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SOYBEAN AND PALM OLEIN OILS: FRYING PERFORMANCE AND CHARACTERISTICS OF FRIED PRAWN CRACKERS

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DEDICATION

This dissertation is dedicated to my wife, Retno, for her continuous love, support, understanding and her patience, and also, to Kirana and Sarah who have their own way to entertain and encourage me to reach this stage.

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ABSTRACT

Four different frying oils: unhydrogenated soybean oil (SO), palm olein (POO) and blends of 80:20 and 60:40 w/w SO:POO were used to fry prawn crackers (PC) intermittently for five days. The degradation of the oils/blends (O/B) were followed by daily measurement by the food oil sensor (FOS), RAU and Fritest, of color (*L*, *a*, *b* and ΔE) and levels of conjugated dienes (DIENES), fatty acid composition, C18:2/C16:0 fatty acid ratio (RATIO), free fatty acids (FFA) and total polar components (TPC). PC fried in each O/B were stored at 25°C for 0 wk (fresh) and 4 wk in the dark (4D) and in the light (4L) and analyzed for flavor volatiles and color, flavor and overall likability scores.

FOS, Fritest and TPC values were not different among frying O/B, and each measurement for each O/B reached maximum value or oil discard point before or by day 5 of frying. The TPC level at discard point (25-27%) was reached by frying day 3 in all O/B mainly because of high TPC (12-14%) in fresh oils. Levels of DIENES and RATIO were higher in SO than in blends or POO and decreased with decreasing SO level in the blends. DIENES and RATIO of each O/B also decreased with increasing frying time. Although FFA content increased with increasing frying time in all O/B and was higher in POO than in other O/B, after frying day 5, it was still below the level (0.5%) recommended for discard of potato chip frying oil. SO had highest levels of C18:2 and C18:3 fatty acids of all O/B while PO had the highest levels of C16:0 and C18:1. Levels of C18:2 decreased in all O/B during frying while levels of C12:0, C20:2 and C22:4 increased. RAU value, a measure of oxidized products, reached discard point by frying day 4 in the blends compared

to day 5 in pure SO and POO, indicating the pure oils were more stable than the blends during frying. POO had a lower *L* value (was darker) and higher *b* value (more yellow) than SO when fresh. All O/B darkened and became more yellow with increasing frying time. After five days frying, POO was still darker than SO or the blends, but SO had similar *b* values as POO (42.3 versus 43.9) and the greatest color change (ΔE) of all O/B. The darker color of POO could cause early discard in institutions using dark color to judge when a frying oil is fully deteriorated.

The color, flavor and overall likability scores of the fried PC were not different among the O/B and averaged 5.9 (were liked moderately). However, 4L PC received a lower flavor and overall likability score (4.9) than that (5.8) of fresh or 4D PC. The 4L PC also had much higher levels of 21 of 23 identified flavor volatiles than those present in the fresh or 4D PC. These latter results indicate that for stored fried PC to maintain acceptable flavor, they must be stored in a light barrier package.

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CHAPTER I

INTRODUCTION

Consumer concerns about saturated dietary fat in the United States of America (USA) are driving most fast food outlets and snack food processors to switch from saturated oils to more unsaturated oils/fats for frying (Wood, 1992). This switch is one reason that POO (a liquid portion of palm oil), which contains 40 to 50% saturated fatty acids (Charpentier, 1991; DeMan et al., 1992; Weiderman, 1991), has fallen into disfavor with the American food business despite its having the lowest price among vegetable oils. On the other hand, a highly unsaturated and low-priced vegetable oil, namely unhydrogenated soybean oil (SO), (Weiss, 1983) often is not considered as a frying oil because of its instability to oxidation and formation of objectionable odor during frying (Mounts and Warner, 1990). In contrast, palm olein oil (POO) is very stable during frying and produces more acceptable fried foods (Kheiri, 1985; Sakata et al., 1985) and is acceptable to consumers in the USA. For example, a study by Augustin et al. (1988) found that the shelf life of potato crisps fried in POO was significantly longer than those fried in SO.

Blending SO and POO can improve the stability and provide more desirable fatty acid composition that would be an improvement to both oils (Basiron, 1989). The addition of SO to POO would decrease the level of saturation in POO. Blending the two oils would decrease the unsaturation level and might increase the stability and flavor desirability of the SO. Reports exist in which a SO:POO (40:60, w/w) blend yielded greater stability than SO containing certain antioxidants during heating

and frying (Berry and Awang, 1981; Chu, 1991). However, the stability of blends containing greater amounts of SO has not been investigated, and no reports were found concerning the influence of any SO:POO blends on the flavor and sensory characteristics of fried foods. Such information is needed if these blends are to be used for frying by fast food outlets and snack food processors.

Prawn crackers, a tapioca-based snack food containing 10-15% shrimp (Anderson, 1988), are a fried snack food popular in Southeast Asian and Oriental countries. In these countries, however, this snack food cannot be purchased readily in the final fried form, but rather as a dried chip ready for frying. This dried chip is available in Oriental groceries in the USA. The freshly fried chip has a very pleasing flavor and texture, and the possibility exists that the fried chip could become a popular snack food in the USA. It is also possible that a market could be developed for the fried form in Southeast Asian and Oriental countries if a high quality product with sufficient shelf life could be produced. Also production of such a product is necessary for successful marketing in the USA.

The cost of producing a snack food with desirable characteristics for market also must be kept as low as possible. The cost, stability, flavor, and acceptability of a fried snack food are dependent, in part, on the oil in which it is cooked (Augustin et al., 1987b). The use of SO and/or POO for production of fried prawn crackers is desirable because both are the least expensive vegetable oils available (Anonymous, 1992a,b; Weiss, 1983). Information concerning quality and stability of prawn crackers fried in either oil is parse. Augustin et al. (1987a) investigated the frying performance of POO with and without antioxidants during production of prawn crackers, but they did not study the characteristics or stability of the fried

crackers. The stability or characteristics of prawn crackers fried in SO or SO:POO blends have not been investigated either. Such information is needed for these oils/blends to be used for commercial production of fried prawn crackers. Therefore the objectives of the present study were presented as following:

1. To determine and compare the degradation and stability of SO and POO, alone and in blends, during frying of prawn crackers.
2. To identify and measure levels of flavor volatiles in fresh and stored (in dark and light) prawn crackers fried in the different oils/blends.
3. To determine the likability of fried prawn crackers by measuring the color, flavor, and overall acceptability of fresh and stored fried prawn crackers fried in the different oils/blends.

CHAPTER II

REVIEW OF THE LITERATURE

The important roles of frying oil during deep-fat frying are to transfer the heat, to facilitate the moisture transfer from the inside the food to the surface, and to cook the interior of frying material (Blumenthal, 1991). Frying conditions such as the presence of the oxygen on the surface of the heated oil, frying temperature, the duration of frying process, and the moisture and fat content in the frying food influence the degradation of frying oil (Gray, 1978; Nawar, 1985a). Because the safety and quality of fried foods are affected significantly by the quality of the oil, some countries have regulations that determine the end use of frying oils.

1. QUALITY OF FRYING OIL

The general criterion of good quality frying oil is that the fat or frying oil should not exhibit unpleasant odor and taste (Firestone et al., 1991; Nawar, 1985a). In the USA there are no specific regulations to control the use of frying fat, except that the fats and oils used in food service establishments must be obtained from an approved source and not adulterated (Firestone et al., 1991). In practice, the quality of frying fat in restaurants and fast food outlets is judged by a single person (frying operator or manager), using sensory observations of the color, odor, and flavor of the frying oil and/or fried food (Melton, 1993). It is common in commercial practice to discard the frying oil when the oil smokes excessively at frying temperatures, foams excessively, produces undesirable flavor and/or

develops a dark color (Clark and Serbia, 1991). Thus, characteristics of the oil such as the color, smoke point, and the odor are important indicators of oil quality. Since the quality of used frying oil is dependent on its previous frying condition of any establishment, for practical purpose of deep frying operation, is difficult to select a particular standard measurement to determine when a frying oil should be discarded or replenished (Melton, 1993).

However, most food establishments that produce deep fried products on a commercial scale use several ways to maintain a high quality of frying oil. One of them is to maintain an equilibrium between the amount of oil absorbed by the product and the amount of fresh oil needed for replenishment during the continuous deep frying operation (Morton and Chidley, 1988). For industrial fryers with capacities up to 2,000 kg/hr, where the fried foods pick up a large amount of oil, the fryer could be completely replenished by fresh oil every 6-8 hours (Morton and Chidley, 1988). When such an equilibrium is reached, the oil degradation caused by heat/oxidation is minimized by the influx of fresh oil and continual absorption by the fried product (Morton and Chidley, 1988). Firestone at al. (1991) reported that the limit of frying life of the oil used in the USA food industry is not regulated strictly, but is determined by each establishment to meet the quality demand of the market. Fortunately, the sensory qualities of the frying oil and/or fried products become undesirable before the oil becomes unsafe. Thus, most large processors carefully monitor flavor acceptance and storage stability of the product (Jacobson, 1991). Also, other researchers stated that the best assessment of the quality of frying oil is based on the sensory quality of the fried food after storage (Brooks, 1991).

On the other hand, some European countries such as Austria, Belgium, France, Federal Republic of Germany, Spain and Switzerland have regulations defining the end point of a frying oil's life. Often, a polar component content of 25% and smoke point of 170°C are the criteria for the end of the frying life of the oil (Firestone et al., 1991). More strict regulations in Belgium also specify that the presence of 2% of linolenic acid in commercial frying oil as the limit (Firestone et al., 1991). Based on the frying oil quality criteria, the extent and the consideration of using a particular frying oil can be explained as follows. Considering the amount of polar component (25%) as the cut-off points for frying fat, unhydrogenated refined-bleached-deodorized (RBD) SO with 7% linolenic acid could be used for frying 200 g frozen prefried french fries in 2.6 L of frying oil at 180°C for 5 minutes for up to 15 frying operations without exceeding the cut off point of the frying oil (Sebedio et al., 1990). Using a similar cut-off criterion, the oil blend of soybean and palm oil (40:60) could be used for a longer period of time due to its better frying performance than the SO alone even with various antioxidants (Chu, 1991).

2. CHEMICAL CHANGES OF OIL DURING DEEP-FAT FRYING

Frying oil undergoes various chemical reactions as the frying progresses. Some important reactions are thermal oxidation, hydrolysis, polymerization, and color formation (Al-Kahtani, 1991; Brooks, 1991; Perkins, 1992). Among those changes, autoxidation can occur even before the oil comes into contact with the food. When the oil is heated during frying, the oxygen from the air catalyzed by

heat oxidizes the unsaturated fatty acids of the oil, resulting in the formation of unstable peroxides (Blumenthal, 1991; Chang et al., 1978; Gray, 1978). Other important changes in frying oil are caused by contact between the hot oil and the food being fried. As a result, the moisture released from the food can hydrolyze the oil. In addition, fat soluble materials such as colorant and fat from the food may interact with the frying oil, resulting in further changes in the frying oil.

Thermal Oxidation

Thermal oxidation of frying oil initially occurs on unsaturated fatty acids in the oils to yield hydroperoxides (Chan et al., 1982; Fritsch, 1981; Shimic et al., 1992). The reported mechanism of hydroperoxides formation follows a free radical-chain reaction involving oxygen and involment of the unsaturated fatty acids has been mentioned by several researchers (Hsieh and Kinsella, 1989; Melton, 1983):

Initiation: $RH + O_2 \text{------} > R\cdot + \cdot OH$ (1)

Propagation: $R\cdot + O_2 \text{------} > ROO\cdot$ (2a)

$ROO\cdot + RH \text{----} > ROOH + R$ (2b)

Termination: $R\cdot + R\cdot \text{-----} > RR$ (3a)

$R\cdot + ROO \text{-----} > ROOR$ (3b)

$ROO\cdot + ROO\cdot \text{---} > ROOR + O_2$ (3c)

The formation of free radicals in the initiation step (1) can be induced by light or heat. The propagation reaction of free radical formation (2a) leads to the formation of peroxy radicals ($ROO\cdot$) that react with unsaturated fatty acids to form hydroperoxides (ROOH). The hydroperoxides of unsaturated fatty acids are important precursors of volatile decomposition products (VDP) of the oil (Fritsch,

1981; Vercellotti et al., 1992a). Hydroperoxides are degraded easily to an alkoxy free radical which decomposes mainly by cleavage on either side of the carbon atom bearing the oxygen atom producing the secondary reaction products such as alcohols, aldehydes, ketones, alkenes and hydrocarbons (Hsieh and Kinsella, 1989; Perkins, 1992).

The susceptibility and the rate of oxidation of fatty acids depends upon their unsaturation (Enser, 1987; Gray, 1978; Hamilton, 1989). Studies in lipid oxidation indicate that oleate is less susceptible to oxidation than linoleate and linolenate (Chan et al., 1982; Hsieh and Kinsella, 1989; Nawar, 1985b; Rossell, 1989a). Furthermore, linolenate, which has two 1,4 pentadiene-like structures, reportedly contributes to more rapid decomposition of hydroperoxides (Chan et al., 1982; Nawar, 1985; Shimic et al., 1992).

Hydroperoxides and dihydroperoxides are unstable and rapidly undergo fission to form aldehydes, alcohols, and ketones which can be oxidized further to form ester and lactones (Hamilton, 1989; Melton, 1993). Based on their volatility, various compounds formed by further reaction of hydroperoxides can be categorized as volatile decomposition products (VDP) and non-volatile decomposition products (NVDP) (Brooks, 1991; Fritsch, 1981; Perkins, 1967; White, 1991). NVDP are mainly formed as the result of polymerization of hydroproxides during frying. On the other hand, volatile compounds are formed as the result of further oxidation and cleavage of hydroperoxides (Hamilton, 1989; Hansen et al., 1994; Vercellotti et al.,1992a). Both VDP and NVDP are of critical importance to development of the best methods to measure the quality of frying oil and frying products (Wu and Nawar,1986).

Some volatile decomposition products (VDP) such as aldehydes, ketones, acids, hydrocarbons, and aromatic compounds are formed as the result of hydroperoxide cleavage (Chang et al., 1978; Fritsch, 1981; Gray, 1978; Hsieh and Kinsella, 1989). These compounds play an important role in the deep frying process because they are inhaled by the frying operator and some of them remain in the oil and absorbed in the fried products (Reddy et al., 1968; White, 1991). While some VDP are toxic, most contribute to the flavor of the oil and fried foods (Fritsch, 1981; White, 1991). Some researchers reported that the formation rate of VDP in the oil increased with decreasing quality of the oil (Dupuy at al.,1973; Ory et al., 1985). During another study, VDP such as hexanal and decadienal accelerated oxidation of unsaturated fatty acids further (Erikson, 1982).

Some researchers investigated acidic VDP and non acidic VDP. Chang et al. (1978) noted that the acidic VDP consisted of saturated acids, unsaturated acids, keto acids, hydroxy acids, and dibasic acids whereas the non acidic VDP consisted of saturated hydrocarbons, unsaturated hydrocarbons, alcohols, saturated aldehydes, unsaturated aldehydes, ketones, esters, lactones, aromatic compounds, and other compounds. A study of VDP derived from corn oil, hydrogenated cottonseed oil, triolein, and trillinolein during simulated frying resulted in the identification of a total of 211 compounds (Chang et al., 1978). Kawada et al. (1967) reported that 30 acidic compounds were identified in the VDP of corn oil during simulated frying. They also mentioned that the acidic VDP are formed predominantly as the result of breakage of the carbon chain through oxidation at an earlier stage of frying and hydrolysis of triglycerides at a later stage (after 30 hr) of frying (Fuller et al., 1971; Kawada et al., 1967; Mokherjee et al., 1988).

Another study of simulated frying also identified a total of 58 non acidic VDP (Reddy et al., 1968). The non acidic VDP are formed predominantly by decomposition of the hydroperoxides (Krishnamurthy and Chang, 1967). Reddy et al. (1968) also reported that frying oils, which contain more unsaturated fatty acids, produce more aromatic compounds, branched chain compounds, and unsaturated ketones during frying. Unlike VDP, NVDP remain in the oil. NVDP consist of unsaponifiable aldehydes, hydrocarbons, and ketones, non oxidized material, cyclic monomer materials, and cyclic and non cyclic dimers. Monomers, resulting from hydrolysis of triglycerides, may cyclize to form cyclic monomers (Meltzer et al., 1981). They may also form from decomposition of fatty acid hydroperoxides. Most of the dimeric fatty acids, which may or may not attached to a triglyceride, are formed by heating and condensation while the cyclic form may result from the Diels-Alder reaction (Perkins, 1992).

The concerns for the NVDP are not only that they remain in the oil, are involved in the browning reaction, and promote further oxidation, but they also are absorbed by the fried foods (Landers and Rathmann, 1981; Stevenson et al., 1984a). The formation of NVDP also is responsible for physical changes in frying oil such as darkening and increasing viscosity as well as chemical changes such as increasing free fatty acids, carbonyls, polar components, and the formation of high molecular products (Paradis and Nawar, 1981b; Perkins, 1967). Since NVDP accumulate in the frying oil, therefore, most of quality control measurements of deep frying oils are based on the measurement of the NVDP (Fritsch, 1981; White, 1991).

Hydrolysis

Hydrolysis of oil occurs when the hot frying oil comes into contact with the moisture from food materials and results in the formation of free fatty acids, mono and diglyceride and glycerine (Blumenthal, 1991; Fritsch, 1981; Stevenson et al., 1984a). The rate at which the oil quality decreases due to hydrolysis, as measured by acid value, is roughly correlated with the degree of saturation of the oil (Handel and Guerrieri, 1990). An increasing amount of free fatty acids in the oil leads to further changes in the oil. Such increases usually are associated with decreases in the smoke point and surface tension of the oil (Nawar, 1985a).

Besides moisture content of the food, frying temperature also affects hydrolysis reaction. The frying temperature can cause the fatty acids in the oil involved in the thermal reaction to form dimers and cyclic compounds (Melton, 1993). In addition, the accumulation of free fatty acids during frying makes them become more sensitive to thermal reaction (Nawar,1985a).

Polymerization

The long chain free radicals formed during frying can interact with each other to form dimers or other polymer compounds. Dimers are formed when two different fatty acids combine. Further reactions between two or more conjugated dienes also can yield cyclic dimers, including monocyclic dimers or tetrasubtituted cyclohexane (Chang et al., 1978; Firestone, 1967). When the oil is heated continuously, more interaction between decomposed products occurs (White, 1991). Most polymer compounds are formed by carbon-to-carbon and/or carbon-to-oxygen-to-carbon bridges among several fatty acids (Stevenson et al., 1984a).

The formation of cyclic dimers from conjugated dienes reportedly is caused by interaction involving two or more fatty acids through the Diels Alders reaction (Perkins, 1992). Meltzer et al. (1981) reported that 0.3-0.6% cyclic monomer were formed during a deep frying study using SO for 104 hr at 195°C.

Because of their high molecular weight, the polymer compounds are non-volatile and remain in the oil until the end of the frying operation, except when they are absorbed by fried food. Reportedly, the formation of polymer compounds increase significantly with the length of the frying operation (Bracco et al., 1981; Cuesta et al., 1991). Another study by Handel and Guerriery (1990) showed that polar compound formation increased with increasing amount of unsaturated fatty acid in the oil. Bracco et al. (1981) also reported that the amount of the polymer compounds increased from 0.2 to 2.4% during the first 24 hr of continuous frying. Due to their high molecular weight and low volatility, the amount of polymer compounds in the oil can be used for determining the quality of the frying oil.

As a result of the molecular changes in the frying oil, the physical characteristics of the oil also undergo some changes as frying progresses. The presence of polymer compound in the oil causes foaming and gum formation in the frying oil (Olieman, 1983). Other indications of the formation of dimer and polymer compounds are decreases in iodine value, increases in viscosity, and increases in refractive index (Nawar, 1985a).

3. CHANGES IN PHYSICAL CHARACTERISTICS OF FRYING OILS

The physical changes occur primarily when chemical structures of the native oil are altered during the frying process. Changes in physical properties of frying oil that occur during the deep frying process are darkening, increases in viscosity (Bracco et al., 1981; Timms, 1985), a tendency of the oil to foam (Berry and Awang, 1981; Smith et al., 1986), a decrease in surface tension (Berry and Awang, 1981), and an increase in dielectric constant (Fritsch et al., 1979). The increase in refractive index, viscosity, and specific gravity change during frying indicate that the oil undergoes polymerization (Coxon, 1987; Perkins, 1992). The viscosity of oil tends to increase after prolonged heating of the oil (Bracco et al., 1981). Along with viscosity increase, tendency of the oil to foam also increases with increasing heating time (Bracco et al., 1981; Stevenson et al., 1984a). The dark color in the frying oil is caused mostly by solubilization of non enzymatic browning products of food components into frying oils (Fritsch, 1981; Stevenson et al., 1984a). In addition, other studies report that the dielectric constant of oil tends to increase with increasing frying time, while the surface tension of oil tends to decrease (Augustin et al., 1987b; Fritsch et al., 1979; Frankel, 1980; Nawar, 1985a) .

4. STABILITY OF OIL DURING FRYING

The stability of oil during frying may be defined as its ability to keep a fresh taste and odor during the frying process and storage (Nawar, 1985a). Stability of

oil during frying depends upon factors such as (a) choice of frying oil, (b) type of food being fried, (c) frying conditions, (d) turn-over rate, and (e) the presence of additives (Clark and Serbia, 1991). Each factor that may affect the stability of oils during frying is discussed below.

Choice of Frying Oil

An acceptable frying oil should possess bland flavor, long frying life, ability to produce a golden brown surface on fried food with acceptable flavor, and resistance to excess smoking after continued use (Lawson, 1985). Besides flavor of the fried product, susceptibility of oil to deteriorate is another main concern for choosing the best frying oil. The susceptibility of the oil to oxidative deterioration is dependent upon the amount and type of unsaturated fatty acids, and the presence of antioxidants in the frying oil.

The amount of unsaturated fatty acids present in oil is critical to oxidative deterioration of oil during frying. During deep frying at 180°C, unsaturated fatty acids tend to oxidize and breakdown into secondary oxidation products, leading to the formation of off flavor (oxidative rancidity) in oils (Fritsch, 1981; Gray,1978; Nawar, 1985a). Rossell (1989a) stated that the relative rates of oxidation of linoleic acid is 10 times higher than that of oleic acid and 100 times higher than stearic acid. Furthermore, the oxidation rate of linolenic acid (18:3) is 15 times higher than that of oleic acid (Rossell, 1989a). The amount of linolenic acid in frying oil is critical to the quality of frying oil. Frying oil with a low linolenic level is one criteria to meet consumer demands of a good quality frying oil. To meet the demand of a low cost frying oil with low linolenic fatty acid, researchers have

developed low-linolenic soybean and canola oil through plant-breeding selection (Carr, 1991; Miller and White, 1988).

Tocopherols (alpha, beta, gamma, and delta homolog), natural antioxidants in processed vegetable oils, provide stability to the oil against oxidation (Elson, 1992). However, during the deep frying process most of the tocopherols in the oil are lost (Salunkhe et al.,1991). Therefore, the stability of frying oils are mostly dependent on other antioxidants that added intentionally to the oil, and the saturation of fatty acids in the oil (Frankel et al., 1985). In practice, the use of additional antioxidant is recommended for industrial frying (Salunkhe et al., 1991).

Soybean Oil

Unhydrogenated SO consists of oleic acid (23.4%), linoleic acid (53.2%), and linolenic acids (7.8%) (Sherwin, 1976). Usually, unhydrogenated SO has an iodine value of 110-128 and contains 940 to 1000 ppm tocopherols (Sherwin, 1976). During a repeated deep frying process, linolenic acid is the first acid oxidized, producing volatile and non volatile decomposition products (List and Mounts, 1990; Varela, 1988). The presence of the terminal 3-pentene in linolenic acid in SO is responsible for the reverted SO flavor which is describe as a beany flavor during the early stage (Frankel et al., 1985) and fishy flavor during the later stages of oxidation (Meijboom and Stroink, 1972).

For cooking and commercial purposes, most SOs are partially hydrogenated so that the oil becomes less susceptible to oxidative deterioration. Most commercial SOs used for frying have iodine values between 105-117 (Weiss, 1983). The total amounts of unsaturated fatty acid in SO may not change

drastically upon partial hydrogenation. However, the level of each type of unsaturated fatty acid in the oil changes upon hydrogenation. For example, partially hydrogenated SO with an Iodine value of 110.7 has only 3.5% linolenic fatty acid, but the oil still has 86.3% unsaturated fatty acids (List and Mounts, 1990). Researchers found that unhydrogenated SO is less stable than POO during frying (Augustin et al., 1988; Sebedio et al., 1990). However, Stevenson et al.(1984b) reported that hydrogenated solid SO performed better than liquid SO during an extended frying study. Other investigators also reported that partially hydrogenated SO (PHSBO) had better stability than POO during frying (Frankel et al., 1985; Husain, 1986). Based on the studies above, it is likely that the hydrogenation of the SO is critical for increasing oxidation stability during frying operation (Augustin et al., 1988; Husain , 1986; Sebedio et al., 1990).

