

## Influence of steam singlet method on oil quality during deep fat frying on a modified fryer

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### Abstract

Nowadays, consumer trends towards healthier and low fat products have a significant impact on the deep fat frying industry. The objective of this study was to design a modified deep fat fryer (MDF) to have a smaller surface area relative to height, with made a steam blanketing over the fryer. Different levels of water injection flow rates have been used (0.1, 0.2 and 0.3 ml/20 min. per 1 liter of tested oil), compared with conventional fryers (CDF). Frying was conducted at  $170 \pm 10$  °C into sunflower oil using CDF ( $H\sqrt{A} = 0.24$ ) and MDF ( $H\sqrt{A} = 0.8$ ) in batch 8 min. 16 batches every day (eight hrs. /day) for up to 40 hrs (Consecutive five days). The modification was intended to related oil deterioration. Water injection had a dual effect. In comparison with CDF, water injection increased the acidity (expressed as oleic acid) from 0.34 % to 0.97 %, after 40 hrs at  $170 \pm 10$  °C of deep fat frying, and a contrarily, the protective role was observed in all the other quality indices. Significant reductions in TBA values (from 8.9 to 4.81 mg malonaldehyde/liter of tested oil), *P*-anisidine values (from 35.6 to 12.9), TPC contents (from 34.5% to 18.64%), conjugated diene (232 nm) (from 8 to 5.59) and conjugated triene (268 nm) (from 1.9 to 1.33) were recorded in sunflower oil compared with CDF. These quality indices of sunflower oil developed dramatically in the first level of water injection flow rate. Consequently, the first level of water injection had the highest ( $P \geq 0.05$ ) inhibitory effect compared with the other levels of water injection. Fatty acid composition of fried oil properties during deep frying CDF and MDF designs were determined. There were significant differences ( $P \geq 0.05$ ) of fatty acids composition between the fried oil induces during using of CDF and MDF designs. Total unsaturated fatty acid at MDF design gave the highest values. Also, organoleptic evaluation of fried potato chips by CDF and MDF were evaluated by panelists. Fried potato chips during the first level of water injection flow rate had the highest ( $P \geq 0.05$ ) flavor (4), crisp (4.5), greasiness (4.6), and overall acceptability (4.8), compared with fried potato chips during other levels of water injection flow rates and with CDF. Findings suggest that determination of the oil quality indices are good makers of sensory evaluation during deep fat frying. Results indicated the changes in moisture content, oil uptake and shrinkage percentages of potato chips at different levels of water injection compared the control samples. The negative correlation coefficient between oil uptake and moisture content was high ( $r = -0.915$ ) and linear regression equation for prediction the oil uptake  $y = 34.1064 - 2.0291X$ . Also, results suggest that during deep fat frying by MDF design may reduce the thermal deterioration of sunflower oil. Water injection can be applied as a simple method to improve oil quality during deep fat frying.

**Keywords:** modified fryer, acid value, *P*-anisidine, thiobarbituric acid, polar compounds, ultra violet absorbance, moisture content, oil uptake, shrinkage, sensory evaluation, water injection.

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## 1. Introduction

Deep fat frying process is a fast and convenient technique widely used either in home or in restaurants. The popularity of frying is related to the unique sensory properties of fried food. The quality of oils and fats during the frying process has a major influence on quality of final product (Andrikopoulos *et al.*, 2003; Suxuan and William, 2012). Deep fat frying involves simultaneous heat and mass transfers in food processing operation by immersing the food as a whole into the hot oil around or more than 180 C temperature (Nayak *et al.*, 2015). The process induces a variety of physicochemical changes in both the food and the frying medium (Ogunmoyela *et al.*, 2016). In this process, a reverse transfer of water vapor from food to the oil and finally to the atmosphere occurs (Nayak *et al.*, 2015). During the process, various chemical reactions such as hydrolysis, oxidation, isomerization and polymerization which resulted in the generation of free fatty acids, low molecular alcohol, aldehyde, ketone, acid, lacton and hydrocarbon, mono, diglycerides, cyclic and epoxy compounds, transacylglycerol monomer, dimer and oligomer. These reactions produce soluble, insoluble, volatile and nonvolatile matters (Nayak *et al.*, 2015; Zhang *et al.*, 2012). Unfortunately, the aforementioned beneficial effects of frying are accompanied by undesirable alteration of the frying medium. Thermal treatment of the frying oils results in oxidative and hydrolytic reactions; chemical and physical changes take place

