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EFFECT OF DEEP FRYING ON THERMAL BEHAVIOR OF SOME VEGETABLE OILS HAVING DIFFERENT OMEGA-FATTY ACIDS

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ABSTRACT: ***Thermal behavior of some vegetable oils such as olein; sunflower; and flaxseed oils were studied during deep frying of potato chips at 180ºC for 40 h. Results revealed that the three oils showed a different thermal behavior during frying process. Five distinctive stages of the thermal behavior were recorded for the three oils. Convection area represented the stage of water loss and oil uptake. Conduction area represented the frying stage. These two areas varied differently among the three oils during heating oils up to 40 hours. Potato chips that fried in flaxseed oil showed the best quality of sensory evaluation during the 8 hrs of heating time. However, Olien oil gave the best frying oil stability at 40 hrs of deep frying. Flaxseed oil gave the highest value of PV and TBA at 32 and 40 hrs after heating as compared to other oils.***

Key Words: ***Olein, Sunflower, Flaxseed oil; Frying; Thermal behavior.***

INTRODUCTION

Deep frying is a very common and popular practice for preparation and manufacture of foods. It is fast, convenient, and energy efficient cooking procedure that increases palatability and provides crust formation together with pleasant flavors and odors (Gertz, 2000). Deep frying has the most attention relative to other methods of cooking (Lake and Scholes, 1997). In deep frying two stimuli should receive the most considerable efforts. The first stimulus is the safety / nutritive value (i.e. the possible formation of toxic or deleterious materials as a consequence of the exposure oils to heat and oxygen. The second stimulus is the changes in frying medium (oil) that influence the sensory quality of the oil and the food fried in it. Changes that take place in oils and fats during deep- frying involve a complex pattern of thermolytic and oxidative reactions (Blumenthal, 1991). The resulting products are of great interest and importance in food industry as they can and will impact consumer acceptability.

Frying process involves heat and mass transfer as well as interaction between the food and the frying medium. In frying, the fats or oils serve as a heat-transfer medium rather than an important ingredient of the fried food (Al-Kahtani, 1991). Heat transfer occurs from the surrounding oil to the

interior of the food, while mass transfer is characterized by the movement of water in form of vapor from the product into the oil (Saguy and Pinthus, 1995). Frying oil becomes contaminated with components of food materials leaching into the oil, water vapor condensing in the oil, thermal breakdown of oil, and oxygen absorbed at the oil interface. The rate at which oil breaks down is dependent on oil temperature, length of heating time; accumulation of food particles in the oil during frying; and surface area of oil exposed to air (Cuesta *et al*., 1993).

Despite the widespread use of the frying process, research on the thermal aspects of frying has been limited. An understanding of the complex processes that occur during frying is necessary to control the quality of the final fried product. The present study, therefore, was conducted to study the thermal behavior of three different vegetables oils varying in their unsaturation during frying of potato chips in order to learn how to control the frying process.

MATERIALS AND METHODS

Materials

Oils

Olein oil as a source of oleic acid (18:1 ω -9) (10 kg) was obtained from Alexandria Oils and Soap Company (AOSCO), Alexandria, Egypt.

Sunflower oil as a source of linloeic acid (18:2 ω -6) (10 kg) was obtained from Arma Oils Co. 10th of Ramadan, Egypt.

Flaxseed oil as a source of linolenic acid (18:3 ω -3) (10 kg) was obtained from a flaxseed oil Mill, Tanta, Egypt.

Potatoes

Potatoes (*Solanum tuberosum, L.*) (20 kg) were purchased from a local market, Alexandria, Egypt.

Preparation of potato chips

Potatoes were peeled, cut into 2-mm thick slices using a rotary slicer (Edelstahl, Rostfrel, England), washed and dried prior to frying.

Determination of the optimum temperature and time of frying

The optimum temperature and time of frying of potato chips (200 g each) fried, separately, in different oils were determined according to (Barbary *et al*., 1999 and 2000). The optimum temperature and frying time obtained for all oils to produce the best quality of potato chips were 180 ºC and 10 min., respectively (Barbary *et al*., 2000).