Palm Olein Oil

POO is considered to be a highly stable frying medium (Berger, 1989). The percentage of major fatty acids of POO are 39.8% palmitic acid, 42.5% oleic acid, 11.2% linoleic acid, and 4.4 % stearic acid (Berger, 1992). RBD POO with an iodine value of 56.1 - 60.6 usually contains 468-673 ppm tocopherols (Goh and Ong, 1985; Hutagalung, 1987). The tocopherols in palm oil consist of 20% alpha tocopherol, 25% alpha tocotrienol, 45% beta tocotrienol, and 10% delta tocotrienol (Maclellan, 1983). The amount of saturated fatty acids (45.2% of total fatty acids in the oil) is the main reason for its stability (Berger, 1992). The compounds responsible for imparting palm aroma are aldehydes, ketones , and terpenes, such as n-nonanal (tallowy, green aroma) and 3,5,5-trimethylcyclohexanone (distinctive

palm oil-nutty aroma) (Dirinck et al., 1977; Kuntom et al., 1989).

The main advantages of using POO as frying oil is that the oil has a low rate of oxidation during frying, a low rate of polymer formation during deodorization (Willems and Padley, 1985), and during frying. Other advantage of POO that the oil has a lower tendency to foam than SO (Augustin et al., 1987c). However, the disadvantage of POO is that it has a tendency to form a darker color when used than SO (Augustin et al., 1987b; Husain, 1986). Studies comparing the frying performance of POO and SO have been conducted by several investigators. Some of the studies compared the quality of unhydrogenated SO to that of POO. Studies reported that POO had better frying performance than unhydrogenated SO (Augustin et al., 1988; Chu, 1991; Sebedio et al., 1990). Husain (1986) compared frying performance of palm oil olein and partially hydrogenated SO (PHSBO). Husain (1986) reported that the result of dielectric constant measurements of the two oils did not differ significantly during a 5-day frying period, but PHSBO did produce a significantly higher foam height than palm oil olein.

Palm Olein Oil and Soybean Oil Blend

Blending is commonly used to improve the quality of oil. The higher levels of saturated fatty acid (16:0) and monosaturated fatty acid (18:1) in POO should contribute stability, while the greater amount polyunsaturated fatty acids in SO could improve the "healthy " image of POO. DeMan et al. (1992) and Yap et al. (1989) reported that by blending SO with hydrogenated POO for soft and hard margarine preparation, soy bean oil would preserve the polyunsaturated fatty acid, while hydrogenated POO would provide the quality of the margarine by providing

prefered beta prime crystals in the product.

Blending SO with POO decreased the amounts of linolenic and linoleic fatty acids while increasing the oleic acid level in the oil blend, thus increasing SO stability (Neff et al., 1994). Blending SO with POO also resulted in a decrease in the formation of hexanal, the major volatile of linolenate hydroperoxides degradation (Neff et al., 1994).

Berry and Awang (1981) found that the iodine value of a SO blend decreased with the addition of POO, whereas the smoke point increased. In addition, measuring the frying performance of a blend of SO and POO, Berry and Awang (1981) reported that no organoleptic differences were detected among potato chips fried in various blends of the oils. Further investigation by Chu (1991) indicated that blend of SOand POO (60:40) had better heat and frying stability than SO treated with 120 ppm TBHQ and 500 ppm ascorbyl palmitate.

Oil Up Take by Food

Studies indicate that the presence of food materials in frying oil contributes to its deterioration (Brooks, 1991; White and Wang, 1986). Fat-soluble material in the food can be extracted into frying oil and contribute to deterioration of frying oil (Blumenthal, 1991). The type and condition of foods fried greatly influence the rate of the deterioration of frying oil. Oil up take is one parameter used to control the frying oil quality based on the contact between the oil and the food. Oil uptake indicates penetration of the oil into the food and possibly facilitates the extraction of fat soluble components from the food.

For a particular product such as a restructured potato, the gel strength in the

raw product and moisture retention in the cooked product increased, resulting the decreased oil uptake during frying (Pinthus et al., 1992). Another study reported that oil uptake during frying increased with increasing amylopectin content of dried keropok (Mohamed et al. 1989). However, the use of pregelatinized starch for the preparation of dried keropok resulted in a 20% decrease of oil uptake during deep frying (Yu and Low, 1992). Based on these results, it is possible that pregelatinized starch used for keropok preparation increased the gel strength of dried keropok resulting in decreased oil uptake. Since tapioca starch is the main ingredient for fish crackers (keropok) and prawn crackers, it is possible that the oil uptake of prawn crackers is similar to that of keropok.

Different preparation methods for keropok or crackers may also influence the oil uptake during cooking. Yu et al. (1981) reported that the cooked fish crackers prepared by an extrusion method have greater expansion and contain less oil than those prepared by the traditional method. Due to the nature of the extrusion process, gelatinization of the starch during cooking can be accomplished at lower temperatures than those in the traditional method (Yu et al., 1981).

Oil uptake also differs among different fried food products. Some factors that influence oil uptake are initial water content, contact surface with oil, type of food, viscosity of the fat, frying temperature, and time of frying (Guillaumin, 1988). A study of surface tension on oil uptake revealed that the oil uptake increased with increasing frying time and higher initial moisture content in the product to be fried (Lamberg et al., 1990; Pinthus and Saguy, 1994). Although fried foods can absorb 5 to 40% oil during frying, the fat absorption in some products can be controlled by reducing the moisture content of the raw product (dehydration) during pretreatment

(Nawar, 1985b). Such control combined with the type of the foods can produce some fried products with different fat levels. For example, the mean fat content in potato chips is 40.4%, but dehydration pretreatment during tortilla chips preparation resulting the fried product with fat content of 24.1% (Guillaumin, 1988). Although foods with lower initial moisture content tend to have lower oil uptake, the expansion of the fried product can cause an increase in the surface area of the food, resulting higher oil uptake on the final product. For example, during one-minute frying of fish crackers (keropok), a 9.5% moisture in the raw material produced 95.5% linear expansion after frying, resulting in a 30% oil content in the fried product (Siaw., 1985; Yu and Low, 1992).

Frying Conditions

Frying conditions that influence frying performance are temperature, oil surface area, and frequency of frying during the whole frying operation. A frying temperature higher than 196°C will reduce oil stability, whereas a frying temperature less than 180°C makes the frying operation less effective (Gere, 1983; Lawson, 1985). In addition, for an increased oil fry-life, reducing the oil temperature is necessary to prevent oxidation when the oil is not being used for long periods of time (Weiss, 1983). The surface area of the frying kettle also contributes to the rate of oil oxidation. Bracco et al. (1981) reported that frying stability (measured by an increase in petroleum ether insoluble, oxidized fatty acid content up to 1%) tended to increase with decreasing frying surface. Increasing frying temperature and frying time results also in decreasing frying stability (Blumenthal, 1991; Brooks, 1991; Sims, 1994). Intermittent frying resulted in

more oil oxidation than continuous frying (Gere, 1983). The heating and cooling cycles during intermittent frying of the oxidation reaction is the main reason for a higher rate of the oxidation reaction. During heating additional free radicals are formed, but the solubility of oxygen decreases with increasing temperatures (Gere, 1983). However, during cooling, the dissolved oxygen content in the oil increases, and the available free radicals have greater contact with the increased oxygen content, resulting in a reaction rate increase (Gere, 1983).

Turn-Over Rate

"Turn-over" refers to the amount of frying oil in the frying kettle replaced by fresh oil to maintain a certain volume of oil in the fryer kettle over a given period of time (Lawson, 1985; Stevenson et al., 1984a). Due to oil absorption by fried foods, the frying fat in the frying kettle must be replenished to maintain a specific level. Absorption of frying oil and addition of fresh oil, consequently, reduce the concentration of NVDP in the oil and prolong the life of frying fat (Rojo and Perkins, 1987). High efficiency frying (high turn-over rate) is maintained by adjusting the quantity of foods being fried based on their moisture content (Morton and Chidley, 1988). Moreover, in a well-organized operation, the equilibrium between the addition of fresh oil and the amount of oil absorbed by the fried food minimizes the extent of oil degradation caused by heat or oxidation (Morton and Chidley, 1988).

The Presence of Additive

The presence of a food additive such as an antioxidant can be used to retard oxidation during the deep frying operation. Tocopherols, natural antioxidants, are

found in both processed SO (940-1000 ppm) and palm oil (560 ppm) (Sherwin, 1976). The residual level of tocopherols in processed SO appears to be optimum for providing oxidative stability, but further processing or frying could strip the residual tocopherols from the oil completely (Miyagawa et al., 1991; Sherwin, 1976). Similarly, tocopherols and tocotrienols in POO decompose with increasing frying time (Sakata et al., 1985). Thus, the use of chemical antioxidants, other than tocopherols, is necessary for commercial deep frying (Asap and Augustin, 1986; Salunkhe et al., 1991).

Chemical additives that can prolong the life of an oil during frying include butylhydrotoluene (BHT), butylhydroyanisole (BHA), methyl silicones, and tertiarybutylhydroquinone (TBHQ). Augustin and Berry (1984) reported that BHT is more effective than BHA in maintaining the quality of frying oil. Augustin and Berry (1984) found that more BHT than BHA was absorbed by the food being fried, but more BHA than BHT was loss from the frying oil by vaporization. Warner et al. (1985) determined that the stability of SO during frying can be improved by addition of methyl silicone or TBHQ. Ahmad and Augustin (1985) also reported that TBHQ improved the stability of palm oil for frying fish crackers. Augustin et al. (1987a) found that addition of 2.0 ppm methyl silicone to RBD POO without additional antioxidants reduced the level of polar components (a measure of oil degradation) in POO by a factor of two. The additives of choice to prolong the life of a frying fat are TBHQ, methyl silicones, and citric acid, a prooxidant metal chelator (Chu, 1991; Weiss 1983).

In addition to prolonging frying life of the oil, chemical antioxidants also can be used to improve the quality of fried products. Higher flavor quality scores of

breads fried in hydrogenated SO have been obtained by addition of TBHQ and methyl silicone to the frying oil (Frankel et al., 1985). Ahmad and Augustin (1985) in another study reported that fish crackers fried in RBD POO containing TBHQ were more stable toward oxidative rancidity than the control fish crackers fried in RBD POO without TBHQ. Augustin and Berry (1984) measured antioxidants from tapioca chips fried in RBD olein and reported that TBHQ was more effective than BHT or BHA in preventing oxidation of the chips during 43 d of storage. However, Fritsch et al. (1975) reported that the superiority of TBHQ over BHT and BHA was dependent upon the frying conditions. During mild (one hr frying at 190°C) frying condition, TBHQ has greater carry-through than BHT, while under more severe frying condition (five hr frying at 190°C), TBHQ provided less protection than BHT (Fritsch et al., 1975).

5. METHODS FOR MEASURING PERFORMANCE OF FRYING OIL

Chemical reactions which take place during frying produce both VDP and NVDP which alter physical and chemical characteristics of frying oils. Under normal frying conditions, 5 to 15% of the frying oils are converted to VDP but only 1% of the VDP remain in the oil due to vaporization (Melton et al., 1994). Methods which have been used to investigate the deterioration of frying oil based on the change in unstable or VDP are level of conjugated dienoic acid (Method Ti 1a-64; AOCS,1983), free fatty acids (method 28.032; AOAC, 1984), peroxide value (Method Cd 8-53; AOCS, 1983), carbonyl compounds (Przybylski and Hougen, 1989; White and Hammond, 1983), acid value (Method Cd 2.201; AOCS, 1983),

pentane measurement (Warner et al., 1974), and volatile concentration (Dupuy et al., 1973).

Other methods based on the measurement of NVDP. These methods include measurement of polar components (Method 28.074; AOAC, 1984), fatty acids (Ackman, 1993; Method cE 1-62; AOCS, 1983), linoleic/palmitic fatty acid ratio (Augustin et al., 1987a), Iodine value (Method 28.023; AOAC, 1984), polymeric triglycerides by liquid chromatography (Wachob, 1993), and alkaline contaminant materials (Blumenthal at al., 1985). Other methods for measuring frying oil deterioration are based on the physical characteristics of the oil as affected by frying operation (White, 1991). Some of those methods include color (Method Cc 13c-50; AOCS, 1983), foam height (Fritsch et al., 1979), refractive index, dielectric constant (Fritsch et al., 1979; Graziano, 1979), oil stability instrument (OSI) (Hill, 1994), and smoke point (Method Cc 9a-48; AOCS, 1983).

For practical purposes for use in food industries, some rapid methods have been developed for measurement of frying oil degradation. Some of these based on VDP measurements include the Fritest for carbonyl compounds (Croon et al., 1986), spot test for free fatty acids (Robern and Gray, 1981), and shortening monitor test for free fatty acid content. Other quick tests based on NVDP include RAU test (Meyer, 1979; Pazola et al., 1983), the WET test for alkaline contaminant materials (Nair and Blumenthal, 1994), and TPM test for total polar materials (Blumenthal et al., 1993). Another practical approach to evaluate the quality of frying oil is using various types of sensory evaluation methods (Mounts and Warner, 1990). Although the methods that are based on measuring NVDP are most often used, apparently, there is no one best method that meet both practical

and research point of view (Melton, 1994).

All methods mentioned above work well on a single frying oil measurement but some of them may not appropriate for measuring a blend of two or more different oils. A study determining the frying performance of a blend of soybean-POO and soybean-sesame oil (Chu, 1991) suggests that some methods cannot be used for determining oil performance of oil blends. Anisidine value, carbonyl value, acid value, and fritest cannot be used for complete observation because the oxidative stability of the oil is affected by the addition and blending of the oils (Chu, 1991). Also, color and viscosity measurement cannot be used as indicators for oil deterioration of an oil blend due to the variability of the color and viscosity of the original oil. Therefore, the measurements may not be significantly different from that of the SO control (Chu, 1991). However, Chu (1991) also stated that total polar components, dielectric constant, refractive index, and iodine value are reliable parameters for the assessment of oil blend performance. Further explanation of some methods are presented in the following sections.

Total Polar Components

Total polar components of the oil is the sum of those materials which are not triglycerides and proceed from low to high concentrations during frying (Blumenthal, 1991). In fresh oils, the polar components consist mainly of terpenes, sterols, and conjugated dienes (Wachob, 1993). The principle measurement of total polar components is utilization of polarity differences to separate oil fractions through selective wash solutions (Wachob, 1993). Determination of total polar components has been widely accepted as an accurate and reproducible method for

measuring frying oil deterioration (Billek et al., 1978; Fritsch, 1981; White, 1991). Such a method has been approved as the standard method by IUPAC (1987) and AOAC (1984).

The polar components measurement is time demanding and labor extensive, which is one of the disadvantages of this method (White, 1991). Because the method is laborious, researchers have resorted to a modified method, using solid phase extraction with silica gel disposable cartridges (Melton et al., 1994). These modifications may result in high or low estimates of the total polar components, depending on the activity of the silica gel. The polarity of the silica gel is dependent on the water content in the silica gel, which differs among sources, and among lots within single sources (Melton, 1994). Wachob (1993) noted similar problem with the original method in that improper conditioning silica gel packing can yield inaccurate estimates of the level of total polar component in an oil.

Researchers have reported that concentration of total polar components determined in frying oil were found to have high correlations with other measurements of frying oil deterioration (Augustin et al., 1987a; Chu, 1991; Yoon et al., 1985). The increase of total polar components has been found repeatedly to be significantly correlated with changes in the dielectric constant (Al-Kahtani, 1991; Augustin et al., 1988; Fritsch et al., 1979; Perez-Camino et al., 1991; Yoon et al. 1985). Investigating the total polar compounds of fifty commercial frying oils, Lumley (1988) reported that unused oil contained 0.4-6.5% total polar components, while the used oils contained 4-46% total polar components. Generally the total polar components level of 27% is used as an indicator for the cut-off point of using frying oil as reported by some investigators (Firestone et al.,

1991).

Fatty Acid Analysis and 18:2/16:0 Ratio

Based on the changes in the oil during frying, researchers have suggested that fatty acid composition changes are good predictors for measuring frying oil quality. Measuring the loss of polyunsaturated fatty acids as the primary changes during lipid oxidations is the principle of this measurement. This method is now an approved method by AOCS (White, 1991). Miller and White (1988) reported that the percentages of unsaturated fatty acids (such as linoleic and linolenic fatty acids) tend to decrease during frying, while the percentages of saturated fatty acids tend to increase in SO heated at 180°C for 40 hr. Augustin et al. (1987c) found that fatty acid changes as measured by an 18:2/16:0 ratio was correlated with both total polar components and dielectric constant measurements.

Free Fatty Acid

Free fatty acid (FFA) measurement also has been used to measure frying oil deterioration. During laboratory frying studies, the FFA content of frying oil was affected by the type of frying oil and the type of food being fried (Lin, 1993). Cuesta et al. (1991) reported that after frying 15 batches of potato chips, linoleic and oleic acids of olive oil showed a tendency to decrease while saturated fatty acid tended to increase. The unsaturated/saturated acid ratio decreased from 7.05 to 6.40 from first to the last batch fried (Cuesta et al. 1991). Husain (1986) in a frying study comparing frying performance of palm oil and partially hydrogenated SO reported that the percentage of FFA in the oils used for frying was correlated

with the level of total polar components. However, Al-Kahtani (1991) reported that the percentage of FFA did not correlate with the total polar components. For determination of the frying performance of oil blends, Chu (1991) stated that in addition of FFA determination, some other methods should be employed to get more accurate observations.

Dielectric Constant

The dielectric constant indicates that oxygen is incorporated into the fat (Perkins, 1992). It also represents the net balance between polar and nonpolar components (Nawar, 1985). Dielectric constant (DC) measurement or Food Oil Sensor (FOS) reading is considered a rapid method that is highly accurate in measuring frying oil deterioration (Fritsch et al., 1979; Graziano, 1979). Also, this method is correlated well with total polar component measurement (Billek et al. 1979; Chu, 1991; Fritsch et al. 1979; Husain, 1986). The only drawback of DC measurement is that the instrument needs to be calibrated with the same fresh oil before it can be used for other measurements in that oil (Paradis and Nawar, 1981a).

A measurement of a dielectric constant or FOS reading of 4.0 by the Food Oil Sensor is widely accepted as a limit beyond which frying oil should be discarded (Chu, 1991; White, 1991). The increase in FOS during frying measured by the Food Oil Sensor correlated significantly with the increase in total polar materials, color change, peroxide value, diene content, and the decrease in iodine values (Chu, 1991). Since dielectric constant measurement can be conducted more rapidly than total polar component methods, this method is used more widely in food industry.

Conjugated Dienoic Acid

Dienoic compounds are formed as the result of condensation of two or more free unsaturated fatty acids in the presence of heat (Chan et al., 1982). The dienoic compounds can be formed as the result of condensation of peroxides or condensation of free unsaturated fatty acids (Croon et al., 1986; Gray, 1978). The formation of dienoic compounds reportedly occurs during both heating and deep frying studies (Berry and Awang, 1981; Chu, 1991; Husain, 1986). Augustin and Berry (1983) reported that dienoic content in POO increases when the oil is heated at 180°C for 8 hr. Another investigator reported that deep frying increases the dienoic content of all different oils studied (Husain, 1986). Conjugated dienoic compounds, which can be formed as the result of oxidized unsaturated fatty acids, can be measured using ultraviolet absorption at 233 nm (Gray, 1978).

The amounts of unsaturated fatty acids in the oil is critical for the formation of dienoic compounds during frying. Fritsch et al. (1979) found that the increase in the conjugated dienoic content was greatest in SO, followed by hydrogenated vegetable oil and animal shortening when each was heated at 190°C for 8 hr. Currently, SO with low linolenic acid, developed trough selective genetic breeding are available in the market (Mounts et al. 1994). However, Miller and White (1988) found that SO, which contained 3.5% or 7% linolenic acid, produced about the same amount of conjugated dienoic compounds when they were heated at 185°C for 40 hr. Croon et al. (1986) reported that conjugated dienoic compound levels in frying oils have a high correlation with total polar components and the dielectric constant.

RAU Test

The RAU test is a colorimetric test with redox indicators which react with all of oxidized compounds in a frying fat. The RAU test value is determined by comparing the developed color mixture of the oil and the reagents with the standard scale containing four color standards (blue, green blue, green olive, and olive). Evaluating 100 samples of frying oils from fast food restaurants, Croon et al. (1986) reported that the measurement of oil degradation, using the RAU test correlated well with the measurements of polar components and FOS readings. Meyer (1979) reported a high correlation between the RAU test and the level of petroleum ether oxidized fatty acids in frying oils. The RAU test can be obtained in the Teskit form.

FRITEST

The Fritest can be obtained in a colorimetric test kit for measuring the concentrations of carbonyl compounds in frying oil (Croon et al., 1986; White, 1991). The developed color from the mixture of oil and reagent is compared to a three color scale where 1 (clear yellow) = good; 2 (dark yellow) = intermediate; and 3 (dark reddish) = bad oil condition. Croon et al. (1986) reported that Fritest measurement correlated well with total polar components concentration. This test, however, is not used extensively to determine oil degradation in the USA.

Color

The standard color measurement of oil is based on AOCS (1983) Method Cc 13c-50. The unit of that color is a photometer color index which represents the average absorbance reading at four wavelengths (AOCS, 1983). Chu (1991) reported that the photometer color index within the same oil increased with frying time. However, the color index of the oil samples cannot be compared across the frying oils due their initial color differences (Chu, 1991). Pazola et al. (1983) in another study reported that color test on frying oil with bromothymol blue correlated well with measurement of fatty acids insoluble in petroleum ether. Pazola et al. (1983) also suggested that bromothymol blue color test along with dielectric constant measurement and sensory evaluation are suitable quality control measurements for both fast food outlets and deep frying industries. However, there is limited information on the basis of the measurements used and the reliability of the color test mentioned by Pazola et al. (1983).

Presently, a spectrophotometer equipped with color software, which can measure the color of any oil and express the result of color measurement in the CIE systems, the Hunter system or other color system, using its correspondent parameters (Aurand et al., 1987; De Man, 1980), is available in the Department of Food Science and Technology at the University of Tennessee. Using this same software, the color difference, ΔE, between fresh and used frying oil samples can be calculated by computer. Several researchers (Husain, 1986; Jafar, 1989; Melton et al., 1994) reported ΔE to increase with increasing degradation in frying oil and to be correlated significantly with increases in free fatty acid content, total polar component concentration and dielectric constant measured by the Food Oil

Sensor. Color measurement of frying oil (to measure darkness of the oil) is often used in restaurants and fast food outlets by the operators using their own visual to assess frying oil degradation (Melton et al., 1994).

6. METHODS FOR EVALUATING FRIED PRODUCTS

Oxidative rancidity of fats in fatty foods is responsible for off-flavor and deterioration of fried products. Oxidative rancidity is caused by oxygen attack on the unsaturated fatty acids of the product, which further produces secondary oxidation product and off-flavor (Rossell, 1989a).

The off flavors are dependent upon the types and concentrations of volatile compounds, particularly the aldehydes in the fried product. The characteristics flavors and sensory thresholds differ among aldehydes. According to Health and Reineccius (1986), saturated aldehydes of low molecular weight (MW) possess unpleasant, pungent, irritating odors which change in profile to a pleasant, fruity character with increasing MW up to C8-C10 aldehydes. With continued increase in MW, the aldehydes develop a waxy odor character. The unsaturated aldehydes have particularly irritating odors (Heath and Reineccius, 1986). Frankel et al. (1985) reported that the threshold values of alkanals were 0.05 to 1.0 ppm; trans-2-alkenals were 0.05 to 2.5 ppm; and of trans, trans-2,4-alkadienals were 0.05 to 0.3 ppm. A change in the geometrical configuration around the double bond from trans to cis configuration decreases the thresholds. For example, cis-2-alkenals have threshold values from 0.0003 to 0.1 ppm and trans, cis-2,4-alkadienals have threshold values from 0.002 to 0.006 ppm (Frankel et al., 1985). However, the

characteristic flavors and thresholds are dependent on the specific aldehydes. Trans-2-hexenal, one of the most common aldehydes monitored for oxidation in fried products, is reported as a green flavor at concentration as low as 0.6 ppm (Hudson, 1989). Other aldehydes such as trans-2-cis-6-nonadienal and trans-6-nonenal exhibit flavor thresholds of 0.0015 and 0.00035 ppm, respectively (Hudson, 1989).

Flavor and Shelf Life of Fried Products

The shelf life of fried products is defined as the time needed to develop unacceptable, rancid flavor (Augustin et al., 1988). It was reported that sensory acceptability of various deep fried products decreased with increasing storage time (Pokorny, 1994). The flavor acceptability of such products commonly is determined by sensory evaluation using a hedonic scale (Berry and Awang, 1981; Jafar, 1989). However, chemical measurements of oxidation, in combination with sensory evaluation, also are used to evaluate the extent of oxidation during shelf life studies (Rossell, 1989a,b; Stevenson et al., 1984a). These chemical measurements include determination of peroxide value of food lipids, changes in types and concentrations of flavor volatiles, and dienoic acid levels (Miller and White, 1988; Pokorny, 1989).