leading to the formation of undesirable secondary products (Sammak, 2013; Seppanen and Csallany, 2002). During intermittent deep fat frying, hydrolysis, oxidation and polymerization reaction cause a spectrum of physical and chemical changes, leading to the formation of decomposition products posing a direct impact damaging both the oil quality and the frying food nutritional value (Dana *et al.*, 2003; Ogunmoyela *et al.*, 2016). Several studies indicated that products generated through oil oxidation can mutagenic and carcinogenic (Saguy and Dana, 2003). Due to public health concerns, there is a strong demand to reduce the oil deterioration during fat frying. Thermally abused fats and oils are usually discarded because accumulation of oxidation products from fats and oils will not only reduce the sensory quality of fried foods but may also diminish their nutrition value (Martin and Ames, 2001; Saker, 2014; Sammak, 2013). Generally, 30 % of used oils with batch process was discarded per week in a commercial frying operation. It is very important to minimize the waste oils generated during deep fat frying the point of the cost for disposal of the waste oil and effective utilization of oils. (Rimac–Brncic *et al.*, 2004). Fujisaki *et al.* (2002) designed a deep fat fryer with low oxygen atmosphere (2% O<sub>2</sub>) using N<sub>2</sub> and then fried frozen chicken with vegetable oil. They reported that the increase in acid value, carbonyl values and the production of polymerized materials, and the decrease in tocopherols were related during frying. However, an N<sub>2</sub> bomb is necessary for this system. Susinggih *et al.* (2000) designed a deep fat fryer under

different vacuum levels the fried pineapple with vegetable oil. They found that the best frying temperature and vacuum pressure which were needed to produce pineapple crispy chips using simple vacuum fryer were 90°C and 700 mm Hg. The vacuum deep fat fryer was developed to reduce the thermal oxidation of fat and oils (Ahmad *et al.*, 2013; Basuny *et al.*, 2012; Diamante *et al.*, 2015; Dueik *et al.*, 2010; Fan *et al.*, 2005; Garayo and Moreira, 2002; Negishi *et al.*, 2003). The generation of volatile compounds in soybean oil was inhibited by water injection, after heating to 200 °C and storage for 26 weeks at 55 °C (Dana *et al.*, 2003). Investigation reveals that several prototype deep fat fryers have been developed. These include: Open fryers which may either be single heat source or double heat sources, as well as pressure fryers designed to keep vapor inside the fryer while cooling (Ogunmoyela *et al.*, 2016). The oil surfaces are designed to be large to enhance the production capacity in conventional fryers. However, the large oil surface increases the likelihood of thermal oxidation. When we measured the surface area (A) and height (H) of the oil bath of the conventional fryers, the  $H/\sqrt{A}$  ratio was below 0.6 (Diamante *et al.*, 2015; Negishi *et al.*, 2003). Hence, we need to improve oil stability and prevent deterioration with new design that minimize the effect of oxygen, are required. We designed a modified deep fat fryer MDF to have a smaller surface area relative to height, which the  $H/\sqrt{A}$  of the oil bath was 0.8, then made steam blanketing over the oil under three different levels of water injection flow

rates, compared with conventional fryers (CDF). We deep-fried potato chips using the MDF and CDF, and then determined chemical characteristics and sensory evaluation during deep fat frying.

## 2. Materials and methods

### 2.1 Materials

#### 2.1.1 Sunflower oil

The refined sunflower oil was obtained from Sohag oil and Soap Company, Sohag, Egypt.