Thermal behavior of oils during frying process

Thermal behaviors of oils during deep frying were conducted according to the method performed by Barbary *et al*. (2000). Oil (2.5 kg each) was initially heated in an electrical deep-fat fryer (Moulinex, France) until reached a 180ºC. The time required to reach that temperature was recorded during the

frying process and assigned as initial time. Potato chips were introduced to the heated oil at 180º C and the oil temperatures were recorded using a metal sensor (Hanna instruments, Highland Industrial Park Woonsocket RI 02895) every minute during frying process. This time was considered as a zero time of frying process. The frying process was continued till the potato chips were fried. This frying process was repeated on the heated oils every 8 hours up to 40 hours in order to study the effect of heating time on the thermal behavior of the oil during deep frying of potato chips.

Peroxide value (PV) of oils

Peroxide value (PV) of the oil was determined according to AOCS official methods (1989) (Method Cd8-53) by titration with standard sodium thiosulphate (0.1 N) and was calculated as mill equivalent peroxides per kilogram oil (meqO_2/kg oil).

Thiobarbituric acid number (TBA) of oils

TBA number of the oil was determined according to Allen and Hamilton (1989). The resultant solutions were measured at 538 nm using spectrophotometer (Safas Monaco, 1900). The TBA number was calculated from the following equation:

TBA number = 7.8*D mg malonaldehyde per kg oil

Where: D is the absorbency against blank at 538 nm.

Sensory evaluation of heated oils

Heated oils were sensory evaluated every 8 hours up to 40 hours. Ten members of trained panels ranked the heated oils for their sensory attributes of visual appearance in terms of color and flavor (odor). A nine point hedonic scale was used according to Warner, (1989). Ranking scale of the heated oils was as follows:

1-3 = the most dark color and the most off flavor.

4-7 = Moderate color and moderate flavor.

8-9 = the best color and the best flavor.

Sensory evaluation of fried potato chips

Potato chips fried up to 40 hours were sensory evaluated every 8 hours of frying. Ten members of trained panels ranked the fried potato chips for their sensory attributes of visual appearance in terms of color; texture as crispness and greasiness; flavor as flavor by mouth (taste) and odor (smell); and overall acceptability. A 5 point hedonic scale was used according to Warner (1989) as follows:

1 = Light yellow; not crispy (soft); most greasy; bitter taste; rancid; soapy flavor; and unaccepted potato chips.

2 = Pale yellow; weak crispy; more greasy; no taste; no flavor; and just accepted potato chips.

3 = Bright yellow; slight crispy; moderate greasy; moderate taste; moderate flavor; and accepted potato chips.
4 = Brownish yellow; moderate crispy ; slight greasy; good taste ; good flavor; and good overall acceptability.
5 = Golden color; crispy; not greasy; best taste; best flavor; and best overall acceptability.

RESULTS AND DISCUSSION

Thermal behavior of oils during frying process

Thermal behaviors (temperature changes) of three fresh oils such as olein (high in 18:1, ω-9), sunflower (high in 18:2, ω-6), and flaxseed (high in 18:3, ω-3) during frying at 180ºC were investigated. Data revealed that the thermal behavior of the oil could be classified into five stages (Figure 1). Stage 1, represented the initial time required the oil to reach 180ºC and kept it constant at this temperature. This initial time varied among the three oils used. It was 10, 9, and 8 minutes for olein, sunflower, and flaxseed oils, respectively. Stage 2, represented a starting frying time (a zero time) when the potato chips were introduced to the oil. After only one minute of frying time, the temperature suddenly decreased from 180ºC to 140º, 140º, and 142ºC for olein, sunflower, and flaxseed oils, respectively (Stage 3). The temperature gradually decreased depending upon the type of oil and reached the minimal temperature (stage 4) at 125.130 and 130 º C for the same oils, respectively. This decrease could be attributed to water evaporation from potato chips (Blumenthal and Stier, 1991). The area under curve between stage 3 and stage 4 was assigned to the convection stage as the potatoes lost completely their moisture contents and started oil uptake (area A). This area varied considerably among oils during frying. Afterwards, the temperature started gradually to increase again to the maximum until the end of frying operation (frying temperature) (Stage 5). The area under curve between stage 4 and stage 5 was assigned to the conduction area as the potatoes fried completely (area B). At stage 5, the end of frying operation, potato chips exhibited the optimum sensory quality. This conduction area is the area, which signifies the quality of fried food, since several physicochemical changes, such as starch gelatinization and cooking take place in the internal core region (Singh, 1995). The greater the conduction area percentage, the greater the oil potential for frying and the better the fried potato chips were. This area also varied considerably among the studied oils.