In some studies, the point at which a fried food product becomes rancid can be assessed by chemical measurements. Warner et al. (1978) reported that flavor scores of fried foods were highly correlated with peroxide values and the amounts of pentane and hexane detected by GC in the headspace of the food products. Vercelloti et al. (1992b) reported that hexanal concentrations exceeding 5 ppm in

the headspace indicate a rancid product. Other investigators reported that thermally released pentane measurements were highly correlated with peroxide value measurement of SO (Evans et al., 1969).

The acceptability of fried foods, as dictated by the types and concentration of volatile compounds, is influenced by the content of unsaturated fatty acids in the fried product and the extent of oxidation that has taken place during frying and storage (Min and Schweizer, 1983). In foods fried in SO, which has 7.5 to 8% linolenic acid, flavor reversion of the fried products reportedly makes the food unacceptable. Some of the flavor components responsible for flavor reversion in SO include cis-3-hexenal (green bean odor), trans-2-hexenal (green, grassy), trans-2-nonenal (rancid), 2-trans-6-cis nonadienal (cucumber flavor), 10-oxo-8-octadecenoic acid and 9- and 10-hydroxy octadecenoic acid (DeMan, 1980; Endo et al., 1991). In contrast to food fried in SO, food fried in the more saturated POO would be expected to have a longer shelf life since saturated fat is less prone to oxidation. Indeed, Augustin et al. (1988) found that potato chips fried in POO had a significantly longer shelf life than those fried in unhydrogenated SO.

Peroxide Value

According to Rossell (1989b), peroxide value measurement is one of the most common methods in rancidity measurement. Peroxide value is reported in unit of milliequivalent of oxygen per kilogram of fat. This method is a very sensitive indicator of the early stages of oxidative deterioration (Hudson, 1989; Nawar, 1985a). However, Fritsch (1994) stated that peroxide measurement is reliable only if the food contains more than 10% fat and has a continuous lipid phase. Another

criterion is that the oil sample should be tested following proper extraction from the food (Fritsch, 1994). Since peroxides and hydroperoxides are unstable, they will breakdown at ambient temperatures to yield a range of volatile components such as aldehydes, ketones, acids, alcohols and other compounds (Gray, 1978). As the result of the instability peroxides and hydroperoxides , the result of peroxide value measurement would dynamically change with increasing frying time (Gray, 1978; Perkins, 1967).

When the rate of degradation of peroxide exceeds the formation rate, the peroxide measurement is no longer valid (Sims, 1994). Because peroxide value is empirical, the result and accuracy of the test are affected by experimental conditions. One is the condition that favors the formation of peroxides over the decomposition (Fritsch, 1994). This method measures the iodine produced from potassium iodide in the presence of peroxides in the oil (Swern, 1964). The common problem in this method is that iodine is absorbed also by the unsaturated bonds of fatty materials and liberated from potassium iodide by oxygen present in the solution to be titrated (Gray, 1978). Another source of error is that new peroxides can be formed during oil extraction from the food due to solvent evaporation (Rossell, 1991). Besides possible error, the weakness of peroxide value determination is that the method cannot detect a low level of VDP that has undesirable flavor such as 6-t-nonenal which causes green-melon off flavor (Rossel, 1989b).

The peroxide value of oil extracted from potato chips stored under the light at ambient temperature increases with storage time (Han, 1989, Lin, 1993). However, Hudson (1989) stated that peroxides and hydroperoxides can breakdown

at ambient temperatures. At 100°C, breakdown takes place in a matter of days resulting in a fall in peroxide value due to decomposition of peroxides (Hudson, 1989). Thus, the temperature and the length of frying with continued frying time may accelerate the decomposition instead of accumulation peroxides.

Other methods have been used in conjunction with the peroxide value to assess oxidation during storage of fried foods. Oxygen absorption rate is more acceptable indicator than peroxide value for total oxidation, especially when peroxide rate of decomposition exceeds the rate of formation (Jarvi et al., 1971; Sims, 1994). Other methods include the amount of flavor volatiles in the headspace or food product (Min and Schweizer, 1983). Przbyiski and Hougen (1989) in another study reported that estimation of volatile carbonyl compounds in stored fried products using a spectrophotometric method can be used to indicate the extent of oil oxidation that has occurred in fried products. However, no report was found on the relationship between this measurement and peroxide value. Another method based on the measurement of octanoate that remains attached to the glycerol after thermal decomposition also has been correlated to peroxide value (Peers and Swaboda, 1979). It was reported that methyl octanoate determinations have a linear relationship with peroxide value produced after thermal decomposition of the oil (Peers and Swaboda, 1979). However, this method is only applicable to oils that have very low octanoate values, such as sun flower and linseed oil.

Several methods for evaluating the oxidation of frying oils and fried products have been developed. Researchers have been using physical and chemical methods along with sensory evaluation methods to determine the extent of oil oxidation of frying oil and fried products. However, since a deep frying process is a dynamic

system, where different kinds of materials from foods may interact with any frying oil in the presence of heat, the extent of oil oxidation of frying oil and fried product is affected by different factors, including the nature of the food being fried. Therefore, the most reliable methods to measure the extent of oxidation of frying oil and fried product are those that are most reliable yet practical to meet the goal of any particular deep frying operation.

CHAPTER III

MATERIALS AND METHODS

1. MATERIALS

Unhydrogenated SO and POO (both refined, bleached and deodorized) were obtained from an oil/fat processor in the USA. Dried, prepared prawn crackers (91 kg) were obtained from South land Traders Inc., San Francisco, CA. Enough oil and crackers were purchased at one time to complete the planned experiment. Solvents, chemicals, and other materials necessary for the methods of analysis for frying oil deterioration, and for chemical analysis of flavor and stability of the prawn crackers, except for specific test kits, were purchased from Baxter Scientific Products (Stone Mountain, GA). Test kits for measuring total oxidative components (Oxifrit or RAU test) and for measuring total carbonyl compounds (Fritest) were obtained from Tennessee Reagents, Nashville, TN.

2. EXPERIMENTAL DESIGN

The design of the experiment was a split plot. The whole plot was the type of oil used for frying. Each plot was split by sampling period (SP) and frying time (DAY). This experiment consisted of frying prawn crackers intermittently in four different oils/blends: unhydrogenated SO, POO, 80:20 w/w SO:POO, and 60:40 w/w SO:POO. During the study a different frying ketle was used for each oil/blend,

and frying was conducted in all oils/blends simultaneously. Prawn crackers (50-g batches) were fried in each oil/blend at 190°C for 12 sec every 30 min for seven hr/day for five consecutive days. Oil samples were obtained at two different sampling periods and on each day of frying (sampling time). The two periods were at the end of each day of frying before make-up oil was added, and at the beginning of each frying day after make-up oil was added. Oil samples were analyzed by quick tests for carbonyl compounds (Fritest), oxidized compounds (Oxifrit test or RAU test), and the dielectric constant (Food Oil Sensor). Oil samples also were analyzed for concentrations of free fatty acids, total polar components, conjugated dienes and linoleic/palmitic acid concentration ratio, and for the Hunter Color Values, *L, a, b,* and ΔE, and fatty acid composition.

For the investigation of storage on the characteristics and flavor of the prawn crackers, crackers fried during the last four hr of the first day of frying and during the second and third day of frying in each oil/blend were frozen and stored under nitrogen at -18°C until all fried crackers had been collected. Then the crackers, which were fried in one oil/blend, were mixed carefully to obtain as much of a homogeneous mixture as possible. Samples (100 g) were obtained from this mixture and stored in sealed 1.9-L clear glass jars for zero wk (fresh conditions) and at ambient temperature in the dark or under fluorescent light for 4 wk. All stored crackers were evaluated for sensory characteristics of color, flavor, and overall likability. Crackers stored for zero wk and for 4 wk in the dark or light also were analyzed for types and concentrations of flavor volatiles.

A replication consisted of frying the crackers in the four different oils/blends for five days and the storage of the fried prawn crackers for zero wk and 4 wk in

the dark or under fluorescent light. Two replications were completed.

3. FRYING PROCEDURE AND CHIP STORAGE

Just prior to the start of the frying experiment, 8.00 kg of an 80:20 w/w SO:POO blend and 8.00 kg of a 60:40 w/w blend of SO:POO were prepared as follows. For each replication, the 80:20 w/w SO:POO blend was prepared by mixing 6.4 kg of SO with 1.6 kg POO in a 19-L bucket. Similarly, the 60:40 SO:POO was prepared by mixing 4.8 kg of SO and 3.2 kg POO in a 19-L bucket. Two other 19-L buckets each containing 8 kg SO or POO, were used also for each replication. All oils in 19-L buckets which were flushed with nitrogen before sealing and were stored at room temperature (25°C) until they were used.

Before the frying operation started, 2,820 g of each fresh oil/blend was added to a separate Dazey Chef's pot 3.8-L fry kettle and heated to a temperature of 190°C for one hr. Before the oils were heated, a 200-g sample of each fresh oil/blend was obtained and stored under nitrogen in a 0.45-L sealed glass jar at -18°C in the dark until analyzed. One hr after the oil was heated at 190°C, frying of 50-g batches of prawn crackers in each of the four oil/blends was started. At the end of each day of frying, each oil/blend was cooled to approximately 60°C, and filtered through a paper filter (Scruggs, Inc., Restaurant Equipment, Knoxville, TN). A 200-g sample of each oil/blend was obtained from the filtered used oil and treated in the same manner as the fresh sample. The remaining oils/blend were flushed with nitrogen and stored overnight in a sealed container.

The fry kettles also were cleaned daily by being washed thoroughly with hot

soapy water followed by a clear water rinse, a vinegar water rinse and then a second clear water rinse before being allowed to drain dry. At the beginning of the next day, each filtered oil/blend was added with enough of matching fresh oil/blend to make up for the oil absorbed by the crackers and that lost during filtration, cleaning and sampling. Therefore, at the beginning of each frying day a total of 2820-g of oil was added back to the same fry kettle used the previous day. A 200-g sample of each oil/blend was obtained after the make-up oil was added and mixed with the filtered oil from the previous day. This sample was treated in the same manner as described previously. Each oil/blend was heated to 190°C for one hr before frying prawn crackers was started. The daily frying, cleaning, and oil sampling procedures were repeated daily through the fifth day of the frying operation.

Fresh prawn crackers or those stored for zero wk were placed in 1.9-L jars, flushed with nitrogen, sealed, placed in an opaque cardboard box, and kept at -18°C for further analysis. Fried crackers stored for 4 wk in the dark were packaged in the 1.9-L glass jars, placed in the cardboard boxes and stored at ambient temperature (25°C) for 4 wk before being flushed with nitrogen, resealed, and kept at -18°C until analyzed. Fried crackers, stored under fluorescent light for 4 wk, were placed in sealed 1.9-L jars which were turned upside down for exposure to the light. These latter chips also were stored at ambient temperature in the same room as those stored in the dark before being treated in the same manner as the other chips prior to analysis.

4. EVALUATION OF OIL SAMPLES

Rapid Tests

All oil samples (n=80) were evaluated by the quick tests: (1) dielectric constant as measured by the Food Oil Sensor, (2) RAU test (Oxifrit-test), and (3) Fritest. The dielectric constant of each oil sample was determined following the procedure described by Fritsch et al. (1979). A Food Oil Sensor, model NI-20 (Northern Instruments Crop, Lino Lakes, MN, USA) was used. The instrument was calibrated to 0.0 with fresh oil prior its being used for measurement of the same oil sample used for frying. The instrument reading ranged from 0.0 to 6.0.

The RAU or Oxifrit test was conducted following a procedure described by Croon et al. (1986). Two drops of oil sample were inserted into a tube containing redox indicators from the test kit. The final color change of the oil sample in the tube was compared with four diagnostic color standards: blue or value 1, green blue or value 2, green olive or value 3, olive brown of value 4 to determine the levels of oxidized compounds present. Low levels of oxidized compounds in the frying oil resulted in a level 1 or a acceptable frying oil while high levels of oxidized compounds resulted in a level 4 or degraded frying oil.

Fritest, a sensitive test for carbonyl compounds, was conducted following the procedure described by Croon et al., (1986). A mixture of oil sample and reagent was compared with the three diagnostic colors. A clear yellow color indicated a low concentration of carbonyl compound or level 1 (fresh oil); a dark yellow, an intermediate concentration or level 2 oil; and dark reddish color, and the highest concentration of carbonyl compounds or level 3 (degraded) frying oil. Each

oil sample after reaction with the reagent was assigned a Fritest value from 0.5 to 3.0 in steps of 0.5 based on the comparison with these color standards.

Chemical and Physical Analyses

The C18:2/C16:0 ratio was determined for all oil samples (n=80) following a procedure developed by Augustin et al. (1987a). The fatty acid composition of each oil sample was determined as described later, and the percentage of C18:2 (linoleic acid) in each oil sample was divided by the percentage of C16:0 (palmitic acid).

Dienoic acid measurement was determined on all oil samples (n=80) according to the AOCS (1983) Method Ti 1a-64. One (1.000) gram of oil sample was diluted with 2,2,4-trimethylpentane (isooctane) to a concentration of 0.1000 g/L solution. The absorbance of the sample was measured at 233 nm against a pure isooctane blank in 1.00 cm quartz cells, using a Shimadzu Model spectrophotomter (Shimadzu Scientific Instruments, Columbia MD). The percentage of conjugated dienoic acid in the sample was determined based on a standard curve and the absorbance value of the oil sample.

Color determination of the frying oils was conducted using a Shimadzu spectrophotometer equipped with color software. To determine color of each oil sample, an oil sample in a liquid form was placed in a 1-cm cuvet, and the spectrum of direct absorbance in the visible ranges was obtained using Shimadzu spectrophotometer Model UV-2101 and PC 160 plus personal spectroscopy software version 1.4 (Shimadzu Scientific Instrument Inc., 1992). The absorbance spectrum of the oil was further analyzed using UV-2101/3101PC optimal color

analysis software version 2,0 (Shimadzu, Scientific Instrument, Inc., 1994) to express the results of color measurement in the Hunter color values, L, a, b of each oil, and the color differences (ΔE) between the fresh and used samples of each oil/blend.

The free fatty acid content was analyzed only on the frying oil samples (n=40) that were taken at the end of each day of frying. This measurement was determined as the percentage oleic acid according the AOCS (1983) Method Ca-5a40. A 50.00 g sample of oil was mixed with neutralized 95% ethyl alcohol and phenolphthalein indicator. A 0.1 N sodium hydroxide solution was used to titrate the mixture until a light pink color appeared (end point). The amount (milliequivalent) of sodium hydroxide required for the titration of the sample was used to calculate the percentage of free fatty acids in the oil.

The levels of total polar components were analyzed only on oil samples (n=40) taken at the end of each day of frying. They were determined by following AOAC (1984) Method 977.27. Total polar materials were determined by dissolving 2.5 g of fat in 150 mL petroleum ether-diethyl ether mixture (PE:EE), 87:13, v/v and loading on a silica gel column packed with silica gel 60 adsorbent (70-230 mesh, Sigma Chemical Co. St. Lois, MO). The non polar lipid were eluted within 60-70 min by controlling eluent flow rate the column. The nonpolar fraction by 87:13 PE:EE solvent was collected, and the weight of the dried residue in that fraction determined for the weight of the nonpolar fraction in the oil sample. The weight of polar material in the 1.000 g oil sample was calculated by difference between the total weight of the sample and the weight of the nonpolar fraction. The percentage of total polar components then was calculated.

Fatty Acid Composition

The fatty acid composition of all oil samples (n=80) was determined by the AOCS (1983) Method Ce 2-6 reported by Ackman (1993). The fatty acid composition of the oil sample was determined by converting the triglycerides into fatty acid methyl esters (FAMEs) followed by gas chromatographic (GC) analysis. The relative percentage of each fatty acid was determined, using a 30-m x 0.25 mm i.d. fused silica SP2330 capillary column (Supelco, Bellefonte, PA) in a Shimadzu 9AM gas chromatograph equipped with a flame ionization detector (Shimadzu Scientific Co., Inc. Columbia, MD) and a Shimadzu CR501 Cromatopac electronic integrator. The GC injector and detector were operated at 250°C. Each sample was analyzed using a temperature program from 130°C to 220°C at the rate of 2°C/min. Standard solutions containing known concentrations of the FAMEs similar to the concentrations present in the samples were analyzed by GC. Correction factors versus palmitic acid (C16:0) to correct for differences in molecular weight among the different fatty acids and the nonlinearity of the detector response (AOCS, 1983) were obtained from analyses of these standards. Positive identification of individual FAME was made by matching the retention times of the sample peak with the corresponding retention time of known standard when analyzed under identical conditions as the sample. The percentage by weight of total fatty acids for each fatty acid was calculated in each oil sample. The following fatty acids with shorthand notation were determined: dodecanoic (C12:0), tetradecanoic or myristic (C14:0), hexadecanoic or palmitic (C16:0), 9-hexadecenoic or palmitoleic (C16:1); 9-trans hexadecenoic or palmitoelaidic (C16:1t); octadecanoic or stearic (C18:0); 9-octadecenoic or oleic (C1:1); 9,12-

octadececadienoic or linoleic (C18:2); eicosanoic or arachidic (C20:0); 9,12,15-octadecatrienoic or linolenic (C18:3); 11-eicosenoic (20:1); 11,14-eicosadienoic (C20:2); 8,11,14,-eicosatrienoic (C20:3); docosanoic (C22:0); tetracosanoic (C24:0); 7,10,13,16-docosatetraenoic (C22:4); 7,10,13,16,19-docosapentaenoic (C22:5); and 4,7,10,13,16,19-docosahexaeoic (C22:6).

5. EVALUATION OF PRAWN CRACKERS

Chemical Composition of Prawn Crackers

The chemical composition of shrimp crackers (moisture and fat contents) were determined before and after frying. Moisture content of the crackers was determined with the vacuum-oven method (AOAC, 1990). The fat content of the cracker samples was evaluated following the Goldfish method using petroleum ether as the solvent (AOAC, 1990).

6.FLAVOR VOLATILE ANALYSIS AND SENSORY EVALUATION

Flavor Volatile Analysis

The flavor volatiles of the crackers were extracted with the modified simultaneous distillation extraction (SDE) method. Crackers (125g) were blended with 960 mL warm (60-70°C) HPLC grade water in an Ozterizer commercial blender for 5 min. The emulsion was transferred into a 1000-mL round bottom flask with an inlet side tube. The round bottom flask was connected to a Likens and

Nickerson extraction apparatus and then immersed in a 128°C silicone oil bath. During collection of the volatiles, nitrogen entering the round bottom flask through the side tube bubbled through the emulsion and passed through a dry-ice ethanol cold trap before bubbling out through HPLC-grade water. The volatiles were extracted for 2.5 hr and collected in a 125-mL Erlenmeyer flask containing 35-mL HPLC-grade dichloromethane. After the extract was cooled for 30 min, 1 mL of pyrogallol solution (0.1 mg/mL in methanol) was added to prevent oxidation of volatiles. The modifications to the method of Macleod and Cave (1975) were the use of dichloromethane instead of isopentane for the volatile solvent, nitrogen bubbling through the sample instead it being stirred, ethanol dry ice instead acetone dry ice for cold trap, and additional of pyrogallol. The extract was concentrated to 1.0 mL by a gas entrainment method (Macleod and Cave, 1975) prior to analysis.

The volatiles were analyzed quantitatively using a 0.25mm i.d x 60 m SP2330 fused silica capillary column (Supelco Inc., Bellefonte, PA) in a Shimadzu Model 9AM gas chromatograph (GC) equipped with a liquid N_2 cryogenic unit, flame ionization detector (FID), and a Shimadzu Model GCMS QP-1000 data processor. For the GC run, a temperature program was used starting at 27°C with a hold for 2.5 min after sample injection in the split mode. In order to obtain the best resolution of the most volatiles, the column temperature was increased from 27 to 100°C at 3°C/min followed by 2°C/min between 100-220°C. When the column temperature reached 220°C, it was held for 30 min before the the oven was cooled for the next injection.

Volatiles from cracker sample in each treatment were analyzed qualitatively under the same conditions as outlined for GC-FID analysis on a Shimadzu Model

9AM gas chromatograph interfaced with a Shimadzu QP1000 mass spectrometer. Positive identification for each volatile was made by matching the retention time of the sample volatile with that of a standard volatile analyzed under exactly the same GC conditions and also matching the mass spectrum of the sample volatile with that of the standard volatile. Tentative identification of a volatile was accomplished by matching the GC retention time with that of a known standard, but without having a matching mass spectrum.

Sensory Evaluation

The objective of the sensory evaluation was to evaluate the likability of color and flavor and overall likability of prawn crackers fried in the different oils/blends and stored under different conditions. Samples (n = 24) of chips fried in each oil/blend and stored at zero wk (fresh) or for 4 wk in the dark (4 wkD) or under fluorescent lights(4wkL) from the two replications were evaluated. An untrained panel consisting of 50 students, faculty, and staff, who were willing to participate in the study and from The University of Tennessee, was recruited. Panelists were asked to complete the questionnaire shown in Appendix A concerning their age, background, etc. Panelists evaluated the color, flavor and overall likability of shrimp crackers on an 8-point hedonic scale (Meilgaard et al., 1991; Stone and Sidel, 1975) shown in Appendix A.

Twelve prawn cracker samples from a single replication representing crackers fried in each of the four oils/blends and stored zero week or for 4 wk in the dark or under fluorescent light were evaluated in a single session. An incomplete block design was generated by Evolutionary Software (Evolutionary

Sooftware Inc.,1991) so that each panelist evaluated six of twelve samples per session. Within one session, the design allowed 25 panelists to evaluate six samples. Before presentation, approximately three pieces of crackers of each sample were put into a small cup and coded with a randomly selected three digit number. For a single panelist, each of the six coded samples was presented, one at a time under white fluorescent lights, for evaluation. Two panel sessions were conducted, one session for each replication of the experiment.

7. STATISTICAL ANALYSIS

Statistical Analysis of Oil Measurements

The effects of the type of frying oil/blend (OIL), oil sampling period (SP), frying time (ST), and all possible two- and three-way interactions were determined on the measurements of oil quality (FOS, RAU, Fritest, conjugated dienoic acid, fatty acid C18:2/C16:0 ratio, and Hunter color values- *L, a, b,* and ΔE-, and the individual fatty acid concentrations) were analyzed according to the analysis of variance shown in Table 1, using PROC GLM (SAS Institute Inc., 1985). Other frying oil quality measurements (FFA and TPC) were analyzed as a function of OIL, ST and OIL x DAY interaction by an analysis of variance shown in Table 2, again, using the PROC GLM of SAS Institute, Inc. (1985). Significant differences among means for OIL, SP and DAY were determined by Student-Newman-Kuel's (SNK) multiple range test at the $p<0.05$ level (SAS Institute, Inc., 1985).

A two-way interaction (OIL x SP, OIL x DAY or SP x DAY) was considered

Table 1--Analysis of variance for measurements of oil quality in frying oils/blends used for frying prawn crackers for five days on 80 oil samples

Source[a]	Degrees of freedom
OIL	3
REP[b]	1
Error A (OIL x REP	3
Sampling time (SP)	1
Frying time (ST)	4
SP x ST	4
OIL x SP	3
OIL x ST	12
OIL x ST x SP	12
Error B	36
Total	79

[a]Rep = replication; OIL = type of oil/blend used to fry prawn crackers; SP = oil sampling period or after daily frying and before daily frying; and DAY = frying time in days.
[b]When REP was not significant ($p < 0.05$), it was combined with Error A which was used to test OIL for significance.

Table 2--Analysis of variance for measurements of oil quality in frying oils/blends used for frying prawn crackers for five days on 40 oil samples

Source[a]	Degrees of freedom
OIL	3
REP[b]	1
Error A (OIL x REP)	3
Frying time (ST)	4
OIL x ST	12
Error B	16
Total	39

[a]OIL = type of oil/blend used to fry prawn crackers; REP = replication; DAY = frying time in days.
[b]When REP was not significant ($p < 0.05$), it was combined with Error A which was used to test OIL for significance.

significant at the $p<0.05$ level. When only OIL x SP was significant for a dependent variable, least squares means (LSM) were obtained for each frying oil (OIL) and sampling (SP), and the significant differences among these eight LSM were identified by the PDIFF option of SAS Institute Inc. (1985). When only OIL x ST interaction was significant, an analysis of variance was run for each oil, and the LSM obtained for each day of frying time (DAY) for each oil. The significant differences among these five LSM for each frying oil were identified again, using the PDIFF option is SAS Institute Inc. (1985). When SP x DAY was significant, the LSM across frying oils for each sampling time and frying time was obtained using SAS Institute Inc. (1985), and the significant differences among these LSM were determined using the PDIFF option again.

In the occurrence where two of the two-way interactions were significant, each interaction was treated separately as a single significant interaction. However, in the case where all three of the two-way interactions were significant or the three-way interaction, OIL x SP x DAY, was significant ($p<0.05$), an analysis of variance was obtained from each frying oil (OIL); the LSM for each sampling time and frying time for that oil were obtained; and the differences amount the ten LSM were determined using the PDIFF option..

Statistical Analysis of Flavor Volatile Concentrations

The concentration of each flavor volatile was analyzed statistically as a function of the type of frying oil (OIL), storage treatment (TRT) and the OIL x TRT interaction, using the PROC GLM option of SAS Institute Inc. (1985) according to that shown in Table 3. Significant OIL and TRT effects ($p<0.05$) on the

Table 3--Analysis of variance for flavor volatiles extracted from prawn crackers fried in different oils/blends and stored for zero wk (fresh) and for 4 wk in the dark or under fluorescent light.