#### 2.1.2 Potato tubers

Potato tubers (*Solanum tuberosum*), were purchased from the local market of Assuit. They were cleaned, sorted, manually peeled using a sharp knife and then sliced to a thickness of 1.2-1.3 mm with a mechanical slicer, the slices were washed with tap water, immersed in 2% salt solution for 5 min. and then washed again with tap water and let for 10 min. to drain of excess water before they fried as reported by Abd-ElGhany (2006).

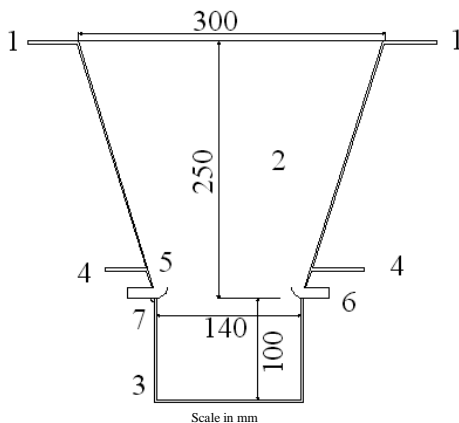
#### 2.1.3 Reagents

All chemical and reagents used in the analytical methods (analytical grade) were produced by Sigma chemical Co. (St. Louis, Mo, U.S.A) and obtained from El-Gamhouria Trading Chemicals and Drugs Co., Egypt.

#### 2.1.4 Modified fryer (MDF)

It was consisted of bath and steam blanket

as shown in Fig. (1), the bath was fabricated from stainless steel. It was 140 mm diameter, 100 mm height and 2 mm thickness. A steam blanket was also fabricated from stainless steel and hinged with bath. It was like a cone and trapezoid cross section. The down base was 140 mm; upper base was 300 mm and 250 mm height. The steam blanket had dual walls to through water tap from up to down as condensation operation of water vapor inhalation contained volatile compounds, which was collected by trap out MDF. The  $H/\sqrt{A}$  of the oil bath was 0.8. The steam blanket partially removed in two cases; a- Put oil, water injection and potato chips, b- Take out the potato chips after frying. Water was injected by a nozzle to reduce the size of water droplets.



1- Water tap in, 2- Steam blanket, 3-Bath, 4- Water tap out, 5- Trap, 6- Water vapor inhalation contained volatile compounds out, 7- Hinge.

Figure (1): Modified deep fat fryer (MDF).

### 2.1.5 Conventional fryer (CDF)

The bath was fabricated from stainless steel. It was 280 mm diameter, 60 mm height and 2 mm thickness. The  $H/\sqrt{A}$  of

the oil bath was 0.241.

## 2.2 Methods

### 2.2.1 Frying process

One and half kgs, (For each treatment) of sunflower oil were used in the modified deep fryer MDF, under different level of water injection flow rates (0, 0.1, 0.2 and 0.3 ml/20 min. per 1 liter) and three kgs. in conventional deep fryer CDF, at  $170 \pm 10^\circ\text{C}$  for 8 min. with a constant product weight/oil volume ratio of 1:6, for up to 40 hours (Garayo and Moreira, 2002). Potato chips were used for frying in batches every eight hours (8 min. /batch), after each frying the oil level was checked and replenished. At four an hours intervals during frying, about twenty milliliters of heated oil was withdrawn and kept in brown bottles in freezer at  $-18^\circ\text{C}$  until used. All fried samples were allowed to cool to room temperature and sensory evaluated. All experiments were run in triplicate and the present results are the average of the obtained results.

### 2.2.2 Analytical methods

Acidity (expressed as oleic acid) was determined by the method of IUPAC (1987). *P*-anisidine value was determined by using the method of AOCS (1992). Thiobarbituric acid (TBA) value was determined by using the method of Keeney, (1971). The polar compounds content (TPC) was determined using chromatographic glass column method as described by Takeoka, *et al.*, (1997). The ultra violet absorbance at 233 nm conjugated diene (CDs) and 268 nm

conjugated triene (CTs) of oil samples were measured using (UV-visible spectrophotometer) as described by Danopoulos and Ninni (1972).