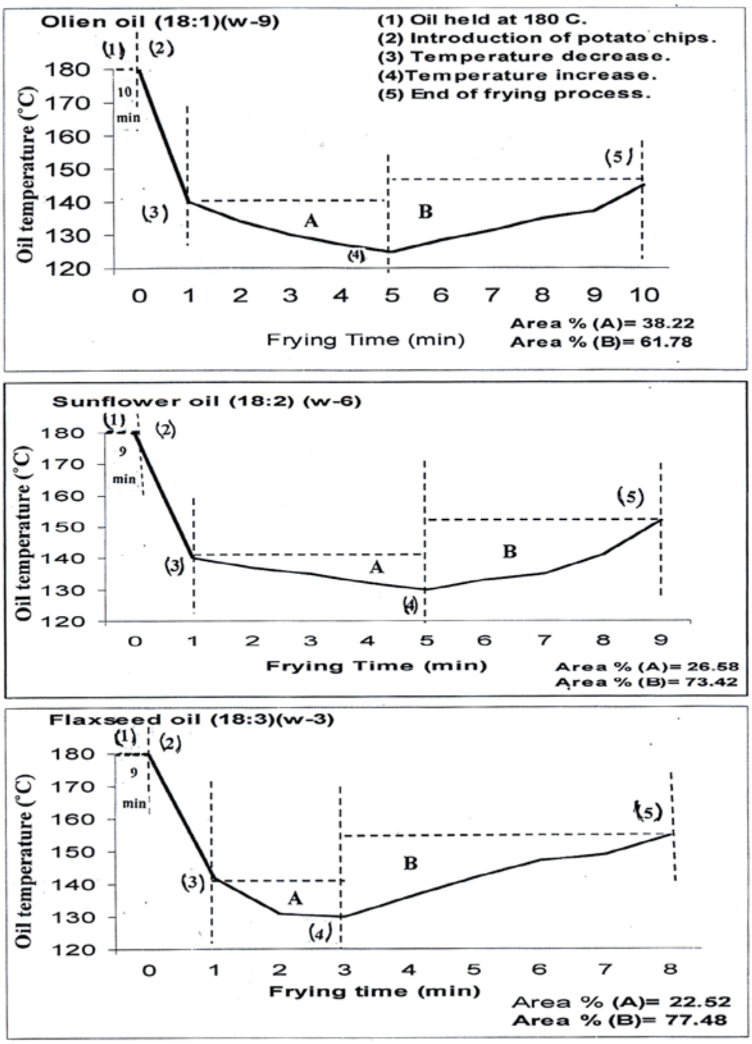

Figure (1): Thermal behavior of different oils having different omega-types during frying potato chips at 180 °C at 0 time (Fresh).
A= Convection stage (Moisture loss and oil uptake).
B= Conduction stage (Frying stage).

Frying process involves heat and mass transfer as well as interaction between the food and the frying medium. Only few studies offered some partial explanation of the mechanism(s) of oil uptake during frying (Saguy and Pinthus, 1995). During immersion frying of foods, there are two distinct

modes of heat transfer, conduction and convection. Convection heat transfer occurs between a solid food and the surrounding oil. The surface interactions between the oil and the food materials are complicated because of the vigorous movement of water vapor bubbles escaping from the food into the oil. Conduction heat transfer occurs within a solid food (Saguy and Pinthus, 1995). The rate of heat transfer is influenced by the thermal conductivity, specific heat, and density (Singh, 1995). The magnitude of these properties changes occurred during the frying process (Buhri and Singh, 1994). The mode of heat transfer between the oil and potato chips in the first minute of frying was neglected because no vaporization of water occurs from the surface of the food and no oil picked up by the food.

Data revealed that the initial time required to reach 180ºC and the frying time increased with increasing the heating time depending upon the oil (Table 1).

Table(1): Effect of heating time (hrs) on the initial heating time (min) and frying time (min) of different oils having different omega-types.

	Olien Oil (18:1)(ω-9)		Sunflower Oil (18:2)(ω-6)		Flaxseed Oil (18:3)(ω-3)	
Heating Time (hrs)	Initial heating time (min)	Frying time (min)	Initial heating time (min)	Frying time (min)	Initial heating time (min)	Frying time (min)
0	10	10	9	9	8	8
8	11	10	11	10	10	12
16	12	12	12	12	11	16
24	13	13	13	16	12	20
32	14	14	14	20		
40	16	16				

The effect of heating time (hrs) on the convection areas (%) of the three different oils was shown in Figure (2). Data generally revealed that the convection areas gradually increased as the heating time of the oils increased up to 40 hours. Nevertheless, the convection areas of olein oil (high in ω -9) showed the highest percents and the convection areas of flaxseed oil (high in ω -3) showed the lowest as compared to other convection areas for other oils. The initial convection areas percent for olein, sunflower, and flaxseed oils was 38.22, 26.58, and 22.52% (at zero time), respectively. These areas percentages increased to 74.20 % (after 40 hrs), 73.05 (after 32 hrs), and 53.47% % (after 24 hrs) of heating, respectively.