Source[a]	Degrees of freedom
OIL	3
REP[b]	1
Error A (OIL x REP)	3
Storage treatment (TRT)	2
OIL x TRT	6
Error B	8

[a]OIL = type of oil/blend used to fry prawn crackers; REP = replication; TRT = Storage of fried prawn crackers for zero wk (fresh) or for 4 wk in the light or under fluorescent light.
[b]When REP was not significant ($p<0.05$), it was combined with Error A which was used to test OIL for significance.

concentration of each volatile were determined, using the SNK option of SAS Institute Inc. (1985). Significant differences among means for OIL or TRT were determined, using the SNK multiple range test at the $p<0.05$ level (SAS Institute Inc., 1985). When the OIL x TRT interaction was significant ($p<0.05$), LSM were obtained for the storage treatments for each frying oil, and the significant differences among the twelve means were determined using the PDIFF option (SAS Institute Inc., 1985).

Statistical Analysis for Sensory Evaluation of Crackers

The sensory scores for color, flavor, and overall likability of prawn crackers was analyzed as a function of the different types of oils/blends (OIL), replication (REP), storage treatments (TRT), and panelist (PNL) and the two- and three-way interactions of these independent variables, using PROC GLM option (SAS Institute Inc.) according to the ANOVA shown in Table 4. Because the 50 panel members did not observe all samples from a single replication, an incomplete block design was used in this study (Meilgaard et al., 1991b). Significantly different means among the different frying oils or storage treatments were identified, using SNK (SAS Institute Inc., 1985) at the $p<0.05$ level. In case of a significant OIL x TRT interaction ($p<0.05$) the least mean squares were obtained for each treatment and oil combination and twelve LSM were separated using the PDIFF option (SAS Institute Inc. 1985).

Table 4--Analysis of variance for sensory evaluation of color, flavor, and overall likability of prawn crackers fried in different oils/blends and stored for zero wk and for 4 wk in the dark or under fluorescent light

Source[a]	Degrees of freedom
OIL	3
REP	1
PNL	49
OIL x PNL	145
REP x OIL x PNL	117
TRT	2
OIL x TRT	6
TRT x PNL	96
OIL x TRT x PNL	55
ERROR	41
CORRECTED TOTAL	599

[a]OIL = type of oil/blend used to fry prawn crackers; REP = replication; PNL = panelist; TRT = storage treatment, 0 wk and 4 wk in the dark or under fluorescent light.

CHAPTER IV

RESULTS AND DISCUSSION

1. FRYING OIL MEASUREMENTS

Several measurements were made on the oils during the frying of prawn crackers. These measurements included the dielectric constant of the oil measured by the Food Oil Sensor (FOS); the RAU test; the Fritest, the levels of conjugated dienoic acids (DIENES); the concentration ratio of linoleic acid/palmitic acid (RATIO); the color of the oils expressed in Hunter Color values (*L*, *a*, *b* and the difference in color (ΔE)); the free fatty acid (FFA) content (% oleic acid), and the level (%) of total polar components (TPC). FFA and TPC were not determined on the oil samples taken after make-up oil was added and before daily frying of prawn crackers commenced; however, all other measurements were made on all oil samples. The characteristics of fresh frying oils are presented in Table 5.

Chemical and Physical Measurements

The analyses of variances for the dependent variables, FOS, RAU, Fritest, DIENES and RATIO, as a function of the type of frying oil (OIL), sampling time (SP), frying time (DAY) in days, and their respective interactions are presented in Appendix B-1. All five dependent variables were affected ($p<0.05$) by SP and DAY; however, only DIENES and RATIO were affected significantly by OIL. No significant interactions were found for FOS or RATIO, but RAU had significant

Table 5--Mean values[a,b] for physical and chemical characteristics[c] and color of the fresh frying oils

Characteristic	Frying oil[d]			
	SO	80:20	60:40	POO
RAU	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
Fritest	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00
DIENES (%)	0.78 ± 0.01	0.74 ± 0.01	0.61 ± 0.01	0.50 ± 0.00
RATIO	4.65 ± 0.08	2.64 ± 0.02	1.52 ± 0.05	0.28 ± 0.01
FFA (% oleic)	0.02 ± 0.01	0.02 ± 0.02	0.03 ± 0.02	0.03 ± 0.02
TPC (%)	12.51 ± 0.22	14.12 ± 0.66	13.51 ± 0.90	12.46 ± 0.76
Color				
L	95.58 ± 0.07	95.32 ± 0.04	94.37 ± 0.11	92.78 ± 0.00
a	-2.10 ± 0.02	-3.45 ± 0.05	-4.69 ± 0.18	-5.29 ± 0.21
b	5.38 ± 0.02	9.08 ± 0.01	12.71 ± 0.55	21.62 ± 0.06

[a]Measured before the oils were heated (n = 2).
[b]Means ± standard deviations.
[c]The values for FOS were 0.000 and the ΔEs in color were 0.00 for all oils/blends.
[d]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.

OIL x SP, OIL x DAY, and DAY x SP interactions while DIENES had an OIL x SP interaction ($p<0.05$) and Fritest had a SP x DAY interaction.

The mean levels of FOS, RAU, Fritest, DIENES and RATIO for the different frying oils, oil sampling times and frying times are presented in Tables 6, 7, and 8, respectively. FOS ranged from 2.1 in POO to 2.3 in SO and the SO:POO blends (Table 6). The RAU values ranged from 1.7 to 2.0 and the Fritest from 1.8 to 2.0 among the frying oils (Table 6). SO had the highest DIENES concentration and POO, the lowest. As expected based on their relative levels of linoleic and palmitic acids among the OIL, SO had the highest RATIO while POO olein oil the lowest.

For the FOS, RAU, Fritest and DIENES measurement, the oil samples taken after frying each day had the higher values (Table 7), while the RATIO value was lower after daily frying than before frying. Also, FOS, RAU, Fritest and DIENES measurements generally increased ($p<0.05$) with increasing frying time while the RATIO decreased (Table 8). However, the degree to which RAU and DIENES changes with sampling time was dependent upon the type of oil (OIL) as shown by the significant interaction of OIL with SP. Also, the rate of change in RAU across frying time was dependent upon OIL. The changes in RAU and Fritest across frying time was dependent also on sampling period (SP).

Increases in FOS of oils during daily frying and across several days of frying in the different oils/blends indicated their dielectric constant increased. Husain (1986) found increases in FOS of SO and POO across several days of frying. Paradis and Nawar (1981) reported that oxidation products found in the oils during frying were primarily responsible for the increase in their dielectric constants. Jafar (1989) reported that the FOS reading increased in a cubic manner across

Table 6--Mean values[a] for frying oil measurements for each oil/blend averaged across oil sampling time and frying time

Measurement	Frying oil[b]			
	SO	80:20	60:40	POO
FOS[c]	2.3	2.3	2.2	2.1
RAU[cdef]	1.7	2.0	2.0	1.9
Fritest[cf]	1.8	2.0	2.0	1.9
DIENES (%)[cd]	1.9a	1.7b	1.4c	1.0d
RATIO[c]	4.3a	2.3b	1.4c	0.2d
Color values				
L[cdef]	90.9a	89.1b	87.8c	86.2d
a[cdef]	-8.8a	-8.3a	-8.2a	-7.5b
b[cdef]	27.5d	30.9c	32.2b	35.3a
ΔE[cdef]	23.2a	23.4a	21.1b	15.4c
FFA (% oleic) [eg]	0.12c	0.13c	0.17b	0.25a
TPC[g] (%)	30.2	30.7	31.0	29.1

[a]Mean values in a row followed by unlike letters are different ($p<0.05$).
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[c]N = 20.
[d]This variable had a OIL x SP interaction ($p<0.05$).
[e]This variable had a OIL x DAY interaction ($p<0.05$).
[f]This variable had a SP x DAY interaction ($p<0.05$).
[g]N = 10.

Table 7--Mean values[a] for oil measurements averaged across type of frying oil and frying time for sampling before addition of make-up oil and after daily frying was completed

	Sampling time[b]	
Measurement	Before	After
FOS[c]	1.4b	3.1a
RAU[cdef]	1.4b	2.4a
Fritest[cf]	1.4b	2.5a
DIENES (%)[cd]	1.1b	1.9a
RATIO[c]	2.2a	2.0b
Color		
L^{cdef}	91.0a	86.8a
a^{cdef}	-7.9b	-8.5a
b^{cdef}	26.3b	36.7a
ΔE^{cdef}	15.1b	26.6a

[a]Mean values in a row followed by unlike letters are different ($p<0.05$).
[b]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.
[c]N = 40.
[d]This variable had a OIL x SP interaction ($p<0.05$).
[e]This variable had a OIL x DAY interaction ($p<0.05$).
[f]This variable had a SP x DAY interaction ($p<0.05$).

Table 8--Mean values of frying oil measurements averaged across types of frying oils and sampling times for each day of frying time

Measurement	Frying time (days)				
	1	2	3	4	5
FOS[b]	1.0	2.0c	2.5b	2.8a	2.9a
RAU[bcde]	1.3e	1.5d	2.0c	2.2b	2.4a
Fritest[be]	1.1e	1.7d	2.0c	2.3b	2.7a
DIENES (%)[bc]	1.1d	1.5c	1.6bc	1.7ab	1.8a
RATIO[b]	2.2a	2.1ab	2.1ab	2.0bc	1.9c
Color					
L[bcde]	92.9a	90.4b	88.3c	86.3d	84.6e
a[bcde]	-6.2c	-8.7a	-9.1a	-8.9a	-8.1b
b[bcde]	18.8e	27.9d	33.4c	37.5b	39.8a
ΔE[bcde]	6.9e	16.9d	22.8c	27.5b	29.8a
FFA (% oleic)[df]	0.09e	0.14d	0.18c	0.21b	0.23a
TPC (%)[f]	24.0c	28.3b	31.7a	33.2a	34.0a

[a]Mean values in a row followed by unlike letters are different ($p<0.05$).
[b]N = 16.
[c]This variable had a OIL x SP interaction ($p<0.05$).
[d]This variable had a OIL x DAY interaction ($p<0.05$).
[e]This variable had a SP x DAY interaction ($p<0.05$).
[f]N = 8.

four days of frying french fries. Smith et al. (1986) stated that the dielectric constant measurement was most useful when the frying time was the only variable. Since the procedure requires the calibration of the instrument with the fresh oil, Wu and Nawar (1986) concluded that FOS is most useful for measuring the deterioration of a single oil during frying.

The decrease in RATIO measurements with increasing frying time in oils is in agreement with results reported by Augustine and Berry. (1984) who fried tapioca chips in refined, bleached, and deodorized POO containing antioxidants. The main reason for the C18:2/C16:0 concentration ratio decreasing during frying is the loss of the linoleic (C18:2) acid during frying. Augustin et al. (1987c) reported that the C18:2/C16:0 ratio measurement correlated well with total polar component levels, dielectric constant measurement (FOS), and the decrease in the iodine value of frying oils during the heating and frying study using RBD POO.

The RAU values for each day of frying (DAY) and oil sampling period (SP) for each frying oil in the present study are presented in Table 9. In general, the RAU value in the samples taken at the end of the frying day increased at a faster rate than those taken before frying (Table 9). In addition the oil blends reached the maximum RAU value faster than the pure oils. However, by the fifth day of frying, the RAU values in all frying oil samples taken at the end of the day had reached the maximum RAU value. These result indicates that somthing in the oil increased the oxidation rate inthe blends. That could be possibly that the higher level of pigments in palm oil increased the oxidation rate of the more unsaturated SO in the blends.

The increase in RAU value with increasing frying time is in agreement with

Table 9--Least squares means[a] of the RAU value of different oils sampled daily before frying of prawn crackers was started and after frying was completed for five consecutive days

Type oil[b]	Sampling time[c]	Frying time (days)				
		1	2	3	4	5
Soybean	Before	1.00f	1.00f	1.25e	1.50de	1.75cd
	After	1.25ef	1.75cd	2.00c	2.50b	3.00a
80:20	Before	1.00d	1.00d	1.50c	1.75c	1.75c
	After	1.75c	2.25b	2.50b	3.00a	3.00a
60:40	Before	1.00f	1.25e	1.50d	2.00c	2.00c
	After	1.50d	2.00c	2.50b	3.00a	3.00a
Palm	Before	1.00f	1.00f	1.50e	1.50e	2.00c
	After	1.75d	2.00c	2.50b	2.50b	3.00a

[a]For one type of oil, means (n = 2) followed by unlike letters are different ($P < 0.05$).
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[c]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.

results reported by Meyer (1979). Meyer (1979) who measured the RAU value of 1,300 frying oil samples from commercial practices, reported that the RAU values of the oils increased with increasing frying time oils were used. Meyer (1979) also mentioned that the measurements of total oxidized compounds in oil using the RAU test correlated well with the total polar component levels in the oils. In another study, Croon et al. (1986) measured the RAU values of 100 samples of frying oils from fast food restaurants and found that the RAU values correlated well with the TPC measurement and the FOS readings.

The Fritest values averaged across types of frying oils for time and frying time are presented in Table 10. For each day of frying, Fritest value was greater in the oil samples taken after frying than before. Also, the addition of make-up oil decreased the Fritest level ($p<0.05$) from those measured at the end of day 1. Similar result occured for each day of frying (Table 10). The Fritest value increased ($p<0.05$) with frying time from day 1 to day 2, from day 2 to day 4, and from day 4 to day 5. Fritest value also increased ($p<0.05$) on the oil samples taken between the first day and the third day of frying and between third and fourth day of frying, reaching a maximum value of 3.00 on the fourth and fifth day of frying. Croon et al., (1986) reported similar results in that the Fritest values increased with increasing frying time.

The mean levels of DIENES for each oil sample (SP) before and after dayily frying for each frying oil (OIL) are presented in Table 11. Daily frying increased the levels of DIENES in each oil (after compared with before sample); however, the level increased more between before and after daily frying in the SO than in the more saturated POO. Augustin and Berry (1983) suggested that the small

Table 10--Least squares means of Fritest values[a,b] averaged across types of frying oils for each sampling time (SP) and frying time (day)

	Sampling time[c]	
Day	Before	After
1	0.50f	1.50d
2	1.00e	1.75cd
3	1.25de	2.25b
4	1.50d	3.00a
5	2.00bc	3.00a

[a]Means followed by unlike letters are different ($p<0.05$).
[b]N = 8.
[c]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.

Table 11--Least squares means of dienoic acid (DIENES) concentrations[a,b] (%) averaged across frying for each type of frying oil (OIL) and sampling time (SP)

	Sampling time[c]	
Frying oil[d]	Before	After
SO	1.38d	2.41a
80:20	1.28d	2.19b
60:40	1.08e	1.76c
POO	0.76f	1.26d

[a]Means followed by unlike letters are different ($p<0.05$).
[b]N = 8.
[c]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.
[d]SO = unhydrogenated soybean oil; POO = palm olein; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.

increase of conjugated dienes at later stages of frying were caused by an equilibrium between the rate of formation of conjugated dienes and the rate of formation of polymers. The higher levels of conjugated dienoic acids in SO than in the 60:40 blend or POO is to be expected since SO contains higher level of polyunsaturated fatty acids than POO. Husain (1986) reported that SO used for frying for five days had higher dienoic acid content than POO used for frying for the same period of time. The increase in the levels of conjugated dienoic compounds in frying oils has been reported both in heating and deep frying studies (Berry and Awang, 1981; Chu, 1991; Husain, 1986).

The Hunter color values, *L*, *a*, *b* and ΔE (difference in color), of the frying oil are presented in Tables 6, 7, and 8 for each OIL, each SP and each DAY, respectively. The analyses of variances for each color parameter as a function of OIL, SP, DAY and their interactions are presented in Appendix B-1. All color values measured were affected ($p<0.05$) by OIL, SP and DAY. The color parameters, *L*, *a*, *b* and ΔE, all had OIL x SP, OIL x DAY and SP x DAY interactions ($p<0.05$).

Without consideration of the interactions, the Hunter color values, *L* and ΔE, were the highest SO, decreased with each addition of POO in the frying oil blends and were the least in the POO frying oil (Table 6). The *b* value among the OIL was smallest in the SO, increased with increasing amount of POO in the frying oil blends, and was greatest in the POO (Table 6). In addition, the Hunter *a* values were significantly more negative in SO and the frying oils blends than in the POO (Table 6). Daily oil samples after frying had greater Hunter color *b* values, ΔE, and lower *L* and *a* values than those sample before daily frying (Table 7). Increasing frying time increased ($p<0.05$) the *b* value, ΔE and but decreased the Hunter *L*

value of the oils. The overall *a* value of all oils/blends reached the lowest point at the third day of frying, and increased its value during day 4 and day 5 of frying (Table 8).

The mean values for Hunter color *L*, *a*, *b*, and ΔE values for each type of frying oil (OIL), sampling time (SP) and frying time (DAY) are presented in Tables 12, 13, 14, and 15, respectively. For the *L* value, the rate of change increased with increasing frying time. The *L* values were higher in the samples taken before daily frying than those taken after daily frying (Table 12). The make-up oil at the beggining of day 2 did not significantly increased the *L* values of all oils/blends. However the make-up oil at the day 3, 4, and 5 significantly increased the *L* values of all oils and bleds, except for SO (Table 12). In addition, the *L* value decreased with increasing amount of PO in the oil and blends. Compared with SO, POO and the blends had greater decreased in their overall *L* value during five days of frying (Table 12). This finding indicate that POO and the oil blends tend to become darker faster than SO.

Depending upon the OIL and the DAY, the Hunter *a* value decreased to the lowest point at the end of day 3 for SO and at the end of day 2 for POO and 80:20 and 60:40 SO:POO blends (Table 13). After reached their lowest value, the *a* value of the oil/blends increased until the end of the study, resulting the *a* values of the oil/blends at he beginning of day 5 were higher than those at at the end of frying at the same day. Further more, addition of make-up oil did not always have a significant effect on the *a* value. The *a* value in SO and in 80:20 SO:POO blend increased significantly after make-up oil was added during day 1, 2, and 3 but the

Table 12--Least squares means[a] of Hunter color *L* values of different oils sampled daily before frying of prawn crackers was started and after frying was completed for five consecutive days

Type oil[b]	Sampling time[c]	Frying time (days)				
		1	2	3	4	5
SO	Before	95.6a	94.0ab	92.9bc	91.7cd	90.0de
	After	93.0bc	91.3cde	88.9ef	86.9fg	85.3g
80:20	Before	95.3a	93.5ab	91.5cd	89.8de	88.3e
	After	92.4bc	88.9e	85.8f	83.1g	81.5g
60:40	Before	94.6a	91.4b	90.3bc	88.0cd	87.6d
	After	90.6b	87.9d	84.5e	82.9e	80.0f
POO	Before	92.8a	90.0b	88.8b	87.0c	85.9c
	After	89.0b	86.0c	83.6d	80.4e	78.4f

[a]For one type of oil, means (n = 2) followed by unlike letters are different ($P < 0.05$).
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[c]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.

make-up oil at the day 4 and 5 did not changed the a value of those oil/blend significantly. On the other hand, the *a* value of POO and 60:40 SO:POO blend did not affected with the everyday make up oil during the study.

The Hunter *b* value of each of the frying oil in the samples taken before daily frying had a greater increase across five days of frying than those samples taken after daily frying (Table 14). Also, the adition of make-up at the begining of day 3, 4, and 5 significantly increase in the *b* value of all oils/blends (Table 14). In addition, the amount of increase in *b* value across five days of frying for the same type of oil sample decreased with increasing levels of SO in the frying oils (Table 14).

The color difference, ΔE, in all oils and blends increased significantly during daily frying. The addition of make-up oil at the begining of days 3,4,and 5 significantly decrease ΔE in all oils(Table 15). From day 1 to day 3 the ΔE of every oil and blend increased at a higher rate than the increase from day 3 to day 5 (Table 15). In general, across five days of frying, ΔE increased most in samples taken before frying compared with samples taken after frying. This latter result indicates that although the addition of make-up oil decreased the ΔE in value in frying oils from day to day, daily frying resulted in a larger increase in ΔE than could be altered by addition of make-up oil (Table15). Overall the ΔE increased faster in SO than in POO and oil blends during five days of frying.

According to deMan (1980), in the Hunter Color system, *L* measures the lightness of the color from white (L = 100) to black (L = 0); *a* measures the red color (positive values) to green color (negative values) dimension; and *b* measures the

Table 13--Least squares means[a] of Hunter color *a* values of different oils sampled daily before frying of prawn crackers was started and after frying was completed for five consecutive days

Type oil[b]	Sampling time[c]	Frying time (days) 1	2	3	4	5
SO	Before	-2.1f	-6.6e	-8.5cd	-9.9ab	-10.2ab
	After	-8.2d	-10.3ab	-11.0a	-10.5ab	-9.6bc
80:20	Before	-3.4g	-7.1ef	-9.2bc	-10.0a	-9.9ab
	After	-8.4cd	-10.3a	-9.7ab	-8.1de	-6.9f
60:40	Before	-4.7e	-8.0d	-9.2abc	-9.6ab	-9.6ab
	After	-8.6cd	-9.9a	-8.9bcd	-8.0d	-5.5e
POO	Before	-5.3c	-8.4ab	-8.7a	-8.6a	-8.4ab
	After	-8.7a	-8.8a	-7.7ab	-6.1bc	-4.5c

[a]For one type of oil, means (n = 2) followed by unlike letters are different ($P < 0.05$).
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[c]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.

Table 14--Least squares means[a] of Hunter color *b* values of different oils sampled daily before frying of prawn crackers was started and after frying was completed for five consecutive days

Type oil[b]	Sampling time[c]	Frying time (days) 1	2	3	4	5
SO	Before	5.4g	16.5f	22.8ef	28.8de	33.4cd
	After	20.8f	29.0d	35.8bc	40.1ab	42.3a
80:20	Before	9.1g	19.3f	27.4d	32.8c	36.1bc
	After	23.1e	34.0c	40.0ab	42.9a	43.9a
60:40	Before	12.8f	23.1e	29.0d	34.6c	36.5c
	After	25.6e	35.1c	40.3b	41.4ab	43.7a
POO	Before	21.6f	29.4e	32.0e	36.1c	38.9bc
	After	32.2e	36.9bc	39.6b	42.9a	43.9a

[a]For one type of oil, means (n = 2) followed by unlike letters are different ($P < 0.05$).
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[c]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.

Table 15--Least squares means[a] of color differences (ΔE) in different oils sampled daily before frying of prawn crackers was started and after frying was completed for five consecutive days

Type oil[b]	Sampling time[c]	Frying time (days) 1	2	3	4	5
SO	Before	0.0g	12.1f	18.7e	24.9d	28.3cd
	After	14.8e	25.4d	32.4bc	36.8ab	39.0a
80:20	Before	0.0f	11.1e	19.6d	26.1c	28.7c
	After	15.2e	26.6c	33.0b	36.1ab	37.6a
60:40	Before	0.0f	11.0e	17.4d	23.2c	25.2c
	After	14.0de	23.9c	29.6b	32.3ab	34.8a
POO	Before	0.0g	8.3f	11.2e	15.7d	18.7bc
	After	11.3e	16.8cd	20.8b	24.7a	26.7a

[a]For one type of oil, means (n = 2) followed by unlike letters are different ($P < 0.05$).
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[c]Before = after make-up oil was added and before daily frying; after = after daily frying and before make-up oil was added.

yellow color (positive values) to blue color (negative values) dimension. The color difference, ΔE, is a measurement of overall color change in a substance when compared with a standard. In this study, the standard was unused frying oil. In the present study, fresh POO was slightly darker, greener and more yellow than the fresh SO (Table 5). During five days of frying prawn crackers, however, the POO became darker (lower *L* value) than the SO (Tables 5 and 12), but less green than the SO (Tables 6 and 13). In contrast with the POO, SO which had a lower *b* value in its fresh oil, increased in yellow intensity to the point where its *b* values were similar to that of POO at the end of five days of frying (Tables 5 and 14). This increase in yellow intensity in the SO resulted in a greater color difference, ΔE, in the SO than in POO, during the five day frying period (Tables 15). In contrast with the used pure oils, the color changes in ΔE of 80:20 and 60:40 w/w blends of SO:POO were more similar to that of the SO than that of the POO (Table 15).

The color difference among the fresh oils is affected mainly the nature and the amount of the color pigments remaining after oil processing, including alkali refining, bleaching and deodorization (Weiss, 1983). In the natural state, palm oil contains a large amount of carotenoid pigments (Choo et al., 1989; Maclellan, 1983). The concentration of carotenoids (500-700 ppm) provides the palm oil an orange-red color (Choo et al., 1989; Goh et al., 1985). About 90% of the carotenes in palm oils consist of α- and β-carotenes (Choo et al., 1989). All three oil processing steps aid in reducing the carotenoid pigments in palm oil to yield an acceptable product to refined, bleached and deodorized (RBD) palm oil prior to fractionation to get POO (Weiss, 1983). Of three refining processes (solvent, physical and alkali) alkali refining produced palm oil with the lowest value for the

Lovibond red color number. Alkali reduced the red color in crude palm oil from 20.0-26.0 on the Lovibond red scale to 0.4-0.8 (Loebis, 1989). An acceptable RBD POO must have a Lovibond red color value of less than 4.0 and a Lovibond yellow color of 35 or less (Brekke, 1990).