### 2.2.3 Potato chips properties

#### 2.2.3.1 Moisture content

Moisture content of potato chip was measured by drying the samples in vacuum oven at 60°C until reaching constant weight (AOAC, 2005).

#### 2.2.3.2 The oil content

The oil content was extracted by chloroform and methanol based on the method proposed by (Pedreschi and Moyano, 2005).

#### 2.2.3.3 Shrinkage

Degree of shrinkage in volume (Sv) was evaluated by:

$$S_v = \frac{V_0 - V_t}{V_0} \times 100$$

Where,  $V_0$  is the original volume of the sample ( $m^3$ ), and  $V_t$  is the volume ( $m^3$ ) of the sample at time  $t$ .

The volume of the sample (elliptical shaped) at any given time can be calculated by:

$$V = (\pi Dd/4) L$$

Where,  $D$  is the larger diameter of the sample (m),  $d$  is the smaller diameter [m] of sample, and  $L$  is the sample's thickness (m).

Ten samples were taken to determine shrinkage for each frying condition at the equilibrium time (Pedreschi and Moyano, 2005).

### 2.2.4 Organoleptic evaluation

A tested panel of 10 numbers from the food Science and Technology Department, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt were asked to evaluate the effect of either conventional or modified deep fat frying on the fried potato for flavor, crisp, greasiness and overall acceptability using a scale from 1-5 points for each character (5) very good, (4) good, (3) fair, (2) poor and (1) very poor. This method was conducted according to the method of El-Naggar (2007).

### 2.2.5 Data analysis

Experimental data were analyzed by analysis of variance (ANOVA). The results were subjected to standard deviation and significance was tested by students ( $t$ ) test. Differences between samples at the 5% ( $P \geq 0.05$ ) level were considered significant (Statistical Graphics Crop., 1998).

## 3. Results and Discussion

### 3.1 Effect of injecting water during deep fat frying on physical and chemical properties

During deep fat frying, a variety of reactions cause a spectrum of physical and chemical changes occur due to

hydrolysis, oxidation and thermal decomposition. Fats and oils are oxidized to form hydroperoxides, the primary oxidation products and secondary oxidation products. These peroxides are extremely unstable and decompose via fission, to form a variety of chemical products such as alcohols, aldehydes, ketones, dimers, trimers, polymer and cyclic compounds (Basuny *et al.*, 2012). Hence, we need to improve oil stability and prevent deterioration with new design that minimize the effect of oxygen, are required. We designed a modified deep fryer MDF (steam blanketing) in which the H $\sqrt{A}$  of the oil bath was 0.8 to minimize the generation of waste oil by reducing thermal oxidation deterioration of oils. The structure of MDF (higher H $\sqrt{A}$ ) contributed to the smaller oil surface. Therefore, the new design reduces oxidation and thermal decomposition. The index of acidity is used as a chemical marker for monitoring the quality of frying operations and is often used for the assessment of frying oils suitability for human consumption. According to Miguel *et al.* (2014), the value of 2% is defined as the limit for oil rejection. Figure (2) shows the evaluation of acid value of fried oil properties during CDF and MDF. The differences in CDF and MDF at various water injection (0, 0.1, 0.2 and 0.3 ml/20 min. per 1 liter) were studied. Water injection had a dual effect on oil quality. In comparison with CDF, acid value of 0.25 % for sunflower oil but increasing the water injection from