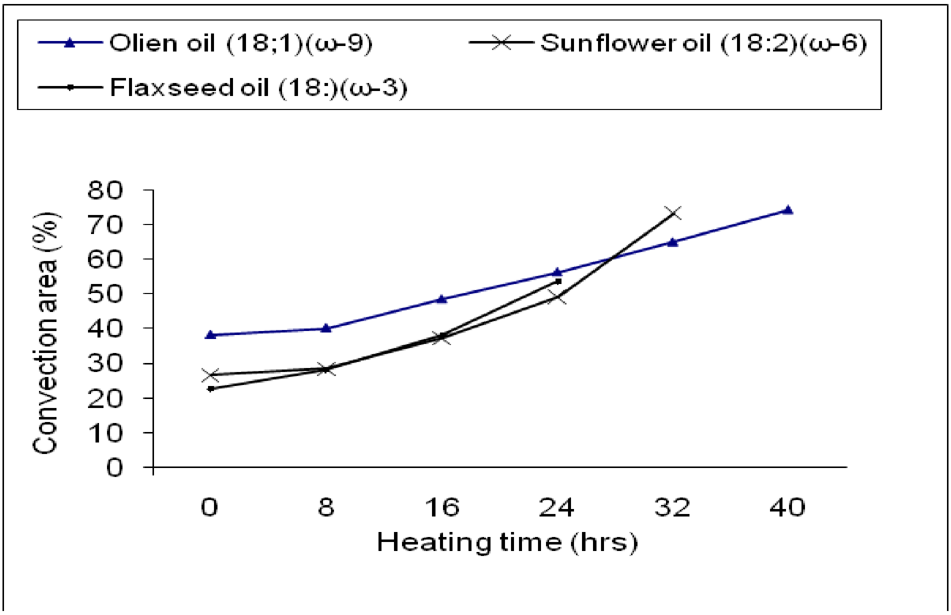

Figure (2): Effect of heating time (hrs) on the convection area (%) of different oils having different omega-types.

The effect of heating time (hrs) on the conduction areas (%) of the three different oils was shown in Figure (3). On contrary to the convection areas, data generally revealed that the conduction areas gradually decreased as the heating time of the oils increased up to 40 hours. However, the flaxseed oil showed the highest conduction area percent, followed by sunflower, and finally by the olein oil. The conduction area of flaxseed oil was 77.48% at the zero heating time, followed by sunflower (73.42%), and olein oil (61.78%). These results indicated that flaxseed oil was the best frying oil which the greater of the conduction area percentage, the greater the oil potential for frying and the better the fried potato chips were. As the time of heating increased, the conduction areas decreased to 46.53% for flaxseed oil (after 24 hrs), 26.95% for sunflower (after 32 hrs), and 25.80% for olein oil (after 40 hrs). These results showed that the olein oil could be used as frying oil for long time, while sunflower oil could be used up to 32 hrs and flaxseed oil (despite showed the best sensory attributes of potato chips) it could not be used as frying oil for a long time (up to 24 hrs) as it exhibited formation of soap and soap–like materials that caused excessive foaming in oil forming a soapy layer on the surface of potato chips (at 24 hrs) preventing the oil to reach potato surface hence increasing the frying time (Gil and Handel, 1995).