In contrast with crude palm oil, crude SO has only 40-50 ppm of carotenoid pigments (Taylor, 1992). Also, the standards for SO color in Lovibond values are lower than for palm oil also. The Nation Oilseed Processors' Association (NOPA) trading rule color specifications for a fully refined SO requires that the oil have not more than Lovibond 2.0 red and no green for fully refined (Erickson, 1995). Erickson (I995) noted that the NOPA color standards were generous, that increased color is an indicator of poorer quality oils and that in United States lighter soybean oisl (Lovibond 0.3 red) has a marketing advantage over more highly colored oils.

Since color of frying oil is one of the characteristics used by restaurants and fast-food outlets to assess the quality of the frying oil (Melton et al., 1995), measurement of color changes in different oils during frying is important. However, if restaurants used bleaching clay to remove color pigment, the color assesment to evaluate oil quality become less important (Melton et al., 1994).

Free Fatty Acid and Total Polar Components

Free fatty acid (FFA) concentration and total polar components (TPC) were analyzed as a function of type of oil (OIL), frying time (DAY) and their interaction (Appendix B-2). The level of FFA was significantly affected by OIL, DAY and OIL x DAY, but only the DAY affected the TPC concentration. The concentrations of FFA and TPC for each type of oil and for each day of frying are presented in Tables 6

and 8, respectively.

Without consideration of the OIL x DAY interaction, POO had the highest amount of FFA of all frying oils while the SO and the 80:20 oil blend had the lowest concentration of FFA. The FFA levels for each type of frying oil and each frying time are presented in Table 16. The FFA content of POOl increased higher than did the SO during the five day frying period. As the level of POO increased in the blends, the FFA concentration increase during frying, and across the five day frying period (Table 16).

The TPC concentration also increased ($p<0.05$) with increasing frying time during the first three days of frying before leveling off at 33.0 - 34.0 % on the fourth and fifth days of frying (Table 8). The level of the TPC also increased from an average of 13.63 % in fresh, unheated oils/blends (Table 5) to 24% TPC after one day heating at 190°C prior to the start of frying prawn crackers on day 1 (Table 8).

Many investigators reported of higher levels of free fatty acids found in fresh palm oil products than in other processed vegetable oils (Chu, 1991; Husain, 1986; Jafar, 1989; Smith et al., 1986). Also, this higher initial free fatty acid level in the fresh oil may contribute to the increased of formation of free fatty acids in POO in the present study. The lower levels of tocopherols in palm oil than in SO (Sherwin, 1976) also may have contributed to an increased rate of FFA formation by oxidation during frying. These increases in free fatty acid content have been found by several investigators (Bracco et al., 1981; Husain, 1986; Smith et al., 1986; Stevenson et al., 1987); in fact, the relationship between FFA

Table 16--The least squares means of free fatty acid concentrations[a] (% oleic acid) for different frying oils/blends during five days of frying prawn crackers

	Frying time (days)				
Oil/blend[b]	1	2	3	4	5
SO	0.07e	0.10d	0.13c	0.15b	0.17a
80:20	0.07d	0.11c	0.13c	0.16b	0.19a
60:40	0.08e	0.13d	0.17c	0.21b	0.24a
POO	0.14c	0.22b	0.28a	0.31a	0.33a

[a]Means (n = 2) in a row followed by unlike letters are significantly different ($p < 0.05$).
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.

content and frying time is, for the most part, linear.

The levels of FFA found in the oils even after five days frying were more consistent with the levels of FFA found in oil used to fry potato chips than those reported in deep frying in restaurants annd outlet. Weiss (1983) reported that if the FFA content of the oil used to fry potato chips reaches 0.5%, the oil should be discarded because in that level of FFA is indicative of potato chips with a decreased shelf life. In comparison, during deep frying in restaurants and fast food outlets, where moist foods such as meat, potatoes, onions, etc., are fried and consumed directly after frying, the level of FFA in the frying oils may reach 5-6% without apparent quality problems in the fried food (Melton et al., 1994). The low level of FFA produced in the frying oils in the present study and the low moisture content in the prawn crackers before frying indicate that FFA in the oils most likely were produced by thermal oxidation and not hydrolysis of the oil triglycerides.

The TPC contents of the fresh oils (Table 5) were higher than that normally found in fresh oils. Melton et al. (1994) reported that TPC levels in fresh oils usually range from 4 to 7%. Reasons why the TPC levels were so high in the fresh oils used in the present study were not investigated. The oils were used within one month of being received from the oil processor and were stored under nitrogen in the original containers at 26.7-29.4°C during that month.

The lack of significant differences among the oils/blends in TPC concentration is in agreement with Husain (1986) who found no differences in TPC level between POO and partially hydrogenated SO used in frying. However, the absence of significant increases in TPC level between days 3 and 5 of frying was in disagreement with the finding of other investigators (Husain, 1986; Jafar, 1989;

and Stevenson et al., 1984b). In addition, Jafar (1989) reported a linear relationship between TPC level in POO and partially hydrogenated SO during five days of frying french fries. Moreover, Stevenson et al. (1984) reported that TPC were highly correlated with hours of frying in seven types of oil consisting of canola and SO products.

The TPC concentration at which frying oils are considered to be deteriorated to the point of discard is 25 - 27%. The frying oils used in the present study reached that level of TPC before the end of the second day of frying (Table 8). The main reason why it took only two days for these oils to reach the 27% level of TPC was the high initial TPC in the fresh oils (Table 5). The rate of TPC concentration increase in frying oils is dependent upon the type of frying oil and the food fried. Husain (1986) reported that the TPC concentration reached 27% by the end of third day of frying breaded fish in partially hydrogenated SO. However, Jafar (1989) reported that by the end of the fourth day of frying french fries in partially hydrogenated SO the TPC had only increased to 12.8%. Fritsch et al. (1979) in another study reported that SO with an iodine value of 122 can reach a TPC concentration of 27% after 32 hours of deep frying of potatoes while another SO with an iodine value of 70 only reached a TPC concentration of 8.5% during the same period. Even though several researchers believe that a TPC concentration of 25-27% indicates that an oil is fully degraded, oils with TPC levels up to 35% still can produce some fried foods with acceptable color and flavor (Melton et al., 1994).

Fatty Acid Composition

The analyses of variance for the effects of frying oils (OIL), sampling time (SP) and frying time (DAY) and their interactions on levels of fatty acids in the oils are presented in Appendix B-3. Eighteen different fatty acids: C12:0 (lauric), C14:0 (myristic), C16:0 (palmitic), C16:1t palmitelaidic), C16:1 (palmitoleic), C18:0 (stearic), C18:1 (oleic), C18:2 (linoleic), C20:0 (arachidic), C18:3 (linolenic), C20:1 (11- eicosenoic), C20:2 (11,14-eicosadienoic acid), C20:3 (8,11,14-eicosatrienoic), C22:0 (docosanoic), C22:4 (7,10,13,16-docosatetraeneoic acid), C22:5 (7,10,13,16,19-docosapentaenoic) and C22:6 (4,7,10,13,16,19-docosahexaenoic) were identified. The concentration of each of the identified fatty acids and the total level of six unknown fatty acids were measured in the frying oils during the current study.

The concentrations of C12:0, C14:0, C16:0, C18:1, C18:2, C18:3, C20:3, C22:0, and C24:0 were significantly different among types of oils (OIL, Appendix B-3). The fatty acid, C18:1, had significant OIL x frying time (DAY) and OIL x SP x DAY where SP = oil sampling time interactions, while C20:1 and C22:6 had OIL x SP interactions ($p < 0.05$), and C22:4 had significant OIL x SP and OIL x SP x DAY interactions. The average concentrations (weight percentages of total methyl esters of fatty acids measured) of all acids in each oil, SO and POO, and in the blended oils, 80:20 and 60:40 w/w SO:POO, are presented in Table 17. POO had the highest concentration of C12:0, C14:0, C16:0, and C18:1 but the lowest concentrations of C18:2, C18:3 and C22:0. SO had the largest level of C18:2, C18:3, C22:0 and C24:0 and smallest level of C12:0, C14:0, C16:0, and C18:1 acids. The 80:20 and 60:40 SO:POO had different ($p < 0.05$) levels of C14:0,

Table 17. Mean concentrations[a,b] of fatty acids in SO, POO, 80:20 and 60:40 W/W blends of SO and POO used for five days of frying prawn crackers and sampled twice daily

	Type of frying oil[c]			
Fatty acid	SO	80:20	60:40	POO
C12:0	0.145c	0.220b	0.245b	0.425a
C14:0	0.155d	0.375c	0.565b	1.175a
C16:0	12.095d	18.880c	24.402b	43.325a
C16:1	0.040	0.040	0.060	0.040
C16:1t	0.065	0.080	0.045	0.050
C18:0	3.535	3.785	3.633	4.185
C18:1[de]	23.465d	27.250c	30.820b	39.685a
C18:2	51.930a	42.605b	34.615c	9.885d
C20:0	0.705	0.720	1.070	0.365
C18:3	6.230a	4.570b	3.195c	0.190d
C20:1[f]	0.280	0.265	0.235	0.180
C20:2	0.130	0.185	0.320	0.210
C20:3	0.080a	0.075a	0.025b	0.000b
C22:0	0.450a	0.325b	0.265c	0.005d
C24:0	0.185a	0.115b	0.095b	0.085b
C22:4[ef]	0.010	0.005	0.015	0.005
C22:5	0.000	0.000	0.010	0.000
C22:6[f]	0.025	0.030	0.040	0.035
Unknowns[g]	0.475	0.475	0.401	0.155

[a]Wt %; n = 20.
[b]Means in a row followed by unlike letters are different ($p < 0.05$).
[c]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:PO;, and 60:40 = weight ratio of SO:POO.
[d]An OIL x frying time (DAY) interaction was found ($p < 0.05$).
[e]An OIL x DAY x sampling time (SP) interaction was found ($p < 0.05$).
[f]An OIL x SP interaction was found ($p < 0.05$).
[g]Consists of 6 different unknown fatty acids with retention times in gas chromatographic analysis of 16.1, 17.5, 18.9, 33.3, 34.2 and 35.2 min, respectively.

C16:0, C18:1, C18:2, C18:3 and C22:0. Als, the level of each of these acids in the blends was significantly different from, but between their respective levels in the SO and POO (Table 17). In addition, SO and the 80:20 blend had higher levels of C20:3 than did of the POO or 60:40 blend. However, the levels of C18:1, C20:1, C22:4 and C22:6 in each oil also were dependent upon the sampling time (SP) and/or the frying time (DAY).

The levels of C12:0, C14:0, C16:0, C16:1, C16:1t, C18:0, C18:1, C18:2, C18:3, C20:1, C22:4 and C22:6 were affected ($p<0.05$) by the sampling time (SP). Oil samples taken daily after frying had higher levels of C14:0, C16:0, C16:1t, C18:1, C20:1, C22:4 and C22:6 than samples taken before frying but after make-up oil was added (Table 18). Samples taken daily before frying had higher amounts of C12:0, C16:1, C18:2, and C18:3 than samples obtained daily after frying. The levels of the fatty acids, C12:0, C18:1, C20:1, C22:4 and C22:6, had interactions of SP with DAY and/or OIL indicating that the concentrations of these latter acids were dependent also on OIL or DAY (Table 18).

The concentrations of C12:0, C18:0, C18:2, C20:2, and C22:4 were affected ($p<0.05$) by frying time (Appendix B-3). However, C12:0 and C22:4 had significant interactions of DAY with OIL and/or SP. Concentrations of the fatty acids for each frying time averaged across sampling times and types of oils are presented in Table 19. As frying time increased from day 1 to day 5, C18:2 level decreased significantly while the concentrations of C12:0, C18:0 and C20:2 generally increased. The level of C22:4 was significantly higher only on day 5 compared with the other days of frying.

Both C12:0 and C22:4 had significant SP x DAY interaction (Appendix B-3).

Table 18--Mean concentrations[a,b] of fatty acids averaged across type of frying oils and frying times for samples taken before and after daily frying of prawn crackers

Fatty acid	Sampling time	
	Before daily frying	After daily frying
C12:0[c]	0.193b	0.325ab
C14:0	0.525b	0.610a
C16:0	24.133b	25.220a
C16:1	0.063a	0.028b
C16:1t	0.045b	0.075a
C18:0	3.713	3.860
C18:1[de]	30.145b	30.465a
C18:2	35.635a	33.883b
C20:0	0.728	0.703
C18:3	3.805a	3.288b
C20:1[f]	0.198b	0.283a
C20:2	0.198	0.225
C20:3	0.035	0.055
C22:0	0.265	0.298
C24:0	0.113	0.128
C22:4[cef]	0.003b	0.015a
C22:5	0.003	0.003
C22:6[f]	0.18b	0.048a
Unknowns[g]	0.181	0.476

[a]Wt %; n=40.
[b]Means in a row followed by unlike letters are different ($p<0.05$).
[c]A sampling time (SP) x frying time (DAY) interaction was found ($p<0.05$).
[d]A OIL x DAY interaction was found ($p<0.05$).
[e]An OIL x SP x DAY interaction was found ($p<0.05$).
[f]An OIL x SP interaction was found ($p<0.05$).
[g]Consists of 6 different unknown fatty acids with retention times in gas chromatographic analysis of 16.1, 17.5, 18.9, 33.3, 34.2 and 35.2 min, respectively.

Table 19--Mean concentrations[a,b] of fatty acids averaged across different frying oils for each day prawn crackers were fried

	Frying time (days)				
Fatty acid	1	2	3	4	5
C12:0[c]	0.144b	0.244a	0.288a	0.313a	0.306a
C14:0	0.475	0.588	0.606	0.563	0.606
C16:0	24.163	24.494	24.956	24.456	25.313
C16:1	0.050	0.050	0.050	0.031	0.044
C16:1t	0.056	0.056	0.063	0.060	0.065
C18:0	3.600b	3.713ab	3.813ab	3.788b	4.086a
C18:1[de]	30.194	30.075	30.419	30.138	30.700
C18:2	35.919a	35.019ab	34.406bc	34.975ab	33.475c
C20:0	0.788	0.563	0.511	0.781	0.925
C18:3	3.831	3.794	3.613	3.406	3.088
C20:1[f]	0.181	0.256	0.256	0.244	0.263
C20:2	0.075c	0.138bc	0.131bc	0.331ab	0.381a
C20:3	0.050	0.050	0.050	0.044	0.031
C22:0	0.275	0.294	0.300	0.275	0.263
C24:0	0.113	0.125	0.125	0.113	0.125
C22:4[cef]	0.000b	0.000b	0.000b	0.006b	0.038a
C22:5	0.000	0.006	0.000	0.000	0.006
C22:6[f]	0.013	0.038	0.044	0.031	0.038
Unknowns[g]	0.073	0.497	0.361	0.445	0.354

[a]wt.%; n=16.
[b]Means in a row followed by unlike letters are different ($P<0.05$).
[c]A sampling time (SP) x days of frying (DAY) interaction was found ($P<0.05$).
[d]An OIL x DAY interaction was found ($P<0.05$).
[e]An OIL x SP x DAY interaction was found ($P<0.05$).
[f]An OIL x SP interaction was found ($p<0.05$).
[g]Consists of 6 different unknown fatty acids with retention times in gas chromatographic analysis of 16.1, 17.5, 18.9, 33.3, 34.2 and 35.2 min respectively.

However, C22:4 also had a significant OIL x SP X DAY interaction, and the influence of all three of these factors will be discussed later. Table 20 shows the concentration means of C12:0 for each sample on each day of frying. For samples taken before daily frying, frying time did not affect ($p<0.05$) on the level of C12:0. However, the oil samples taken at the end of days 4 and 5 had higher levels of C12:0 than those taken before frying on each respective day. In samples taken at the end of frying day, C12:0 levels on days 4 and 5 were higher than those on days 1 and 2. Also, addition of make-up oil at beginning of day 4 or 5 significantly decreased C12:0 level from oil sampled after dayly frying on days 3 or 4 (Table 20). These results indicate that C12:0 was either being produced by thermal oxidation of unsaturated fatty acid suc as C18:2 or increased by being leached from prawn crackers.

The fatty acids C20:1, C22:4 and C22:6 had a significant OIL x SP interaction (Appendix B-3). However, since C22:4 also had a significant three-way interaction of OIL x SP x DAY as noted previously, only C20:1 and C22:6 are discussed here. Table 21 presents the mean levels of C20:1 and C22:6 for each sample taken from the different oils. In general, the average concentration of C20:1 and C22:6 at the end of frying day tend to be higher than at the beginning of frying day, especially the levels of C20:1 in SO and C22:6 in POO. In addition, the level of C20:1 in POO and 60:40 SO:POO blend were not affected by daily frying, whereas the C20:1 level in SO and 80:20 SO:POO blends were increased significantly during daily frying (Table 21). Similarly, the level of C22:6 in SO and 80:20 blend were not affected by the daily frying, whereas the level of POO and 60:40 SO:POO blend were significantly increased during daily frying (Table 21).

Table 20--Mean concentrations[a,b] of C12:0 fatty acid from different sampling periods for each day of frying prawn crackers averaged across types of oils

Sample[c]	Frying time (days)				
	1	2	3	4	5
1	0.125e	0.200cde	0.238bcde	0.175e	0.225cde
2	0.163de	0.288bcd	0.338abc	0.450a	0.388ab

[a]Wt. %; n=8.
[b]Means followed by unlike letters are different ($p<0.05$).
[c]1 = sample taken before frying began each day; 2 = sample taken after frying was finished each day.

Table 21--Mean concentrations[a,b] of fatty acids, C20:1 and C22:6, for each frying oil and sampling time combination averaged across frying time

Fatty acid	Sample[d]	Type of frying oil[c]			
		SO	80:20	60:40	POO
C20:1	1	0.190cd	0.190cd	0.210cd	0.200cd
	2	0.370a	0.340ab	0.260bc	0.160d
C22:6	1	0.020c	0.030bc	0.020c	0.000c
	2	0.030bc	0.030bc	0.060ab	0.070a

[a]Wt. %; n=10.
[b]For any one fatty acid, means in a column or row followed by unlike letters are different ($p<0.05$).
[c]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[d]1 = sample taken before frying began each day; 2 = sample taken after frying was finished each day.

Although C18:1 had a significant OIL x DAY interaction (Appendix B-3), it also had a significant OIL x SP x DAY interaction, and in combination with C22:4 will be discussed from the standpoint of the three-way interaction.

Table 22. presents the mean levels of C18:1 and C22:4 from each sampling time on each day of frying for each type of oil. In SO, with the exception of day 3, the levels of C18:1 remained fairly constant across 5 days of frying in samples taken before frying began. However, C18:1 levels in SO taken at the end of day 1 through day 5 were increased. These trends, however, were not observed in the oil blends or POO.

The C18:1 levels did not change in samples taken after daily frying in 80:20 blend. But, C18:1 concentrations in samples taken before daily frying on day 1, 2 and 3 were significantly lower than that taken before daily frying on day 5 in the 80:20 blend (Table 22). The level of C18:1 in 60:40 blend taken at the end of daily frying on day 1 through 5 did not significantly different. But in samples taken before daily frying, the level of C18:1 was the highest on day 1 and the lowest on day 4 (Table 22). No significant differences were found in C18:1 level in POO among samples or days of frying. The only significant difference found for C22:4 was in the 60:40 blend in which samples taken after frying on day 5 had higher levels than at any other time (Table 22).

The levels of the fatty acids C14:0, C16:0, C18:0, C18:1, C18:2, C20:0, C18:3 and C20:1 in Table 17 are similar to the levels of the respective acids reported in SO by Weiss (1983). However, the levels of C18:2 and C18:3 (52.930 and 6.238%, respectively) in the present study are lower than levels of C18:2 and C18:3 (54.5 and 8.3%, respectively) reported by Weiss (1983). The

Table 22--Mean concentrations[a,b] of fatty acids, C18:1 and C22:4, for each frying oil sampled before and after frying each day for five days of frying

F.acid Oil[c]	Sample[d]	Frying time (days) 1	2	3	4	5
C18:1						
SO	1	22.500d	23.000cd	23.700abc	23.250cd	23.300bcd
	2	23.300bcd	23.600abc	24.100ab	23.700abc	24.200a
80:20	1	26.100b	26.500b	26.650b	27.150ab	28.750a
	2	28.650ab	27.350ab	27.750ab	27.850ab	27.550ab
60:40	1	33.050a	30.200bc	30.700bc	28.800c	30.450bc
	2	30.550b	30.900b	31.250b	31.250b	31.350b
POO	1	39.700	39.600	39.800	39.750	40.250
	2	39.500	39.450	39.700	39.350	39.750
C22:4						
SO	1	0.000	0.000	0.000	0.000	0.000
	2	0.000	0.000	0.000	0.000	0.100
80:20	1	0.000	0.000	0.000	0.000	0.000
	2	0.000	0.000	0.000	0.000	0.050
60:40	1	0.000b	0.000b	0.000b	0.000b	0.000b
	2	0.000b	0.000b	0.000b	0.050ab	0.100a
POO	1	0.000	0.000	0.000	0.000	0.050
	2	0.000	0.000	0.000	0.000	0.000

[a]Wt. %; n=2.

[b]For any one oil, means followed by unlike letters are different ($p<0.05$).

[c]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.

[d]1 = sample taken before frying began each day; 2 = sample taken after frying was finished each day.

lower levels may occur because the polyunsaturated acids were thermally oxidized during frying. Polyunsaturated fatty acids are oxidized more readily than monounsaturated or saturated fatty acids at frying temperatures (Lin, 1993). The mean concentrations of fatty acids in Table 17 were averaged across five days of frying prawn crackers.

The levels of C12:0, C14:0, C16:0, C18:0, C18:1, C18:2, C20:0 and C20:1 found in the POO (Table 17) in the present study are similar to concentrations of acids reported in POO by Han (1989) and for POO by Weiss (1983). Levels of C18:3, C22:0 and C24:0 also were close to the levels of those same acids reported by Han (1989). However, the level of C18:2 (9.885%) was lower in the present study than that (10.52%) reported in POO by Han (1989). This observation may be due to C18:2 degradation during frying of prawn crackers.

The major concentration differences between SO and POO, however, are for C16:0, C18:1, C18:2, and C18:3 fatty acids. These differences are inherent to the oils. When all fatty acids are expressed as weight percentages such that the total concentration is 100%, any significant decrease in the percentage of one acid may result in the significant concentration of one or more other fatty acids. During frying, oils degrade mainly via thermal oxidation of the unsaturated fatty acids (Melton et al., 1994). The relative oxidation rate of C18:2 is ten times that of C18:1 and one hundred times the oxidation rate of C18:0 (Lin, 1993). Therefore, decrease in levels of the naturally occurring polyunsaturated fatty acids in an oil/fat during frying is expected.

However, during daily frying, frying oil/fat is absorbed by the food fried, lost during filtration and cleaning, and in case of a frying study, to sampling also. Then,

fresh oil is added back to the fry kettle with the used frying oil to fill the kettle to the full mark. So while daily frying should reduce the naturally occurring fatty acids, C18:2 and C18:3, in the frying oils and oil blends in the present investigation, addition of daily make-up oils/blends should increase the levels of these fatty acids in samples taken before daily frying compared with samples taken after frying. Thus, in all oil samples, frying resulted in lower levels of C18:2 and C18:3 in the sample taken after daily frying compared with samples taken before frying commenced. The decrease of the concentrations of these acids during daily frying, most likely, contributed to the increases in concentrations of C14:0, C16:0 and C20:1 in the samples taken at the end of the day. Also, addition of fresh oil/blends partially replenished the C18:2 and C18:3 levels in the samples taken before daily frying contributing to the differences found in their concentrations between before and after samples.

On the other hand, other explanations are needed to explain minor differences in fatty acid concentrations between oil samples obtained before and after daily frying. For example, the levels of C16:1 decreased during daily frying while the level of trans-C16:1 increased (Table 18). The decrease in the level of C16:1 is almost the same as the increase in the level of C16:lt; therefore, it is feasible that C16:1 (cis form naturally occurring) was converted to the C16:1t at frying temperature (190°C). The increased concentration of trans fatty acids due to heating of frying oil at 190°C was also reported by Kemeny et al. (1992).

The longer chain unsaturated fatty acids (C22:4 and C22:6) which do not exist normally in SO or POO may be from adulteration of the frying oils/fats by the lipids of the prawn crackers. The leaching of food lipids into frying oil/fat has been

well documented (Melton et al., 1994; Weiss, 1983).

2. CHEMICAL AND SENSORY CHARACTERISTICS OF FRIED PRAWN CRACKERS

Chemical Composition

The moisture and the fat contents of prawn crackers before and after frying are presented in Table 23. The fried prawn crackers absorbed oil during frying, and their fat content increased substantially. At the same time, some of moisture present in prawn crackers before frying evaporated during frying, resulting in lower moisture content in the fried prawn crackers. The expansion of the crackers during frying create a larger surface area for facilitating the oil pick-up during frying. Analysis of variance for the effect of the type of oil on the fat content of the fried product indicated that the fat content of fried prawn crackers was not affected by the type of oils.