0.1 to 0.3 ml/20 min. per 1 liter after 40 hrs at 170°C accelerated, as expected, the hydrolytic reactions giving rise to the formation of free fatty acids and increased acid values (0.97 % for first water injection level), (1.04 % for second level), (1.08 % for the third level) and (0.3% for without water injection treatment) against 0.34% for CDF. Consequently, spraying of the frying oil with water remarkably increased the acid values throughout the whole experiment period. The relatively higher values for acid value than control samples could be attributed to rate of hydrolysis reactions. A water spray injection level of 0.3 ml /20 min. per 1 liter over sunflower oil led to an acid value of 1.08 % after 40 hrs at 170°C, while in oil kept under the same conditions and without water spray, the values was 0.3 %. The increase in acid values was due to a large water injection level. The results obtained were nearly similar with those obtained by Basuny *et al.* (2012), they reported that water and steam involve the breakage of triglycerides and produce mono-glycerides, triglyceride, free fatty acids and glycerol. The role of water spray and oil quality during frying were evaluated. The water released during frying enhances heat transfer, may cause oil deterioration, and on the other hand also can prevent oxidation (Dana *et al.*, 2003; Saguy and Dana, 2003). It is worthy to mention that a linear with a significantly correlation between frying time and acid value. The correlation coefficient of the third level of water injection was the

lowest ( $r = 0.684$ ) followed by the first and second levels of water injection ( $r = 0.758$ ), while in oil kept under the same conditions and no water spray injection ( $r = 0.958$ ) against ( $r = 0.995$ ) for CDF design.

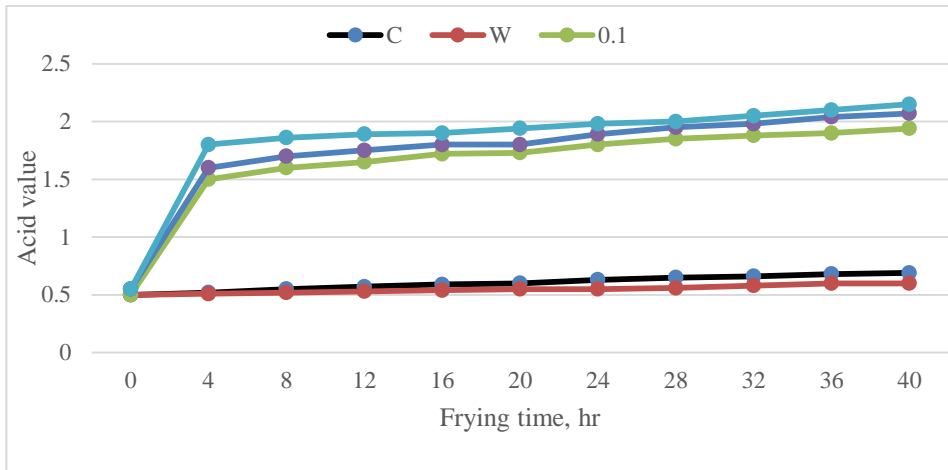


Figure (2): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on acid value.

An opposite trend was observed in most parameters of deterioration. It could be observed that, the changes in *P*-anisidine values in sunflower oil during prolonged frying with CDF and MDF as shown in Figure (3). In comparison with the control, *P*-anisidine value of 5.3alkenal /kg of oil, increasing the water injection level from 0.1 to 0.3 ml/20 min. per 1 liter decreased *P*-anisidine values. The *P*-anisidine values were markedly lower due to water injection in sunflower oil. The *P*-anisidine values decreased from 23.45 to 12.9alkenal /kg of oil when the water injection level was 0.1 ml/20 min. per 1 liter. The *P*-anisidine values for CDF oil was much higher 35.6alkenal /kg of oil for sunflower oil. Nevertheless, had significantly ( $P \geq 0.05$ ) changes were observed in *P*-anisidine value cited above

between all levels of water injection throughout the 40 hrs at 170°C of deep fat frying. Whereas, *P*-anisidine value decreased dramatically in the first level of water injection (12.9alkenal /kg of oil) when the water level injection was decreased. Hence, the first level of water injection flow rate had the highest ( $P \geq 0.05$ ) inhibitory effect on *P*-anisidine value in sunflower oil. Thereupon, water injection appreciably reduced *P*-anisidine value in sunflower oil. These reduction effects may be due to generating a steam (blanket) over the oil and preventing contact between air and oil. It can also play a role as a physical agent for steaming out, the volatile oxidative products from the oil and enhancing their evaporation (Rimac-Brncic *et al.*, 2004; Shaker, 2014). This protective effect was

observed previously during the frying of corn and canola oil saturated with water, *P*-anisidine value decreased from 77 and 97 to 39 and 67 mmol/kg respectively, when the water injection level increased from 0.1 to 1 ml/min. after frying for 20 hrs (Dana *et al.*, 2003). This protective role of water could be due to the large steam bubbles released from the oil.