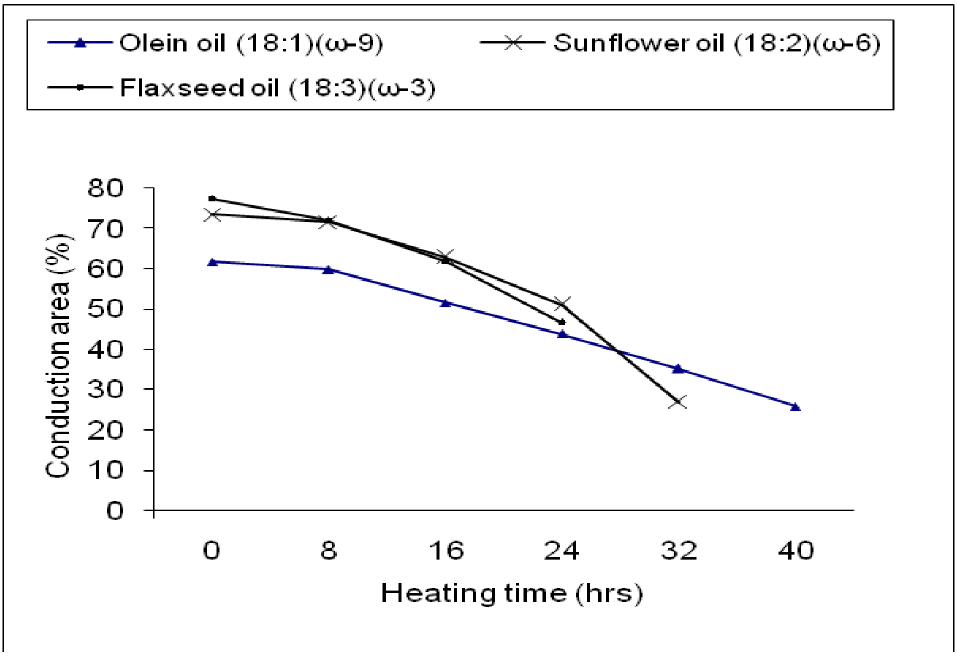

Figure (3): Effect of heating time (hrs) on the conduction area (%) of different oils having different omega-types.

The increases observed in both the initial time required to reach 180 ºC and the frying time as the heating continued up to 40 hours could be attributed to many factors: (1) As the high heat capacity of oils is diminished by the prolonged heating, the oil would loss its functional properties as a heat transfer medium (Blumenthal, 1991) and as a result, the time required to achieve the best frying will increase, (2) formation of soap and soap–like materials will cause excessive foaming in oil forming a soapy layer on the surface of potato chips preventing the oil to reach potato surface hence increasing the frying time (Gil and Handel, 1995), (3) as saturation increases during frying, viscosity, melting points of oils will increase causing oil to need longer time reaching the required temperature (Hernandez, 1989; Tyagi and Vasishtha, 1996 and (4) frying process causes the formation of fatty acids (i.e. $C_{18:1}$ *cis* melts at 14ºC while $C_{18:1}$ *trans* melts at 51 ºC (Nawar, 1996). These *trans* fatty acids will increase viscosity and melting points.

Peroxide Value (PV)

Figure (4) shows the PV (meqO_2/kg oil) for the three oils during frying process at 180 ºC for 40 hours. Generally, the PV increased with increasing the heating time up to 40 hours. Results revealed that the PV increased from 0.4, 0.9, and 3.2 (meq/kg oil) for olein, sunflower, and flaxseed oils to 0.4, 1.6,

and 8.0 (meq/kg oil), respectively after 8 hrs of heating with increasing ramp rates per heating hour (increment %) of 0, 9.7, and 18.8%, respectively. Results also revealed that the longer the heating time, the higher the PV observed. The PV continued to increase as the heating time increased up to 40 hrs. The PV reached 9.8 for olein oil after 40 hrs of heating, 16.4 for sunflower oil (after 32 hrs), and 20.0 meqO_2/kg oil for flaxseed oil (after 24hrs). The increment percentage in PV also increased as the heating time increased. The lower ramp rate observed for olein oil during heating after 40 hours(as compared to other two oils) could explained on the basis of presence of oleic acid (the main constituent of olein oil) (Fedeli, 1988). The higher ramp rate, however, observed for sunflower and flaxseed oils could be attributed to their high content of $C_{18:2}$ in sunflower oil and the high content of $C_{18:3}$ in flaxseed oil. These acids provided more active methylene groups, which were more prone to oxidative deterioration (Tyagi and Vasishtha, 1996).