Other investigators (Han, 1989; Husain, 1986) reported similar results in that different oils used to fry potato chips did not affect the fat content in the chips. Likewise, Robertson et al. (1978) reported that the chips fried in SO had the same fat content as that in chips fried in POO.

Volatile Analysis

Twenty-three volatiles (Table 24) from fried prawn crackers were identified in the present study. The analyses of variances for concentrations of these volatiles as functions of type of oil (OIL), storage treatment (TRT), and the OIL x

Table 23--Mean moisture and fat contents[a,b] of prawn crackers before and after frying

Prawn cracker state	Moisture (%, wb)	Fat (%, wb)
Before frying	9.16 ± 0.05	6.63 ± 0.08
After frying	3.33 ± 0.06	29.41 ± 0.03

[a]Percentage wet basis (n=4).
[b]Means ± standard deviations.

Table 24--Mean concentrations[a,b] averaged across storage conditions of volatiles isolated from prawn crackers fried in different oils

Volatile	RT[d]	Frying Oil[c]			
		SO	80:20	60:40	POO
Pentanal	29.209	2.92	3.70	3.30	2.17
Hexanal	26.614	12.20	13.43	12.05	7.44
2-pentylfuran[e]	30.825	0.56	0.76	0.76	0.65
Heptanal	33.379	0.65	0.51	0.50	0.43
2,3-Hexane-dione[e]	34.344	0.19	0.18	0.16	0.12
2-Methyl-pyrazine[f]	37.151	0.07	0.11	0.12	0.08
T-2-Hexenal	37.693	0.23	0.27	0.21	0.19
Octanal[f]	40.196	1.20a	0.62b	0.39b	0.21b
T-2-Heptenal	44.791	0.79	1.01	0.97	0.95
2-Ethyl-3-methylpyrazine[f]	45.992	0.02b	0.02b	0.09a	0.01b
Nonanal[f]	46.735	2.34a	0.98b	0.82b	0.51b
T-2-Octenal	51.526	1.57	1.55	1.57	1.25
Decanal	53.007	0.46	0.42	0.22	0.25
C,T-2,4-Hepta-dienal[e]	54.871	0.06b	0.13ab	0.18a	0.15ab
T,T-2,4-Hepta dienal[f]	56.125	0.05b	0.29a	0.42a	0.39a
T-2-Nonenal	57.672	0.36	0.34	0.28	0.23
Undecanal	60.453	0.20	0.20	0.21	0.16
T-2-Decenal[f]	63.746	3.18a	1.31b	0.91b	0.32c
T,T-2,4-Nona-dienal	68.168	0.69	0.75	0.61	0.44

Continued

Table 24--Continued

Volatile	RT[d]	Frying oil[c] Soy	80:20	60:40	Palm
T-2-Undecenal[f]	69.335	2.89a	1.30b	0.86bc	0.53c
C,T-2,4-Decadienal	72.077	2.21	5.60	6.04	4.64
T,T-2,4-Decadienal	73.917	12.85	26.69	28.50	22.84
Tetradecanal	79.538	0.80	0.64	0.50	0.15

[a]Mg volatiles isolated from 125-g prawn crackers by 2 hr simultaneous distillation extraction with CH_2Cl_2.
[b]n = 6; Means in a row followed by unlike letters are different ($P < 0.05$).
[c]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.
[d]GC retention time in min.
[e]Tentative identification
[f]A frying oil x storage treatment interaction ($P < 0.5$) was found.

TRT interaction are listed in Appendix C. The type of oil (OIL) affected ($p<0.05$) the levels of octanal, 2-ethyl-3-methylpyrazine, nonanal, c,t-2,4-heptadienal, t,t-2,4-heptadienal, t-2-decenal, t-2-undecenal, and c,t-2,4-decadienal. The TRT (fresh, storage for 4 wk in the dark or storage for 4 wk in the light) affected the concentrations of all volatiles except 2-methylpyrazine and tetradecanal. However, the influences of OIL and TRT were dependent on each other for 2-methyl pyrazine, octanal, 2-ethyl-3-methylpyrazine, nonanal, t,t-2,4-heptadienal, t-2-decenal, and t-2-undecenal as shown by a significant OIL x TRT interaction for each of these volatiles in Figs. 1 - 7, respectively.

The mean concentrations of the volatiles for each type of oil are shown in Table 24. In general, prawn crackers fried in SO had the highest levels of octanal, nonanal, t-2-decenal and t-2-undecenal and had the lowest concentrations of t,t-2,4- heptadienal. Crackers fried in the 60:40 w/w blend of SO:POO had the greater amount of 2-ethyl-3-methylpyrazine than the prawn crackers fried in any of the other oils/blends. Prawn crackers fried in POO had the lowest level of t-2-decenal and t-2-undecenal. However, the differences among oils for octanal, t,t-2,4-heptadienal, 2-ethyl-3-methylpyrazine, nonanal, t-2-decenal and t-2-undecenal were dependent upon the storage treatment of the prawn crackers as previously noted.

Compared with fresh prawn crackers and those stored for 4 wk dark, prawn crackers stored in the light for 4 wk had the highest levels of all volatiles except for 2-methylpyrazine and tetradecanal which were not affected by TRT (Table 25). Fresh prawn crackers had the lowest levels of c,t-2,4-heptadienal and t,t-2,4-heptadienal of all treatments. For those volatiles which had a OIL x TRT interaction ($p<0.05$), however, the differences among storage treatments were dependent

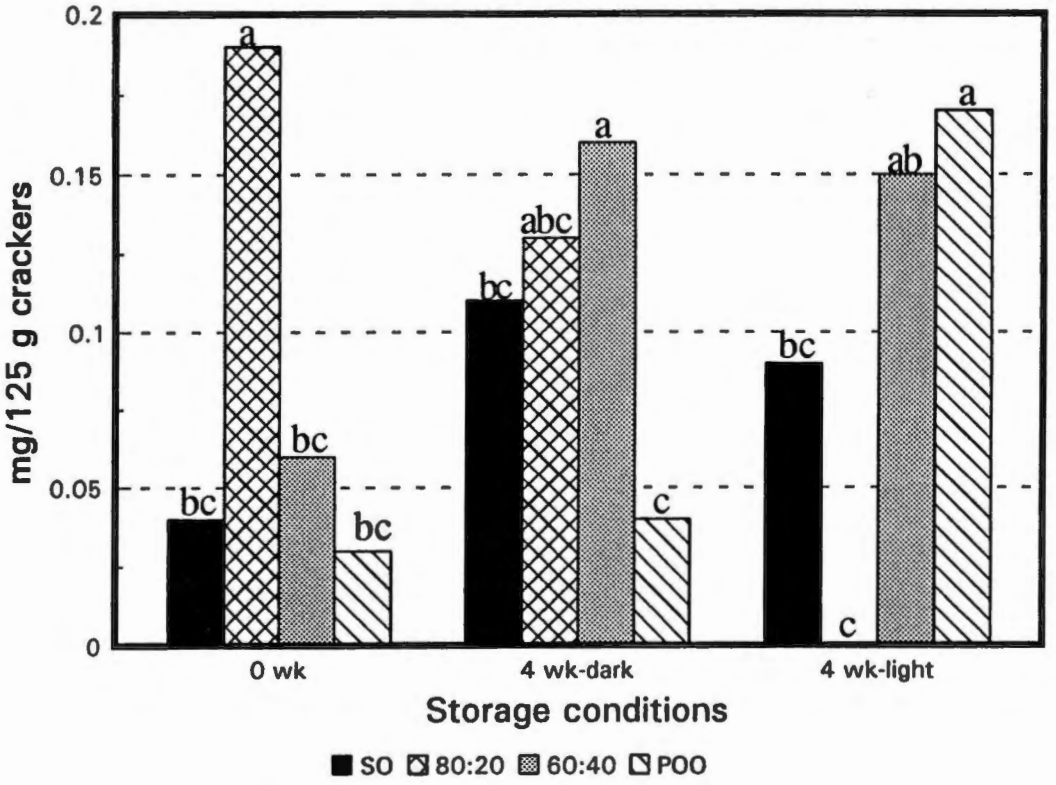


Fig. 1-Mean concentrations of 2-methylpyrazine in prawn crackers fried in different oils (SO, 80:20 and 60:40 w/w SO:POO, and POO) and stored for 0 wk or for 4 wk in dark or light; bars with unlike letters are different ($p<0.05$).

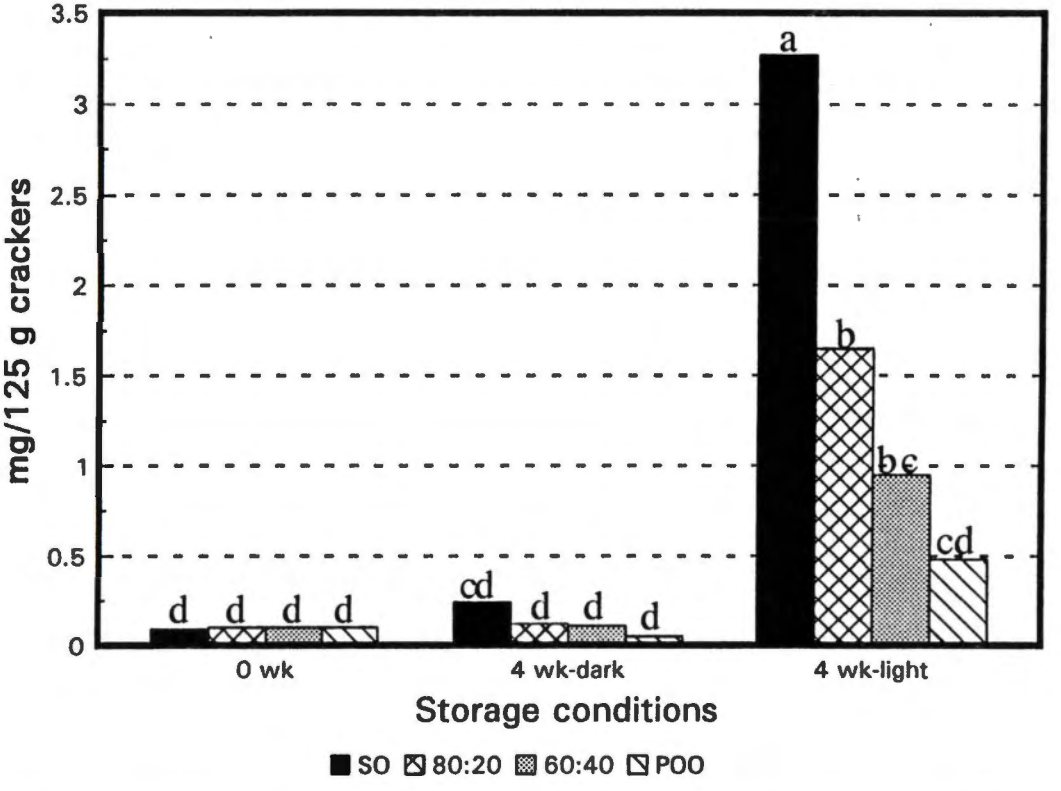


Fig. 2-Mean concentrations of octanal in prawn crackers fried in different oils (SO, 80:20 and 60:40 w/w SO:POO, and POO) and stored for 0 wk 4 wk in dark or light; bars with unlike letters are different ($p<0.05$).

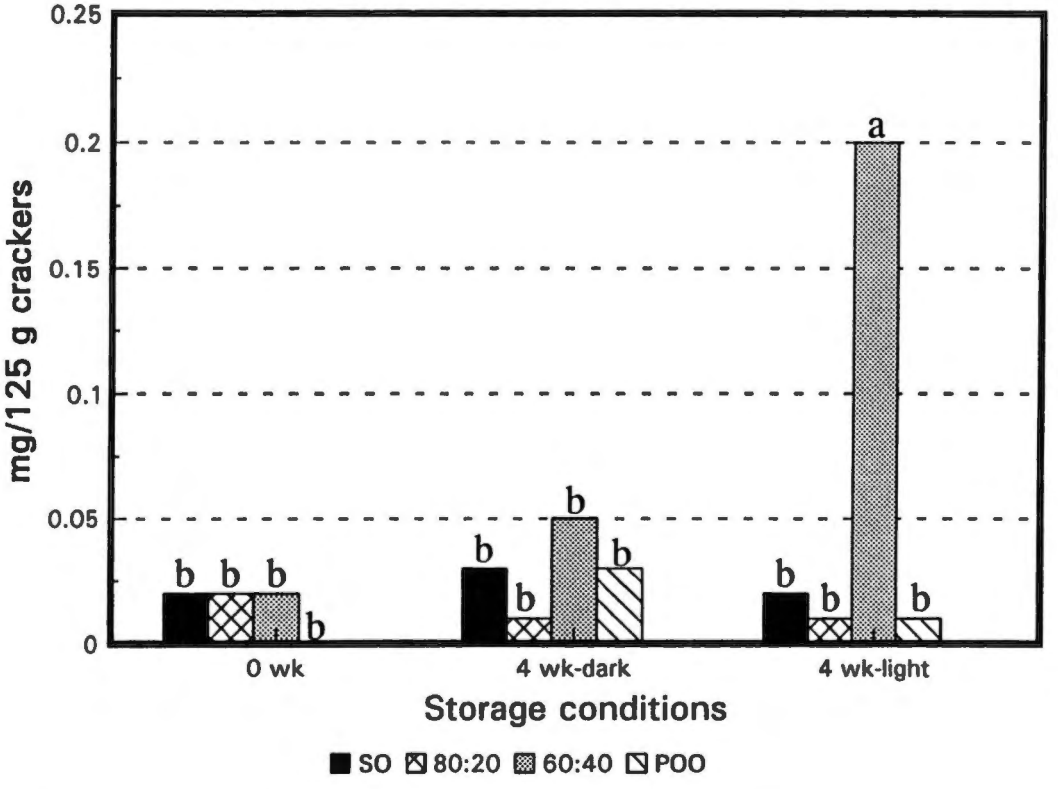


Fig. 3-Mean concentrations of 2-ethyl-3-methylpyrazine in prawn crackers fried in different oils (SO, 80:20 and 60:40 w/w SO:POO, and POO) and stored for 0 wk or for 4 wk in dark or light; bars with unlike letters are different ($p<0.5$).

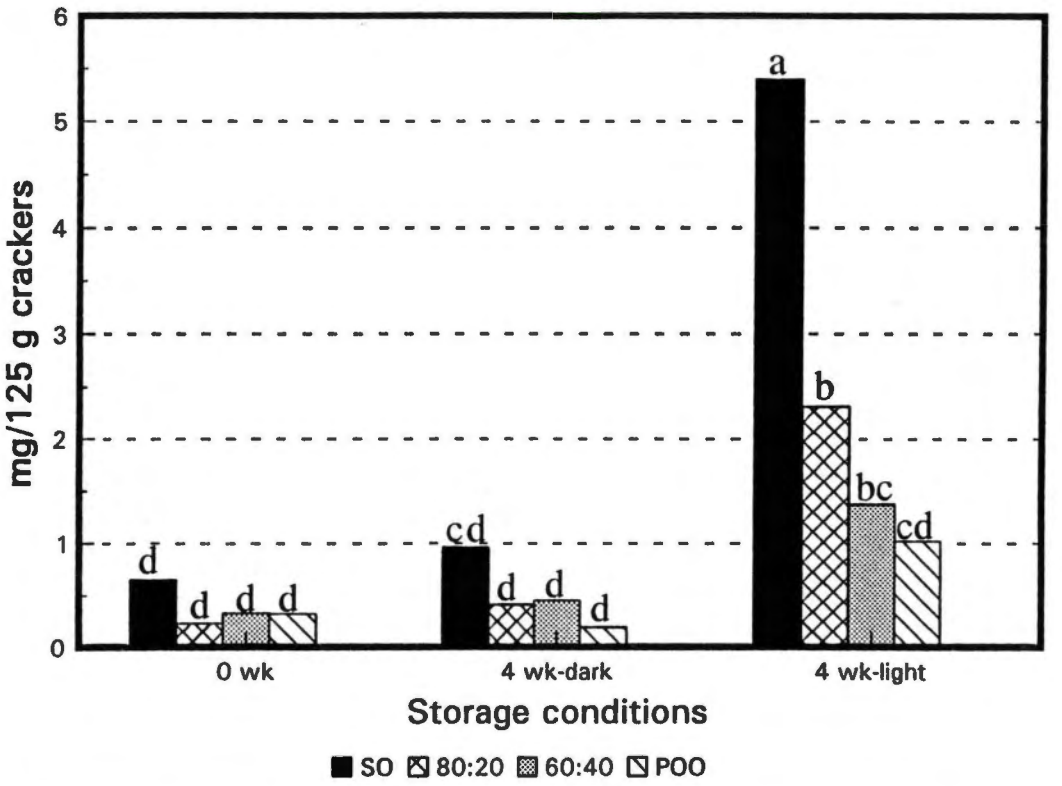


Fig. 4-Mean concentrations of nonanal in prawn crackers fried in different (SO, 80:20 and 60:40 w/w SO and POO, and POO) and stored for 0 wk or for 4 wk in dark or light; bars with unlike letters are different ($p<0.05$).

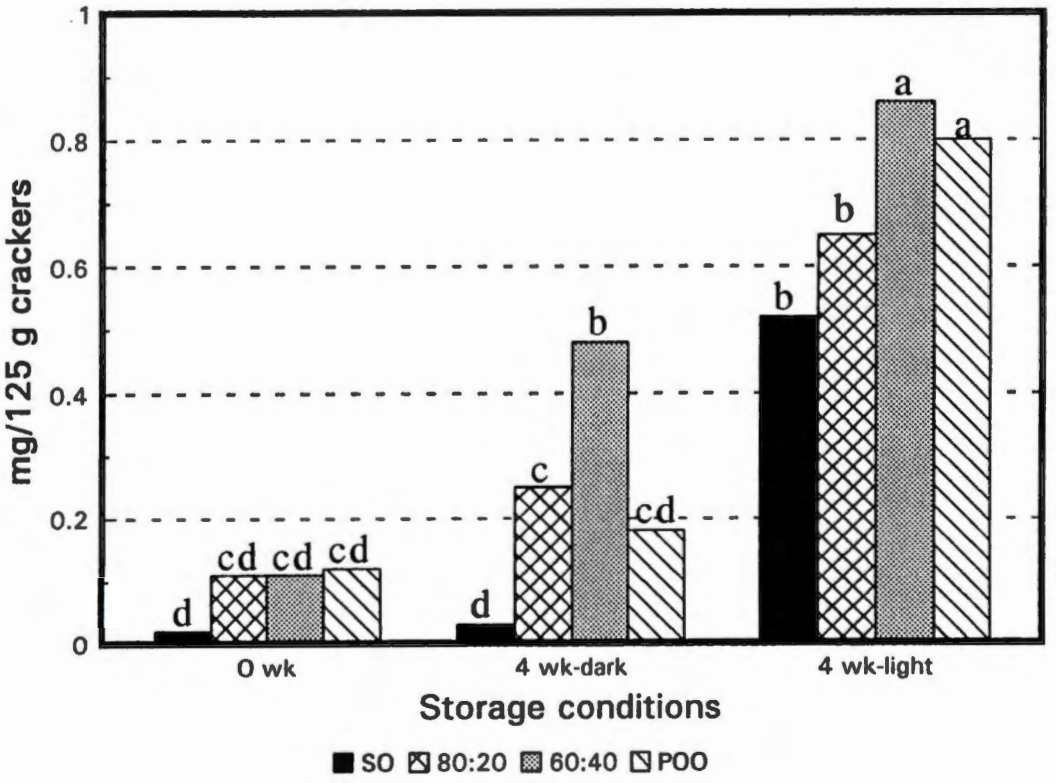


Fig. 5-Mean concentrations of T,T-2,4-heptadienal in prawn crackers fried in different oils (SO, 80:20 and 60:40 w/w SO:POO, and POO) and stored for 0 wk or for 4 wk in dark or light; bars with unlike letters are different ($p<0.05$).

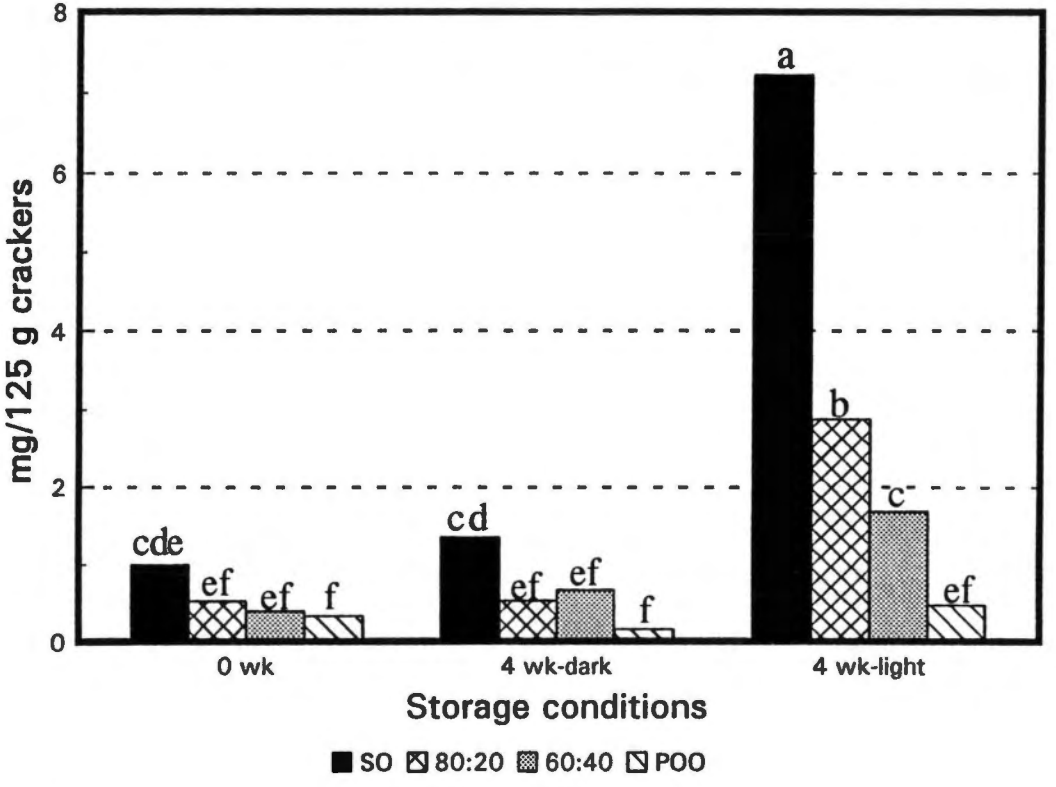


Fig. 6-Mean concentrations of T-2-decenal in prawn crackers fried in different oils (SO, 80:20 and 60:40 w/w SO:POO, and POO) and stored for 0 wk or for 4 wk in dark or light; bars with unlike letters are different ($p<0.05$).

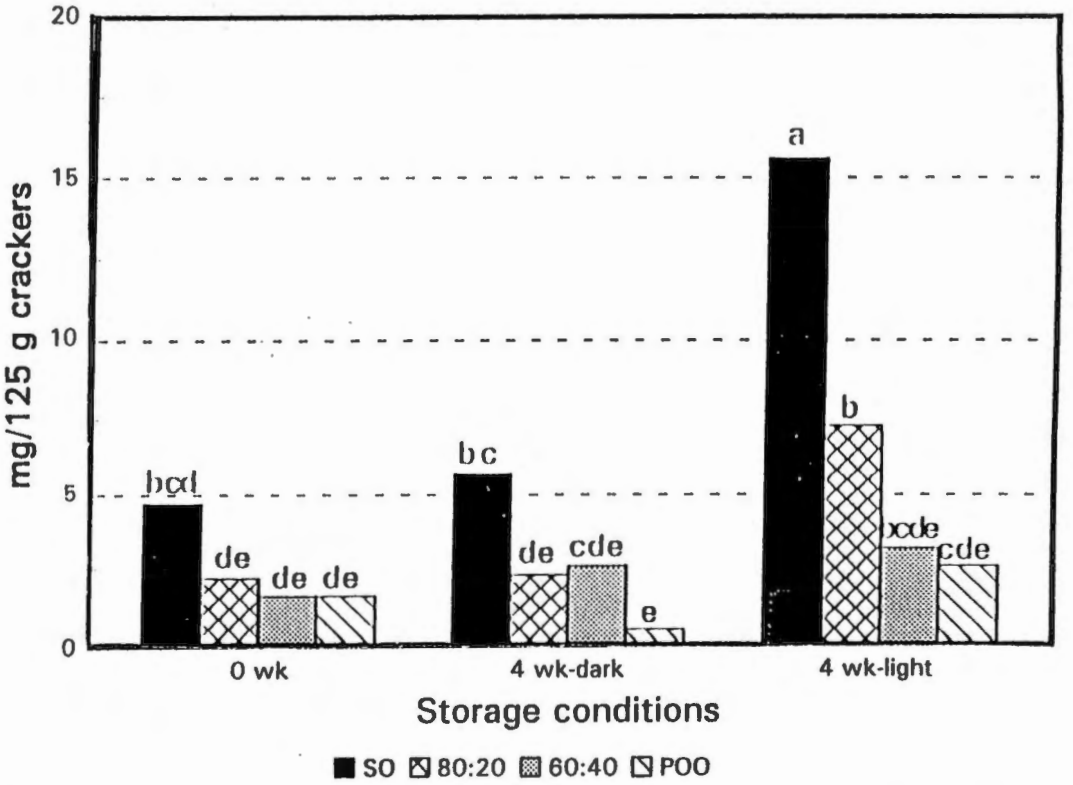


Fig. 7-Mean concentrations of T-2-undecenal in prawn crackers fried in different oils (SO, 80:20 and 60:40 w/w SO:POO, and POO) and stored for 0 wk or for 4 wk in dark or light; bars with unlike letters are different ($p<0.05$).