These results are coincident with those reported by Saguy and Dana (2003) and Dana *et al.* (2003). It is interesting to notice that a linear increasing with a significantly correlation between frying time (FT) and *P*-anisidine value. The positive correlation coefficient between frying time and *P*-anisidine value was very high ( $r= 0.994$ ).

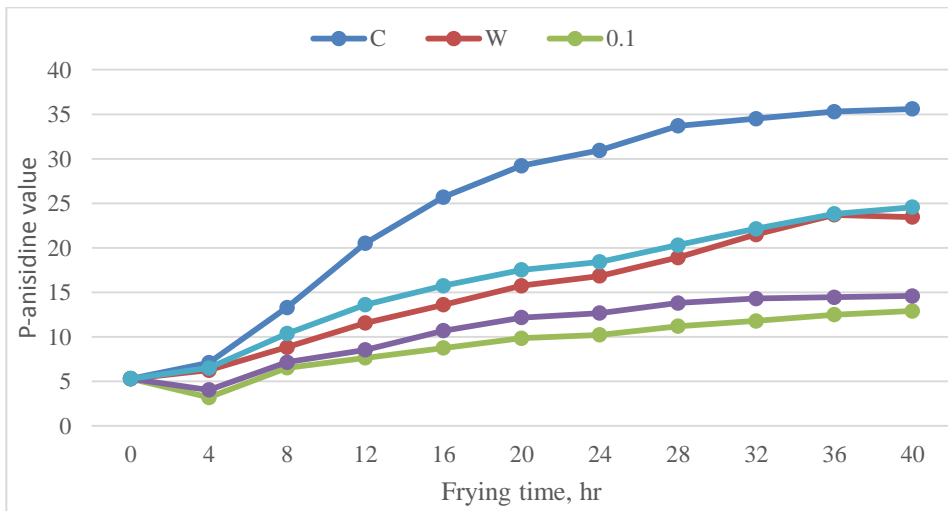


Figure (3): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on *P*-anisidine value.

Therefore, the linear regression equation for prediction the *P*-anisidine value of sunflower oil was:

$$Y_{(P\text{-anisidine value})} = 5.225 + 0.492X_{(FT)}$$

Meanwhile, it could be observed a moderate correlation coefficient between *P*-anisidine value and acid value ( $r= 0.682$ ). The measure of *P*-anisidine value is useful to correlate total Polar compounds (TPC), which is a laborious and expensive method. To examine the

relationship between *P*-anisidine value (Rapid and simpler measurements of oxidation, we plotted the data obtained during frying experiments at 170°C for 40 hrs, *P*-anisidine value has a linear relationship with TPC. The respective correlation coefficient was ( $r= 0.979$ ). The linear regression equation for prediction the TPC of oil was:

$$Y_{(TPC)} = -2.635 + 1.3858X_{(P\text{-anisidine value})}$$

Thereafter, the results suggest that determination of *P*-anisidine value is



good marker of TPC in deep fat frying. With regards to the influence of TPC as a .basis for the assessment of the end point of frying we chose 25 – 27 % TPC which is the regulatory limit in many European countries (Ahmad *et al.*, 2013; Dueik *et al.*, 2010). It is obvious from Figure (4) that, the water injection appreciably TPC concentration in MDF design in comparison with the CDF design, a water injection level of 0.1 ml / 20 min per 1 liter over sunflower oil led to a TPC of 18.64 % after 40 hrs at 170° C, while in

oil kept under the same condition and no water spray, the TPC was 22.74 %. TPC value decreased ( $p \geq 0.05$ ) dramatically in the first level of water injection level (18.64%) as the water injection level decreased. Meanwhile, TPC content formed in sunflower oil significantly increased with prolonging frying period. Obtained data in Figure (4), also showed that, caused in general, a highly inhibition of TPC content at a variable rates depend upon frying time and water injection level.