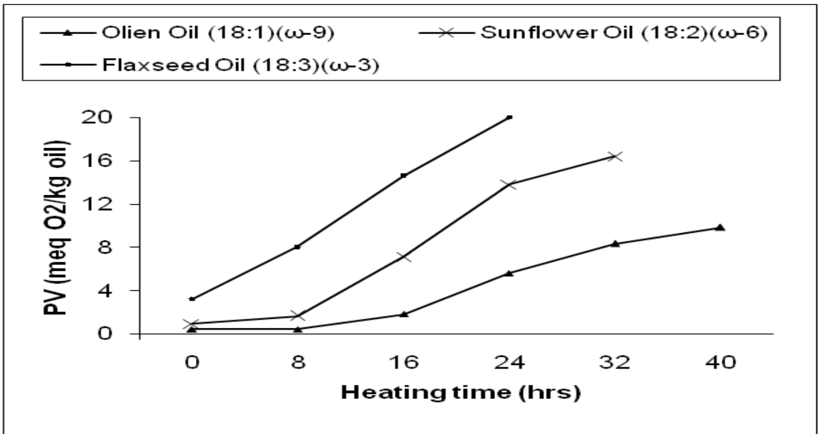

Figure (4): Effect of heating time (hrs) on the peroxide value (meqO_2/kg oil) of different oils having different omega-types.

Thiobarbituric acid (TBA)

Figure (5) shows the effect of heating time on the TBA values (mg malonaldehyde/kg oil) of the three oils. Results revealed that TBA values increased from 1.4, 2.6, and 4.6 (mg malonaldehyde/kg oil) for olein, sunflower, and flaxseed oils, respectively at zero heating time to 6.6, 10.0, and 17.6 (mg malonaldehyde/kg oil) after heating for 40, 32, and 24 hrs for the same oils, respectively. As the TBA value is a measure of oxidation, these results were expected. Flaxseed oil that had the highest oxidation rate among the three studied oils also had the highest TBA values.

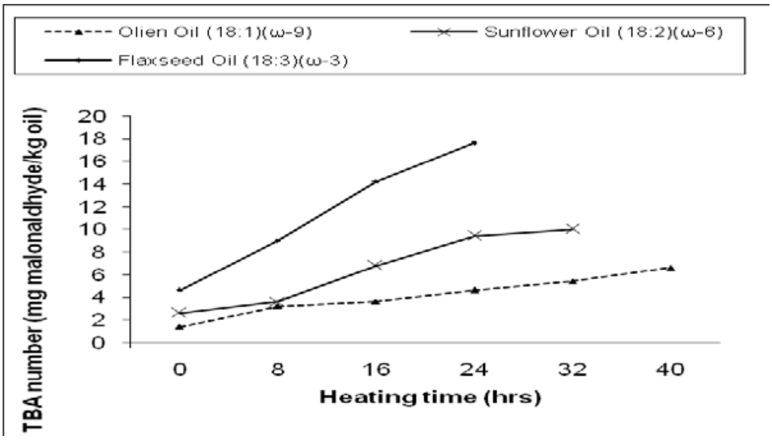

Figure (5): Effect of heating time (hrs) on the TBA number (mg malonaldhyde/kg oil) of different oils having different omega-types.

Sensory evaluation of heated oils

Sensory evaluation of frying oil and/or fried food is still the ultimate test recognized by most countries that defines when frying oil should be discarded (Melton *et al*., 1994).

The three heated oils were sensory evaluated in terms of color and odor every 8 hours up to 40 hours of heating. Sensory data in terms of color (Figure 6 a) revealed that the color of the three oils was markedly affected by increasing the time of heating. Flaxseed oil developed the darkest color after 24 hrs as compared to other two oils. As the heating time continued to 24 hrs for flaxseed and 32 hrs for sunflower the oils gradually started to foam. These foams started to appear progressively after 24 and 32 hours of flaxseed and sunflower oil, respectively. Olein, which contains high amount of oleic acid ($C_{18:1}$), slightly foamed after 40 hours. Earlier foaming in flaxseed oil could be attributed to its fatty acid composition, which contains high amount of linolenic acid (C18:3$_{)}$.Sunflower oil contains high amount of lionleic acid (C18:2$_{)}$ as deterioration rate for oleic: linoleic: linolenic is 1: 10: 20-30 (Warner, 1995).