Table 25--Mean concentrations[a,b] averaged across frying oils of volatiles isolated from prawn crackers stored zero or 4 wk in the dark or 4 wk in the light

Volatile	RT[c]	Storage treatment		
		0 Wk	4 Wk dark	4 Wk light
Pentanal	20.209	0.46b	0.65b	7.95a
Hexanal	26.614	0.55b	0.92b	32.39a
2-Pentylfuran[d]	30.825	0.32b	0.33b	1.40a
Heptanal	33.379	0.09b	0.15b	1.33a
2,3-Hexanedione[d]	34.344	0.07b	0.08b	0.35a
2-Methyl-pyrazine[e]	37.151	0.08	0.11	0.10
T-2-Hexenal	37.693	0.04b	0.04b	0.58a
Octanal[e]	40.196	0.10b	0.13b	1.59a
T-2-Heptenal	44.791	0.15b	0.20b	2.44a
2-Ethyl-3-methylpyrazine[e]	45.992	0.01b	0.03b	0.07a
Nonanal[e]	46.735	0.38b	0.50b	2.60a
T-2-Octenal	51.526	0.22b	0.50b	3.72a
Decanal	53.007	0.20b	0.20b	0.62a
C,T-2,4-Hepta-dienal[de]	54.871	0.04c	0.11b	0.25a
T,T-2,4-Hepta-dienal[e]	56.125	0.09c	0.24b	0.54a
T-2-Nonenal	57.672	0.15b	0.17b	0.58a
Undecanal	60.453	0.16b	0.10b	0.31a
T-2-Decenal[e]	63.746	0.56b	0.68b	3.06a
T,T-2,4-Nona-dienal	68.108	0.16b	0.17b	1.44a

Continued

Table 25--Continued

Volatile	RT[c]	Storage treatment		
		0 Wk	4 wk dark	4 wk light
T-2-Undecenal[e]	69.335	0.83b	0.93b	2.43a
C,T-2,4-Decadienal	72.077	2.30b	3.69b	7.87a
T,T-2,4-Decadienal	73.917	13.87b	20.45b	33.84a
Tetradecanal[d]	79.538	0.36	0.49	0.71

[a]Mg volatiles isolated from 125-g prawn crackers by 2 hr simultaneous distillation extraction with CH_2Cl_2.
[b]n=8; Means in a row followed by unlike letters are different ($P<0.05$).
[c]GC retention time in min.
[d]Tentative identification
[e]A frying oil x storage treatment interaction ($P<0.05$) was found.

upon the type of oil in which the crackers were fried as stated previously. The least squares means concentrations of 2-methylpyrazine from prawn crackers fried in each oil and stored for zero wk (fresh) or for 4 wk light or 4 wk dark are presented in Fig. 1. For each storage treatment, the levels of 2-methylpyrazine had different patterns among the frying oils/blends which resulted in the significant OIL x TRT interaction. In the crackers stored for 4 wk in the dark, those fried in the 60:40 oil blend had a higher amount of 2- methylpyrazine than those fried in POO or SO. In contrast, fresh (zero week) prawn crackers fried in the 80:20 blend compared with those fried in other frying oils/blends, had the largest concentration of 2-methyl pyrazine (Fig. 1). In prawn crackers stored in the light for 4 wk, those fried in POO had a greater concentration of 2-methylpyrazine than those fried in the 80:20 oil blend or SO. Levels of 2-methylpyrazine were not different ($p<0.05$) among types of oils or storage treatments as shown in Tables 24 and 25, respectively.

Shown in Fig. 2 are the least squares means levels of octanal in prawn crackers fried in the different oils and stored under different conditions. In general, the level of octanal in prawn crackers stored for 4 wk L decreased ($p<0.05$) as the unsaturation of the fatty acids in the frying oils/blends decreased (Table 17). However, octanal in the prawn crackers fried in POO, the most saturated frying oil, was not significantly different from that in the prawn crackers fried in any other oil and stored zero week or 4 wk in the dark. The OIL x TRT interaction ($p<0.05$) was due to the different concentration patterns across the frying oils for two or more of the storage treatments. The same general pattern of concentration change across oils for the different storage treatments found for octanal also was observed for

nonanal (Fig. 4), t-2-decenal (Fig. 6) and t-2-undecenal (Fig. 7). However, in prawn crackers fried in SO and stored in the dark for 4 wk, the levels of t-2-decenal and t-2-undecenal generally were higher (Figs. 6 and 7, respectively) than that in prawn crackers fried in the other oils/blends and then stored in the same way.

The significant OIL x TRT interaction for 2-ethyl-3-methylpyrazine was due also to the differences in concentration patterns across the frying oils between two or more of the storage treatments. However, the only significant differences in level of this volatile was the much higher level present in prawn crackers fried in the 60:40 blend and stored in the light for 4 wk compared with the levels in prawn crackers fried in other oils in any storage treatment (Fig. 3).

The concentration of t,t-2,4-heptadienal in the prawn crackers also had a significant OIL x TRT interaction as shown by the differences in concentration patterns across the frying oils among the different storage treatments (Fig. 5). In prawn crackers stored for 4 wk in the dark, those fried in the 60:40 blend oil had higher levels of the t,t-2,4-heptadienal than those fried in any of the other oils/blends for that storage treatment (Fig. 5). In crackers stored for 4 wk in the light, crackers fried in the 60:40 blend or in POO had higher concentrations than those fried in the SO or the 80:20 blend. No differences existed in the t,t-2,4-heptadienal concentrations in fresh crackers fried in the different oils/blends.

Oxidation of different fatty acids can result in specific aldehydes and other volatiles. For example, pentanal, hexanal, heptanal, octanal, t-2-nonenal, t,t-2,4-nonadienal , t,t-2,4-decadienal and c,t-2,4-decadienal are formed by the fission of specific hydroperoxides from the oxidation of linoleic acid (18:2) (DeMan et al., 1992 ; White and Hammond, 1983). Oxidation of oleic acid (18:1) may result in

the formation of nonanal, decanal, t-2-decenal and t-2-undecenal, while oxidation of linolenic acid (18:3) can result in t-2-hexenal, c,t-2,4-heptadienal, t,t-2,4-heptadienal, and 2-pentylfuran (Nawar, 1985b). In the present study, the higher levels of octanal and t-2-undecenal in prawn crackers fried in SO (Table 24) most likely occurred because SO had the highest level of 18:2 among the frying oils/blends used (Table 17). However, crackers fried in SO also had the highest concentrations of nonanal, t-2-decenal and t-2-undecenal (Table 32), all of which are secondary products of 18:1 oxidation. In this study, SO had the lowest level of 18:1 and POO the highest level (Table 17).

However, the exact volatiles and their concentrations produced during oxidation of frying and subsequent storage of a fatty food are dependent upon the temperature of the oxidation reaction (Nawar, 1985a) as well as several other factors. Nawar (1985) showed that volatiles such as 2-pentylfuran, hexanal, 2-heptenal, octanal, t,c-2,4-decadienal, and t,t-2,4-decadienal reached a maximum concentration during the first few hours of heating a frying oil to frying temperatures but declined in concentration with continued heating. The volatiles present in the prawn crackers fried in the different oils were those produced at frying temperature as well as those produced at ambient temperature during storage in the dark and light.

Volatiles, such as those identified in the prawn crackers (Table 24), in a food system are in a dynamic state. They are formed, react with other components and are lost through volatilization (Nawar, 1985a; Pokorny, 1989). The volatiles, particularly the unsaturated carbonyls, can react with food amino acids or proteins via the nonenzymatic browning reaction to form different volatiles such as

pyrazines (Heath and Reineccius, 1986). Thus, while frying oils influence the flavor of a food through the types of volatiles produced by oxidation of the fatty acids present in the oil/fat, other factors also must be considered.

The concentration of specific volatiles in fried foods also may be dependent upon the foods. Other investigators found that potatoes in the form of chips (Han, 1989) and french fries (Jafar et al., 1989) fried in partially hydrogenated SO had higher concentrations of t,t-2,4-decadienal than the respective potato product fried in POO. This volatile, which is derived from the oxidation of C18:2, imparts a pleasant deep-fried flavor to foods (Mokherjee et al., 1965), and a frying oil with a higher C18:2 content such as SO should produce foods with more t,t-2,4-decadienal than POO which contains less linoleic acid. In contrast to what was expected in the present study, crackers fried in the oil blends and POO, all of which had less C18:2 than SO, appeared to have higher concentrations of t,t-2,4-decadienal than those fried in the SO (Table 24).

The large increases in the concentrations of most of the flavor volatiles in prawn crackers during 4 wk storage in light (Table 25) are in contrast to increases in concentrations of only a few volatiles in potato chips fried in SO, POO or cottonseed oil by Han (1989). Han (1989) found concentration increases in 3-ethyl-2-methylpyrazine and t,t-2,4-heptadienal in potato chips stored for 4 wk in the light. Lin (1993) found concentration increases in several volatiles (hexanal, 2-ethyl-6-methylpyrazine, 2-furaldehyde, t,t-2,4-heptadienal, and c,t-2,4-decadienal) during the four-week storage period in the light of potato chips fried in different oils (high oleic sunflower oil, canola oil, regular sunflower and cottonseed). However, when fried prawn crackers were stored for 4 wk in the light, there were significant

concentration increases in almost every flavor volatile identified (Table 25) with very large increases in some (pentanal, hexanal, t-2-hexenal, t-2-decenal. and the decadienals). These concentration increases indicate an increased in oxidation because of exposure to light. Since these prawn crackers were stored in glass jars which filter out UV light below 300-325 nm, direct photochemical oxidation was not possible (Frankel, 1985). However, it is possible that photosensitized oxidation occurred due to oxygen being activated to singlet oxygen by visible light in the presence of a photosensitizer such as chlorophyll, flavin, pheophytins, porphyrin, protoporphyrin, or riboflavin (Frankel, 1985). The results found in the present study indicate that the photosensitizer likely presence in the prawn crackers is not present in potato chips. Potato chips fried in different oils, including POO, and stored for 4 wk in the light (Han, 1989; Lin, 1993) were stored in the same type of glass jar used to store the prawn crackers did not produce high levels of volatiles during storage treatment.

Sensory Evaluation of Fried Prawn Crackers

The analyses of variance for the effects of type of frying oil (OIL), storage treatment (TRT) and panelist (PNL) and their interactions on the color, flavor and overall acceptability scores of prawn crackers fried in SO, POO, or in 80:20 and 60:40 w/w blends of SO:POO are presented in Appendix C. The least means squares of the color, flavor and overall acceptability scores of prawn crackers as affected by type of frying oil are given in Table 26. The color, flavor and overall acceptability scores of prawn crackers fried in different oils were not significantly

Table 26-Least squares means of sensory scores[a] of prawn crackers fried in different types of oils

Sensory characteristic	Type of frying oil[b]			
	SO	80:20	60:40	POO
Color score	5.91	5.81	5.85	5.94
Flavor score	5.51	5.47	5.47	5.55
Acceptability score	5.43	5.43	5.49	5.57

[a]N = 600; 8-point scale where 1 = dislike extremely and 8 = like extremely.
[b]SO = unhydrogenated soybean oil; POO = palm olein oil; 80:20 = weight ratio of SO:POO; and 60:40 = weight ratio of SO:POO.

different. The color, flavor and overall acceptability scores ranged from 5.43 to 5.94 which were between " like slightly" (5.0) and "like moderately" (6.0) on an eight-point hedonic scale (Appendix A). Based on the volatile compounds found in the prawn crackers, the concentration of the volatile, t,t-2,4-decadienal, that imparts a pleasant deep fried flavor to fried foods was not significantly different among the frying oils (Table 24). It is possible that this flavor volatile compound was present at adequate concentrations in crackers fried in all oils/blends to contribute a pleasant deep fried flavor to all crackers. Augustin et al. (1987a) reported that prawn crackers fried in POO were preferred to those fried in SO. However, Augustin et al. conducted their study in Malaysia, where most people (including the panel) were familiar with prawn crackers. In the present study, only 55% of the panel members were familiar with prawn crackers. Therefore, it is possible that the familiarity of the panel with the product in the study of Augustin et al. (1987a) may have affected the color, flavor and overall acceptability scores of prawn crackers.

The mean color, flavor and overall acceptability of prawn crackers from the different storage treatments are presented in Table 27. The flavor and overall acceptability scores of prawn crackers were affected ($p<0.05$) by storage treatment while the color scores of the prawn crackers were not ($p>0.05$). The average flavor score of the crackers stored for zero weeks was not significantly different from the crackers stored for 4 wk in the dark, but both were higher than that of crackers stored for 4 wk under the light. The difference in the overall acceptability scores among storage treatments was similar to that of the flavor scores (Table 27).

Table 27--Least mean squares of sensory scores[a,b,c] of prawn crackers from different storage treatments averaged across type of frying oils and panelists

Sensory characteristic	Storage treatments[c]		
	0 wk	4 wk light	4 wk dark
Color	5.91c	5.75d	5.97c
Flavor	5.84c	4.86d	5.81c
Acceptability	5.75c	4.92d	5.80c

[a]N = 200.
[b]Means in a row followed by unlike letters are different ($p < 0.05$).
[c]8-point scale where 1 = dislike extremely and 8 = like extremely.

The flavor of fried foods is dictated by the types and concentrations of volatile compounds present and is influenced by the content and type of unsaturated fatty acids in the fried foods. The extent of oxidation that has taken place during frying and storage also influences the flavor of fried foods (Min and Schweizer, 1983). Fuller et al. (1971) reported that a sensory panel was able to differentiate chips stored under fluorescent light for three days from those stored under nitrogen in the dark. Certainly the fact that most all of the flavor volatiles in the prawn crackers increased in concentration during four week storage in the light is responsible for the decreased flavor and overall acceptability of the prawn crackers. Several of these volatiles have been reported to be responsible for the reversion flavor on SO including t-2-nonenal (rancid) (Endo et al., 1991; Warner et al., 1974) identified and measured in the present study . In addition, pentanal and hexanal reportedly have a negative correlation with flavor score where the higher the concentration of these two volatiles, the lower the flavor score (Warner et al., 1978). Still other investigators have reported that t,t-2,4-heptadienal contributes to unpleasant flavor (Melton et al., 1993). All of these volatiles increased significantly during storage of the prawn crackers in the light for 4 wk.

The findings of the present study were in agreement with other studies reported on the storage of fried products. Han (1989) reported that potato chips stored in the light for 4 wk had higher increases in peroxide value and developed less desirable flavor than those stored in the dark. Lin (1993) reported similar results for potato chips fried in canola oil, regular sunflower, high oleic acid sunflower and cottonseed oil and stored in the light for 4 wk. The presence of a rancid flavor in stored fried product was noted also by Dornseifer and Powers

(1965). Potato chips fried in cottonseed oil and stored in sunlight for five days was found to develop a rancid/oxidized flavor as judged by a sensory panel. Robertson et al. (1978) reported that only gradual degradation of potato chip flavor occurred with increasing storage time from zero to ten weeks in the dark at 31°C.

Yu and Tan (1990) also reported that the overall acceptability of prawn crackers is related to the flavor of the crackers. Beside flavor and color, the expansion of the crackers during frying/cooking has been used as a quality parameter of crackers/keropok or similar products (Yu et al., 1981). Another consideration that may influence the acceptability of the prawn crackers is the familiarity of the panel with the product, including the flavor.

Demographic Background of the Sensory Panel

The sensory panel that evaluated the prawn crackers in the current study consisted of 53% male and 47% female. Most of the panel were under the age of 34 years of age (79%) compared with the 21% there were 35 years or older. One group (50.5%) of the panel consumed deep fried products several times a week, while another panel group ate deep fried products once a week or less. Most of the panel members (94.8%) liked shrimp flavor compared with 5.2% that did not.

The panel was composed of 50.5% of people who considered the U.S.A. as their home country while the remainder considered another country besides the U.S.A. as their country. Over half of the panel (55.7%) was familiar with or had tasted prawn crackers previously, while 44.3% of the panel had never been exposed to prawn crackers.

CHAPTER V

SUMMARY

In this study, the degradation of SO, POO and blends of 80:20 and 60:40, w/w, SO:POO during intermittent frying of prawn crackers for up to five days was determined. Samples of each oil/blend taken on each day of frying were analyzed by FOS, RAU, Fritest and color measurement and for levels of conjugated dienes, fatty acids, C18:2/C16:0 ratio (RATIO), FFA and TPC. Also, prawn crackers fried in each oil/blend were stored for 0 week (fresh) and for 4 wk in the dark and 4 wk in the light at 25°C. All crackers were analyzed for levels of different flavor volatiles, and color, flavor and overall acceptability scores. Moisture and fat levels of prawn crackers before and after frying were also determined.

During the five days of frying, each oil/blend degraded to the point of discard as determined by the measurements of FOS, Fritest and TPC levels. FOS, Fritest and TPC were not different ($p<0.05$) among oils/blends, and individually, proceeded at similar rates of increase across frying time for each oil/blend. However, the TPC level reached the point of discard (25-27%) by the second day of frying, whereas it took four to five days of frying for FOS and Fritest to reach maximum levels or discard points. The reason for TPC reaching such concentrations so quickly was because of the high level (12.5-14.1%) in the fresh oils/blends; normally, fresh oils contain only 4-7% TPC.

The RAU test, which measures levels of oxidized compounds in frying oils, showed that the 80:20 and 60:40 SO:POO blends reached maximum value or point of discard by the end of day 4 of frying compared to day 5 for pure SO and POO.

These results indicate that, perhaps, something in the POO, such as the increased levels of carotenoid pigments, destabilized the more unsaturated SO, making it more susceptible to thermal oxidation.

While FFA levels increased in all oils during five days of frying, they did not reach a discard point for frying oils/blends. FFA levels were highest in fresh POO and increased at a greater rate ($p<0.05$) in POO than in other oils/blends during five days of frying than in SO. FFA levels and rates of increase in the blends were between those of POO and SO. However, the FFA levels an any oil/blend even after five days of frying were less than 0.50%, the level at which frying oil for potato chips should be discarded to prevent flavor problems in the chips during storage.

Because of the inherent differences in the fatty acid composition of SO and POO, SO had the highest C18:2/C16:0 ratio and highest diene concentration of all oils/blends. During five days of frying, the C18:2/C16:0 decreased and the diene level increased in each oil/blend showing again the degradation during frying.

Fatty acid analyses showed that SO was rich in C18:2 compared with POO (51.9 versus 9.9%, respectively) and had significantly higher levels of linolenic then POO (6.2 versus 0.2%). Compared with SO, POO had higher amounts of C16:0 (43.3 versus 12.1%) and C18:1 (39.7 versus 23.5%). In all oils/blends, eighteen fatty acids were identified and measured. Averaged across frying time, levels of C18:2 decreased ($p<0.05$) due to thermal oxidation during five days of frying. The mean amounts of C12:0, C18:0, C20:2 and C22:4 increased during this same period. While C12:0 may have been formed from the oxidation of C18:2, increases in levels of C20:2 and C22:4 most likely were due to their leaching from the prawn

crackers during frying. Increases in the amount of C18:0 were most likely because that the fatty acid concentrations were expressed in relative weight percentages where a significant decrease in the level of one fatty acid usually results in the increase of the level of another, more stable, fatty acid.

All oils/blends became darker (decreasing *L* value) and more yellow (increasing *b* value) during five days of frying prawn crackers, but SO had the greatest overall color change, ΔE, of all oils/blends. This was mainly because compared with POO, fresh SO had a very low *b* value (5.4 versus 21.6), but after five days frying, SO had nearly the same *b* value as POO (42.3 versus 43.9, respectively). In contrast, the *L* value of POO decreased from 92.8 to 78.4 during five days of frying compared with a decrease from 95.6 to 85.3 for SO. The darker color of the POO at the end of the frying period indicates that POO might be discarded before it is fully deteriorated in a fast food outlet where dark color is the only criterion of when to discard a frying oil.

The insignificant differences among the frying oils/blends in concentrations of eighteen of the twenty-three volatiles identified in prawn crackers indicate that the frying oil/blend had little influence on the flavor of the prawn crackers. Sensory evaluation of the crackers also failed to show significant differences in the flavor or overall acceptability scores of the prawn crackers among the different oils/blends. Prawn crackers fried in any oil/blend had flavor and overall acceptability scores of approximately 5.9 on a scale where 5 = like slightly and 6 = like moderately. However, storage of the prawn crackers in the light for 4 wk at 25°C resulted in large increases in the levels of twenty-one of the volatiles and decreased ($p < 0.05$) the flavor and overall likability scores from 5.8 to 4.9. Storage of the prawn

crackers fried in any oil/blend in the dark for 4 wk increased ($p<0.05$) the concentrations of only t,t-2,4-heptadienal and c,t-2,4-heptadienal slightly over those in fresh chips and did not affect the flavor or overall likability scores significantly.

These results indicate that either SO or POO could be used to produce acceptable fried prawn crackers. The choice of which oil, SO or POO, most likely would be based on the cheapest and/or the "healthiest" oil, rather than the quality of the crackers. However, to maintain the best quality in stored fried prawn crackers, they must be packaged in a light barrier bag.

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APPENDICES

APPENDIX A--

SENSORY DEMOGRAPHIC QUESTIONNAIRE AND SCORE CARD

Appendix A-1--
Sensory demographic questionnaire

Panelist number _____

Please complete the following questionnaire. The information is needed purpose of classification.

1. Gender: Male _____ Female _____

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

3. How often do you consume deep-fried chips?
   _____ Several times a week
   _____ Once a week
   _____ Less than once a week

4. What kind of deep-fried chips do you most oftenly consumed?
   _____

5. How well do you like the flavor of shrimp?
   Like extremely _____
   Like very much _____
   Like moderately _____
   Like slightly _____
   Dislike slightly _____
   Dislike moderately _____
   Dislike very much _____
   Dislike extremely _____

6. Have you tasted shrimp crackers or similar product before?
   _____ Yes _____ No

7. What is your home country?_____

Appendix A-2--
Sensory score card

Panelist number _____

Thank you for participating for tasting shrimp flafoured crackers. You will receive six samples. For each sample indicate how well do you like or dislike the color, flafor , and overall acceptability of the crackers by cheking the term that best describe your feelings toward the sample. Please rinse your mouth with water after tasting each of the cracker sample.

How well do you like the color of shrimp?

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

How well do you like the flavor of shrimp?

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

How well do you like the crackers of overall?

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

If the product you tasted today was available in the market, would you buy it?