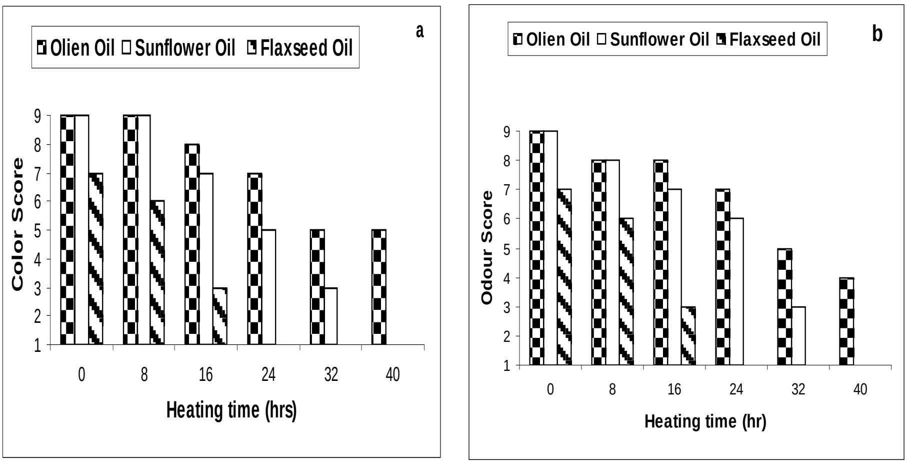

Figure (6): Effect of heating time (hrs) on sensory attributes of different oils having different omega-types heated at 180 ºC up to 40 hrs.

Sensory attributes of odor of different oils are shown in Figure (6 b). Data revealed that oils differently retained their odor up final heating time, except flaxseed oil, which developed strong off-flavor intensity after 24 hours. The heated oils affected flavor of fried potato chips directly through absorption into the pores of the potato chips and absorption as a film on surface. Various chemical reactions and their products also modify the flavor of potato chips (Pokorny, 1989). So, potato chips quality was used as an indicator for the quality of oil during frying process.

Sensory evaluation of potato chips

Fried potato chips were sensory evaluated every 8 hours of frying. Effect of heating time on the visual appearance of potato chips in term of color is shown in Figure (7 a). Results revealed that potato chips fried in all oils showed golden color, however, potato chips fried in flaxseed oil showed the best color, at the beginning of heating time up to 8 hrs then gradually deteriorated as the heating time continued for the final heating time. Color of potato chips fried in olein oil, nevertheless, was the most stable up to 32 hrs then gradually changed to bright yellow at 40 hours of heating. Color of potato chips fried in sunflower oil steadily decreased as the heating time increased.

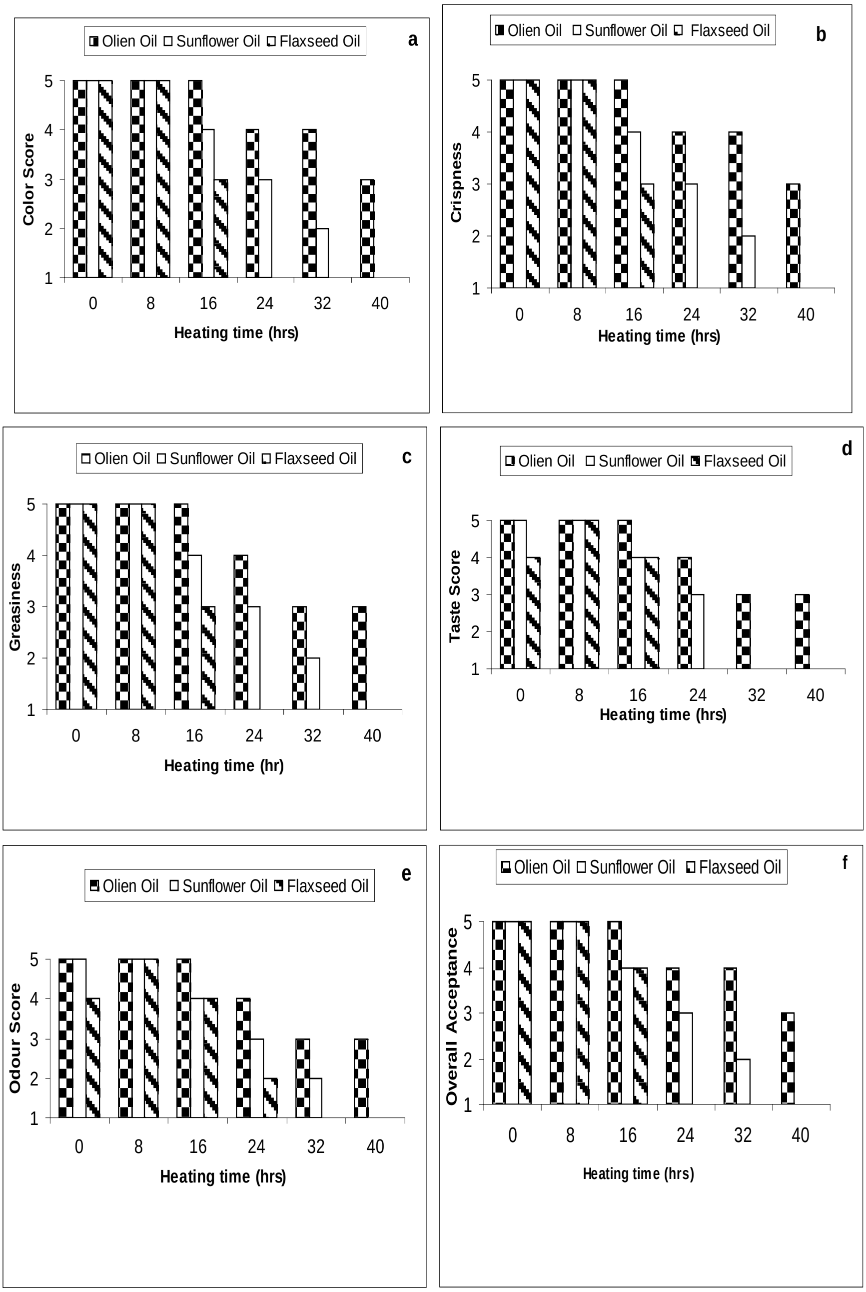

Figure (7): Effect of heating time (hrs) on sensory attributes of potato chips fried in different oils having different omega-types at 180 ºC up to 40 hrs.

Sensory attributes of chips texture in terms of crispness is shown in Figure (7 b). Data revealed that potato chips fried in olein oil showed the most crispness up to 16 hours of heating then became slightly crispy at 40 hours of heating as compared to those fried in sunflower and flaxseed oil. Potato chips fried in sunflower and flaxseed oil showed stable crispness up to 8 hours then started to decrease.

Sensory attributes of greasiness (Figure 7 c) revealed that potato chips showed no greasy texture up to 8 hours of heating. As the time of heating continued, potato chips showed different greasiness according to the type of oil used in frying. Potato chips fried in olien oil, however, showed the least greasiness up to 40 hours of heating.

Sensory results of flavor by mouth (taste) (Figure 7 d) revealed that potato chips fried in flaxseed oil at zero time had the taste of flaxseed oil but after 8 hours of heating this taste was eliminated and showed the best taste as compared to others. However, as the heating time continued up to 24 hrs, the taste of potato chips started to decrease. On the other hand, potato chips fried in olein oil had the best taste up to 16 hours of heating and slightly affected by the time of heating for 40 hours. Potato chips fried in sunflower oil had the best taste up to 8 hours and had the lower taste after 32 hours of heating.

Sensory evaluation of flavor in term of odor and smell (Figure 7 e) showed similar results to those obtained for taste.

The overall acceptability of potato chips is shown in (Figure 7 f). Data showed similar results to those obtained for taste and odor.

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تأثير التحمير على السلوك الحراري لبعض الزيوت النباتية ذات أحماض اوميجا مختلفة

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الملخص العربي

تم دراسة السلوك الحراري لبعض الزيوت النباتية ذات أنواع أوميجا مختلفة (زيت أولين الغني بأوميجا –٩ ، زيت عباد الشمس الغني بأوميجا– ٦ ،و زيت بذور الكتان الغني بأوميجا–٣) أثناء تحمير بطاطس الشبسى عند درجه حرارة ١٨٠ °م . أوضحت النتائج أن هذه الزيوت النباتية الثلاثة لها سلوك حراري مختلف أثناء عملية التحمير، وتم تسجيل مساحتان لمنحنى السلوك الحراري الأولى وهي مساحة التسخين بالحمل الحراري CONVECTION وتمثل مرحله فقد الماء من البطاطس وامتصاص الزيت والثانية هي مساحة التسخين بالتوصيل الحراري CONDUCTION وهي تمثل مرحلة التحمير المسئولة عن جودة البطاطس المحمرة أثناء التحمير. وقد وجد أيضا أن البطاطس الشبس الناتجة من التحمير في زيت بذور الكتان كانت الأفضل في خواصها الحسية خلال الساعات الأولي من التحمير (٨ ساعات) واستمر الزيت في التحمير حتى ٢٤ ساعة، بينما كان زيت الأولين الأطول في عملية التحمير حتى ٤٠ ساعة وتشير النتائج أن رقم البيروكسيد و قيمة الثيوباربيوتريك كانت مرتفعة في زيت بذور الكتان عند التحمير لمده ٣٢ و ٤٠ ساعة بالمقارنة بالزيوت الأخرى.