Yes_____ No_____

Comments:

APPENDIX B--

ANALYSIS OF VARIANCES FOR MEASUREMENTS OF OIL DEGRADATION, COLOR AND FATTY ACID COMPOSITION DURING FRYING OF PRAWN CRACKERS INTERMITTENTLY FOR FIVE DAYS

Appendix B-1--Analysis of variance[a] for characteristics of frying oils during frying of prawn crackers

General Linear Models Procedure

Dependent Variable: FOS

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.783744	0.20	0.8915
OIL*REP	4	5.227465		
SP	1	56.666611	693.83	0.0001
DAY	4	36.526245	111.81	0.0001
OIL*SP	3	0.117814	0.48	0.6976
OIL*DAY	12	0.246275	0.25	0.9932
DAY*SP	4	0.671395	2.06	0.1072
OIL*DAY*SP	12	0.184005	0.19	0.9982
Error	36	2.940180		
Corrected Total	79	103.363740		

General Linear Models Procedure

Dependent Variable: RAU

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.925000	4.48	0.0906
OIL*REP	4	0.275000		
DAY	4	14.500000	133.85	0.0001
SP	1	17.112500	631.85	0.0001
OIL*DAY	12	0.700000	2.15	0.0377
OIL*SP	3	0.262500	3.23	0.0336
DAY*SP	4	0.762500	7.04	0.0003
OIL*DAY*SP	12	0.237500	0.73	0.7125
Error	36	0.975000		
Corrected Total	79	35.750000		

Dependent Variable: Fritest

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.834375	1.51	0.3411
OIL*REP	4	0.737500		
SP	1	24.753125	642.24	0.0001
DAY	4	24.481250	158.80	0.0001
OIL*SP	3	0.134375	1.16	0.3376
OIL*DAY	12	0.493750	1.07	0.4141
SP*DAY	4	0.981250	6.36	0.0006
OIL*SP*DAY	12	0.693750	1.50	0.1695
Error	36	1.387500		
Corrected Total	79	54.496875		

continued

General Linear Models Procedure

Dependent Variable: DIENES

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	9.108190	94.20	0.0001
OIL*REP	4	0.529583		
SP	1	12.226570	379.36	0.0001
DAY	4	4.165510	32.31	0.0001
OIL*SP	3	0.831735	8.60	0.0002
OIL*DAY	12	0.511445	1.32	0.2489
SP*DAY	4	0.087876	0.68	0.6092
OIL*SP*DAY	12	0.242259	0.63	0.8057
Error	36	1.160269		
Corrected Total	79	28.863438		

General Linear Models Procedure

Dependent Variable: RATIO

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	176.53304483	2123.33	0.0001
OIL*REP	4	0.11085290		
SP	1	0.70378064	20.00	0.0001
DAY	4	0.71573819	5.08	0.0024
OIL*SP	3	0.15798631	1.50	0.2320
OIL*DAY	12	0.70345585	1.67	0.1169
SP*DAY	4	0.11484450	0.82	0.5236
OIL*SP*DAY	12	0.25801579	0.61	0.8186
Error	36	1.26710484		
Corrected Total	79	180.56482385		

General Linear Models Procedure

Dependent Variable: L

Source[b]	DF	Sum of Squares	F Value	Pr > F
OIL	3	240.93883	19.56	0.0075
OIL*REP	4	16.42305		
SP	1	488.41786	1190.52	0.0001
DAY	4	690.74657	420.92	0.0001
OIL*SP	3	10.14062	8.24	0.0003
OIL*DAY	12	10.91747	2.22	0.0324
SP*DAY	4	31.59868	19.26	0.0001
OIL*SP*DAY	12	4.09526	0.83	0.6182
Error	36	14.7692		
Corrected Total	79	1508.0475		

continued

Appendix B-1--Continued

Dependent Variable: a

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	14.066615	9.94	0.0252
OIL*REP	4	1.88718		
SP	1	7.78752	17.55	0.0002
DAY	4	88.63761	49.93	0.0001
OIL*SP	3	27.41570	20.59	0.0001
OIL*DAY	12	41.98337	7.88	0.0001
SP*DAY	4	139.02992	78.32	0.0001
OIL*SP*DAY	12	2.45056	0.46	0.9248
Error	36	15.97652		
Corrected Total	79	339.23500		

Dependent Variable: b

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	637.97308	7.48	0.0406
OIL*REP	4	113.6551	28.41	
SP	1	2161.7442	2005.70	0.0001
DAY	4	4516.5372	1047.63	0.0001
OIL*SP	3	68.8758	21.30	0.0001
OIL*DAY	12	191.3860	14.80	0.0001
SP*DAY	4	91.2479	21.17	0.0001
OIL*SP*DAY	12	12.0118	0.93	0.5299
Error	36	38.8008		
Corrected Total	79	7832.2319		

General Linear Models Procedure

Dependent Variable: ΔE

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	831.74464	10.44	0.0231
OIL*REP	4	106.2638		
SP	1	2682.7387	3160.60	0.0001
DAY	4	5423.3607	1597.01	0.0001
OIL*SP	3	39.0056	15.31	0.0001
OIL*DAY	12	163.0664	16.01	0.0001
SP*DAY	4	55.9464	16.47	0.0001
OIL*SP*DAY	12	15.1475	1.49	0.1745
Error	36	30.5636		
Corrected Total	79	9347.8373		

[a]OIL*REP included REP and was used as the error term to test oil for significance and Errorwas the error term for the other sources.
[b]OIL=type of frying oil; REP=replication; SP=sampling time; DAY=frying time (days).

Appendix B-2--Analyses of variance[a] for free fatty acids (FFA) and total polar components (TPC) of different types of frying oils used to fry prawn crackers for five days

General Linear Models Procedure

Dependent Variable: FFA

Source[b]	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.1056223	236.51	0.0001
OIL*REP	3	0.0006498		
DAY	4	0.1023728	171.93	0.0001
OIL*DAY	12	0.0068071	3.81	0.0072
Error	16	0.0024582		
Corrected Total	39	0.3588999		

Dependent Variable: TPC

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	20.43795	0.89	0.4682
OIL*REP	3	18.29129		
ST	4	541.80559	17.66	0.0001
OIL*ST	12	44.77894	0.49	0.8943
Error	16	122.68563		
Corrected Total	39	762.64971		

[a]OIL*REP included REP and was used as the error term to test OIL for significance and Error was the error term for the other sources.
[b]OIL=type of frying oil; REP=replication; and DAY=frying time (days).

Appendix B-3--Analyses of variances[a] for fatty acid concentrations in different oils, alone and in combination, used for up to 5 days for frying prawn crackers

Fatty acid=C12:0

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.84543750	12.3	0.0173
REP*OIL (Error 1)	4	0.09150000		
SP	1	0.35112500	32.12	0.0001
DAY	4	0.31075000	7.11	0.0003
SP*DAY	4	0.13325000	3.05	0.0292
OIL*SP	3	0.02837500	0.87	0.4680
OIL*DAY	12	0.13525000	1.03	0.4429
OIL*SP*DAY	12	0.14475000	1.10	0.3869
Error 2	36	0.39350000		
Corrected Total	79	2.43387500		

Fatty acid=C14:0

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	11.52550000	178.69	0.0001
REP*OIL (Error 1)	4	0.08600000		
SP	1	0.14450000	6.64	0.0142
DAY	4	0.19175000	2.20	0.0884
SP*DAY	4	0.06175000	0.71	0.5912
OIL*SP	3	0.08550000	1.31	0.2866
OIL*DAY	12	0.20825000	0.80	0.6509
OIL*SP*DAY	12	0.24825000	0.95	0.5112
Error 2	36	0.78400000		
Corrected Total	79	13.33550000		

Fatty acid=C16:0

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	10794.67637500	1918.67	0.0001
REP*OIL (Error 1)	4	7.50150000		
SP	1	23.65312500	15.83	0.0003
DAY	4	13.26175000	2.22	0.0864
SP*DAY	4	6.00125000	1.00	0.4183
OIL*SP	3	6.36237500	1.42	0.2531
OIL*DAY	12	21.74925000	1.21	0.3122
OIL*SP*DAY	12	9.83575000	0.55	0.8675
Error 2	36	53.80350000		
Corrected Total	79	10936.84487500		

continued

Fatty acid=C16:1

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.02340000	0.60	0.6483
REP*OIL (Error 1)	4	0.05200000		
SP	1	0.02450000	5.96	0.0197
DAY	4	0.00425000	0.26	0.9026
SP*DAY	4	0.01925000	1.17	0.3400
OIL*SP	3	0.00550000	0.45	0.7217
OIL*DAY	12	0.02775000	0.56	0.8570
OIL*SP*DAY	12	0.05075000	1.03	0.4449
Error 2	36	0.14800000		
Corrected Total	79	0.33800000		

Fatty acid=C16:1t

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.00748412	0.16	0.9211
REP*OIL (Error 1)	4	0.06430952		
SP	1	0.01726566	10.84	0.0022
DAY	4	0.00100115	0.16	0.9585
SP*DAY	4	0.01039493	1.63	0.1877
OIL*SP	3	0.00100726	0.21	0.8883
OIL*DAY	12	0.01756106	0.92	0.5390
OIL*SP*DAY	12	0.02571313	1.34	0.2373
Error 2	36	0.05735714		
Corrected Total	79	0.21200000		

Fatty acid=C18:0

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	3.38781760	0.84	0.5386
REP*OIL (Error 1)	4	5.37838889		
SP	1	0.56998267	5.41	0.0259
DAY	4	1.52608804	3.62	0.0143
SP*DAY	4	0.43834375	1.04	0.4004
OIL*SP	3	0.44438542	1.41	0.2573
OIL*DAY	12	2.28809375	1.81	0.0851
OIL*SP*DAY	11	0.26665625	0.23	0.9937
Error 2	35	3.68661111		
Corrected Total	77	19.45961538		

continued

Faty acid=C18:1

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	302.09160000	234.86	0.0001
REP*OIL (Error 1)	4	1.71500000		
SP	1	2.04800000	4.80	0.0350
DAY	4	4.19675000	2.46	0.0630
SP*DAY	4	3.11075000	1.82	0.1459
OIL*SP	3	2.42100000	1.89	0.1486
OIL*DAY	12	11.90125000	2.32	0.0253
OIL*SP*DAY	12	13.77525000	2.69	0.0108
Error 2	36	15.36500000		
Corrected Total	79	2941.89800000		

Fatty acid=C18:2

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	1939.60420000	346.69	0.0001
REP*OIL (Error 1)	4	7.45950000		
SP	1	61.42512500	26.79	0.0001
DAY	4	51.71575000	5.64	0.0012
SP*DAY	4	6.59425000	0.72	0.5846
OIL*SP	3	10.59437500	1.54	0.2208
OIL*DAY	12	27.13925000	0.99	0.4799
OIL*SP*DAY	12	25.12875000	0.91	0.5436
Error 2	36	82.54550000		
Corrected Total	79	19775.39387500		

Fatty acid=C18:3

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	34.23415000	9.61	0.0267
REP*OIL (Error 1)	4	4.75050000		
SP	1	5.35612500	6.42	0.0158
DAY	4	6.03075000	1.81	0.1491
SP*DAY	4	2.66575000	0.80	0.5343
OIL*SP	3	2.97437500	1.19	0.3282
OIL*DAY	12	13.39825000	1.34	0.2411
OIL*SP*DAY	12	5.40125000	0.54	0.8742
Error 2	36	30.05450000		
Corrected Total	79	463.39887500		

continued

Fatty acid=C20:0

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	2.07080000	1.32	0.3851
REP*OIL (Error 1)	4	2.09500000		
SP	1	0.01250000	0.01	0.9049
DAY	4	1.84825000	0.53	0.7110
SP*DAY	4	3.80125000	1.10	0.3715
OIL*SP	3	1.97050000	0.76	0.5238
OIL*DAY	12	12.08075000	1.17	0.3433
OIL*SP*DAY	12	5.45575000	0.53	0.8834
Error 2	36	31.10500000		
Corrected Total	79	63.34200000		

Fatty acid=C20:1

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.03960000	0.64	0.6300
REP*OIL (Error 1)	4	0.08300000		
SP	1	0.14450000	14.99	0.0004
DAY	4	0.07200000	1.87	0.1374
SP*DAY	4	0.09050000	2.35	0.0729
OIL*SP	3	0.15050000	5.20	0.0043
OIL*DAY	12	0.17300000	1.50	0.1711
OIL*SP*DAY	12	0.13450000	1.16	0.3449
Error 2	36	0.34700000		
Corrected Total	79	1.31200000		

Fatty acid=C20:2

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.69295000	1.04	0.4671
REP*OIL (Error 1)	4	0.89250000		
SP	1	0.01512500	0.15	0.7013
DAY	4	1.17925000	2.91	0.0347
SP*DAY	4	0.66925000	1.65	0.1822
OIL*SP	3	0.38137500	1.26	0.3039
OIL*DAY	12	1.24075000	1.02	0.4504
OIL*SP*DAY	12	0.59675000	0.49	0.9063
Error 2	36	3.64250000		
Corrected Total	79	8.99987500		

continued

Appendix B-3--Contineud

Fatty acid=C20:3

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.01015000	13.53	0.0146
REP*OIL (Error 1)	4	0.00100000		
SP	1	0.00800000	2.64	0.1128
DAY	4	0.00425000	0.35	0.8417
SP*DAY	4	0.00325000	0.27	0.8964
OIL*SP	3	0.00500000	0.55	0.6511
OIL*DAY	12	0.01275000	0.35	0.9723
OIL*SP*DAY	12	0.02375000	0.65	0.7822
Error 2	36	0.10900000		
Corrected Total	79	0.25800000		

Fatty acid=C22:0

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.15975000	3.25	0.1422
REP*OIL (Error 1)	4	0.06550000		
SP	1	0.02112500	3.31	0.0770
DAY	4	0.01500000	0.59	0.6732
SP*DAY	4	0.01700000	0.67	0.6193
OIL*SP	3	0.04237500	2.22	0.1031
OIL*DAY	12	0.09600000	1.25	0.2864
OIL*SP*DAY	12	0.03200000	0.42	0.9462
Error 2	36	0.22950000		
Corrected Total	79	1.90187500		

Fatty acid=C24:0

General Linear Models Procedure

Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.02120000	14.13	0.0135
REP*OIL (Error 1)	4	0.00200000		
SP	1	0.00450000	2.79	0.1033
DAY	4	0.00300000	0.47	0.7606
SP*DAY	4	0.01300000	2.02	0.1127
OIL*SP	3	0.00550000	1.14	0.3468
OIL*DAY	12	0.02800000	1.45	0.1899
OIL*SP*DAY	12	0.01200000	0.62	0.8105
Error 2	36	0.05800000		
Corrected Total	79	0.24800000		

continued

Appendix B-3--Continued

Fatty acid=C22:4

General Linear Models Procedure
Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.00100000	0.89	0.5193
REP*OIL (Error 1)	4	0.00150000		
SP	1	0.00312500	8.33	0.0065
DAY	4	0.01700000	11.33	0.0001
SP*DAY	4	0.00750000	5.00	0.0026
OIL*SP	3	0.00437500	3.89	0.0166
OIL*DAY	12	0.00300000	0.67	0.7707
OIL*SP*DAY	12	0.01250000	2.78	0.0088
Error 2	36	0.01350000		
Corrected Total	79	0.06387500		

Fatty acid=C22:5

General Linear Models Procedure
Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.00240000	1.60	0.3225
REP*OIL (Error 1)	4	0.00200000		
SP	1	0.00000000	0.00	1.0000
DAY	4	0.00075000	0.84	0.5068
SP*DAY	4	0.00125000	1.41	0.2516
OIL*SP	3	0.00000000	0.00	1.0000
OIL*DAY	12	0.00225000	0.84	0.6072
OIL*SP*DAY	12	0.00375000	1.41	0.2081
Error 2	36	0.00800000		
Corrected Total	79	0.01950000		

Fatty acid=C22:6

General Linear Models Procedure
Dependent Variable: PERCENT

Source	DF	Sum of Squares	F Value	Pr >F
OIL	3	0.00175000	0.07	0.9748
REP*OIL (Error 1)	4	0.03500000		
SP	1	0.01800000	11.78	0.0015
DAY	4	0.00925000	1.51	0.2188
SP*DAY	4	0.00325000	0.53	0.7131
OIL*SP	3	0.01500000	3.27	0.0321
OIL*DAY	12	0.01875000	1.02	0.4497
OIL*SP*DAY	12	0.01875000	1.02	0.4497
Error 2	36	0.05500000		
Corrected Total	79	0.17550000		

[a]Error 1 included REP and was used as the error for testing the OIL source; Error 2 was used as the error term for testing SP (sampling time) DAY (day of frying), and interactions.

APPENDIX C--

ANALYSES OF VARIANCES FOR THE FLAVOR VOLATILES OF PRAWN CRACKERS

Appendix C--Analyses of variances[a] for flavor volatiles isolated from prawn crackers fried in different oils and stored for 0 week or for 4 weeks in dark or light

Volatile = Pentanal
General Linear Models Procedure

Dependent Variable: C

Source[b]	DF	Sum of Squares	F Value	Pr > F
OIL	3	7.62851935	1.32	0.3842
OIL*REP	4	7.69696655		
TRT	2	291.32299478	53.48	0.0001
OIL*TRT	6	13.03600224	0.80	0.5975
Error	8	21.79065410		
Corrected Total	23	341.47513702		

Volatile = Hexanal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	124.51893225	1.33	0.3816
OIL*REP	4	124.62680210		
TRT	2	5345.94309141	80.60	0.0001
OIL*TRT	6	238.76589195	1.20	0.3943
Error	8	265.30975786		
Corrected Total	23	6099.16447556		

Volatile = Amyl furan
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.16779980	0.76	0.5721
OIL*REP	4	0.29429152		
TRT	2	6.24029253	44.64	0.0001
OIL*TRT	6	0.26521402	0.63	0.7032
Error	8	0.55920740		
Corrected Total	23	7.52680527		

continued

Volatile = Heptanal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.16213962	1.08	0.4529
OIL*REP	4	0.20039782		
TRT	2	7.77135778	78.30	0.0001
OIL*TRT	6	0.27505808	0.92	0.5251
Error	8	0.39699995		

Volatile = 2,3-Hexanedione
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.01623274	0.71	0.5938
OIL*REP	4	0.03039741		
TRT	2	0.40709295	41.88	0.0001
OIL*TRT	6	0.01090703	0.37	0.8763
Error	8	0.03888142		
Corrected Total	23	0.50351155		

Volatile = 2-Methylpyrazine
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.00787415	0.75	0.5782
OIL*REP	4	0.01406618		
TRT	2	0.00258437	0.39	0.6917
OIL*TRT	6	0.07623769	3.80	0.0431
Error	8	0.02677219		
Corrected Total	23	0.12753458		

continued

Volatile = T-2-Hexenal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.02014048	0.27	0.8449
OIL*REP	4	0.09956309		
TRT	2	1.54530715	40.29	0.0001
OIL*TRT	6	0.18076059	1.57	0.2705
Error	8	0.15341716		
Corrected Total	23	1.99918847		

Volatile = Octanal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	3.37015185	14.13	0.0135
OIL*REP	4	0.31795221		
TRT	2	11.59253169	49.16	0.0001
OIL*TRT	6	5.60969285	7.93	0.0050
Error	8	0.94327272		
Corrected Total	23	21.83360132		

Volatile = t-2-Heptenal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.17605478	1.01	0.4747
OIL*REP	4	0.23188681		
TRT	2	27.26613066	130.26	0.0001
OIL*TRT	6	0.11549543	0.18	0.9732
Error	8	0.83729165		
Corrected Total	23	28.62685933		

continued

Volatile = 2-Ethyl-3-methylpyrazine
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.02260884	14.14	0.0135
OIL*REP	4	0.00213126		
TRT	2	0.01151072	12.40	0.0035
OIL*TRT	6	0.02556168	9.18	0.0031
Error	8	0.00371418		
Corrected Total	23	0.06552668		

Volatile = Nonanal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	11.79009271	13.90	0.0139
OIL*REP	4	1.13109444		
TRT	2	24.85152422	81.22	0.0001
OIL*TRT	6	11.70841372	12.76	0.0010
Error	8	1.22385586		
Corrected Total	23	50.70498095		

Volatile = t-2-Octenal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.42037526	0.36	0.7884
OIL*REP	4	1.57197541		
TRT	2	60.51504513	86.82	0.0001
OIL*TRT	6	1.27238166	0.61	0.7192
Error	8	2.78796865		
Corrected Total	23	66.56774611		

continued

Volatile = Decanal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.26293804	5.87	0.0602
OIL*REP	4	0.05977405		
TRT	2	0.93272275	11.25	0.0047
OIL*TRT	6	0.22728570	0.91	0.5303
Error	8	0.33150823		
Corrected Total	23	1.81422877		

Volatile = c,t-2,4-Heptadienal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.04632156	13.07	0.0156
OIL*REP	4	0.00472613		
TRT	2	0.18480645	27.51	0.0003
OIL*TRT	6	0.06105784	3.03	0.0750
Error	8	0.02687055		
Corrected Total	23	0.32378253		

Volatile = t,t-2,4-Heptaadienal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.48800687	39.85	0.0019
OIL*REP	4	0.01633003		
TRT	2	0.82002570	39.81	0.0001
OIL*TRT	6	0.34494303	5.58	0.0148
Error	8	0.08238533		
Corrected Total	23	1.75169095		

continued

Volatile = t-2-Nonenal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.06854608	4.95	0.0782
OIL*REP	4	0.01846593		
TRT	2	0.93004408	16.98	0.0013
OIL*TRT	6	0.29119350	1.77	0.2221
Error	8	0.21903985		
Corrected Total	23	1.52728943		

Volatile = Undecanal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.00841104	0.39	0.7684
OIL*REP	4	0.02887176		
TRT	2	0.18282601	7.22	0.0161
OIL*TRT	6	0.07752127	1.02	0.4747
Error	8	0.10122501		
Corrected Total	23	0.39885509		

Volatile = t-2-Decenal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	27.52058893	127.35	0.0002
OIL*REP	4	0.28813325		
TRT	2	31.89258044	108.74	0.0001
OIL*TRT	6	26.18165883	29.76	0.0001
Error	8	1.17315156		
Corrected Total	23	87.05611301		

continued

Volatile = t,t-2,4-Nonadienal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	0.32799738	2.93	0.1627
OIL*REP	4	0.14909165		
TRT	2	8.15252620	91.56	0.0001
OIL*TRT	6	0.84123282	3.15	0.0685
Error	8	0.35617039		
Corrected Total	23	9.82701843		

Volatile = t-2-Undecenal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	19.72911816	264.95	0.0001
OIL*REP	4	0.09928477		
TRT	2	12.77814628	31.34	0.0002
OIL*TRT	6	7.97605208	6.52	0.0093
Error	8	1.63069598		
Corrected Total	23	42.21329726		

Volatile = c,t-2,4-Decadienal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	52.55113901	10.52	0.0228
OIL*REP	4	6.65917297		
TRT	2	134.72370531	11.89	0.0040
OIL*TRT	6	62.45326216	1.84	0.2087
Error	8	45.31534685		
Corrected Total	23	301.70262630		

continued

Volatile = t,t-2,4-Decadienal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	880.17588643	5.83	0.0607
OIL*REP	4	201.16158993		
TRT	2	1656.36498274	7.60	0.0141
OIL*TRT	6	930.74872486	1.42	0.3135
Error	8	871.52203395		
Corrected Total	23	4539.97321792		

Volatile = Tetradecanal
General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	1.39768908	3.41	0.1332
OIL*REP	4	0.54578341		
TRT	2	0.51157062	3.95	0.0641
OIL*TRT	6	0.75912973	1.95	0.1871
Error	8	0.51808865		
Corrected Total	23	3.73226150		

[a]OIL*REP was used to test the OIL source for significance; error was used to test the TRT and OIL*TRT for significance.

[b]OIL = type of frying oil; REP = replication; TRT = fresh, stored four weeks in the light or stored four weeks in the dark.

APPENDIX D--

ANALYSES OF VARIANCES FOR THE SENSORY SCORES OF FRIED PRAWN CRACKERS

Analyses of variance[a] for sensory evaluation of color, flavor and likability of prawn crackers fried in different oils and stored for zero weeks (fresh) and for four weeks in the dark or under fluorescent lights

Dependent Variable: Color

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	1.02215536	0.38	0.7660
REP	1	7.90022936	8.87	0.0048
PNL	49	192.20663328	4.41	0.0001
OIL*PNL	145	118.23427276	0.92	0.6552
REP*OIL*PNL	117	202.24064838	1.94	0.0084
TRT	2	1.07962312	0.61	0.5501
OIL*TRT	6	3.86968932	0.72	0.6324
TRT*PNL	96	86.51923932	1.01	0.4956
OIL*TRT*PNL	55	60.83028717	1.24	0.2354
Error	41	36.50000000		
Corrected Total	599	873.36000000		

Dependent Variable: Flavor

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	1.16060018	0.28	0.8372
REP	1	4.69724771	3.44	0.0709
PNL	49	256.26056634	3.83	0.0001
OIL*PNL	145	208.97724922	1.06	0.4340
REP*OIL*PNL	117	266.07190357	1.66	0.0319
TRT	2	57.06170344	20.89	0.0001
OIL*TRT	6	4.15975418	0.51	0.7990
TRT*PNL	96	159.68347364	1.22	0.2425
OIL*TRT*PNL	55	73.86493707	0.98	0.5286
Error	41	56.00000000		
Corrected Total	599	1559.99833333		

Dependent Variable: Likability

Source	DF	Sum of Squares	F Value	Pr > F
OIL	3	1.74132486	0.44	0.7237
REP	1	4.26720183	3.25	0.0786
PNL	49	266.63397364	4.15	0.0001
OIL*PNL	145	186.99883524	0.98	0.5447
REP*OIL*PNL	117	263.66562760	1.72	0.0246
TRT	2	45.36532085	17.30	0.0001
OIL*TRT	6	5.04534813	0.64	0.6965
TRT*PNL	96	124.65048638	0.99	0.5286
OIL*TRT*PNL	55	66.74151358	0.93	0.6095
Error	41	53.75000000		
Corrected Total	599	1433.95833333		

[a]OIL=type of oil/blend used to fry prawn crackers; REP=replication; PNL =panelists; TRT=storage of fried prawn crackers for zero week or for four weeks in the dark or under fluorescent light.

VITA

Budiyanto was born in Yogyakarta, Indonesia, on February 2, 1959. He attended public schools in Jakarta, Indonesia. He graduated from Gadjah Mada University, Yogyakarta, in 1985 with a Bachelor of Science degree in Food Science and Technology. In 1985, he moved to Jakarta working with a nonprofit organization to improve the quality of foods sold by street vendors who live in the slum areas. In 1986, he moved to Bengkulu as a new faculty member of Bengkulu University.

In 1987, he received a scholarship to pursue a Master of Science Degree in Education. After completing the Master's degree in 1988, he went back to Bengkulu to teach. He received another scholarship from his government for entering the doctoral program at The University of Tennessee, Knoxville, in the Food Science and Technology Department in 1991. He plans to return to Indonesia and do research and teaching at The University of Bengkulu after completing his doctorate program in August, 1996.