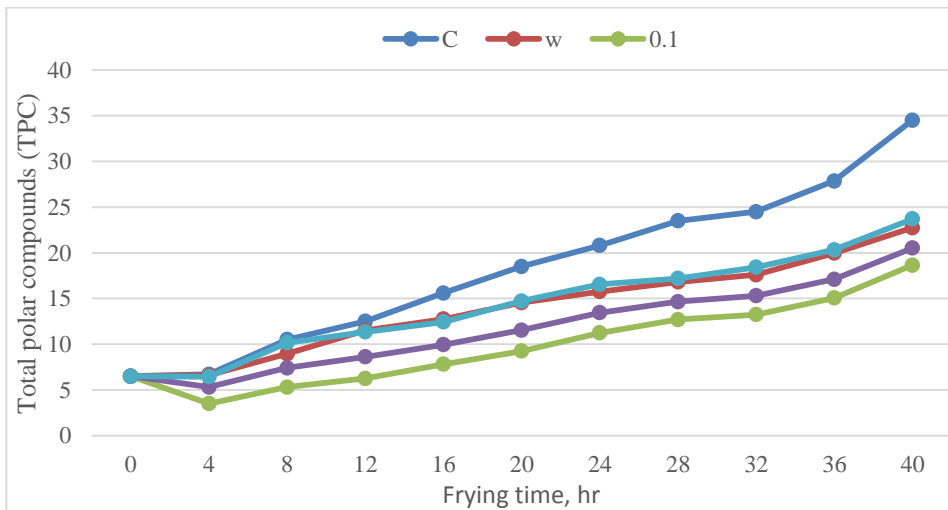


Figure (4): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on total polar compounds (TPC).

These findings are in agreement with those Negishi *et al.* (2003) who reported that the thermal oxidation that produced TPC during deep fat frying at fryer, the ratio between height (H) and surface area (A) was 0. 93 could be retarded due to small surface of oil in contact with air. These results demonstrated that MDF

was able to retard oxidation during deep fat frying .Hence, the inclusion of TPC value as a criterion for oil quality should be considered for monitoring changes in frying oils. It is worthy to mention that TPC content increased linearly with prolonged time during deep fat frying of oil at 170°C. The correlation coefficient

between the frying time and TPC was ( $r = 0.955$ ), and the linear regression equation for prediction TPC value was:

$$Y_{(TPC)} = 3.27 + 0.3342 X_{(FT)}$$

Many researchers revealing a decrease in total polar compounds with increasing water injection (Delgado *et al.*, 2014), and as a consequence, the deterioration oil ratios is reduced by the water injection during intermittent deep fat frying processes. The above mentioned results are in harmony with those obtained by Suxuan and Willium (2012). With respect to thiobarbituric acid (TBA) value, which is considered a good chemical quality measure to identify the oxidation state of oil to measure the secondary oxidation. TBA test is a condensation reaction between the TBA and malonaldehyde (El-Naggar, 2007). As shown in Figure (5), water injection appreciably reduced TBA value in MDF method in comparison with CDF method. TBA value decreased from 8.9 to 4.81 when water injection level was 0.1 ml / 20 ml per 1 liter. A water spray level of 0.1 ml / 20 min over sunflower oil led to a TBA value of 4.81 after 40 hrs at 170°C, while in oil kept under the same conditions and no water spray injection, the TBA value was 7. TBA value was considerably higher in CDF design, probably due to the higher surface area as compared with MDF design. Generally, first level of water injection level had significantly ( $p \geq 0.05$ ) lower TBA value (4.81) compared with the second level of

water injection (6.74) and / or third level of water injection. These findings are in harmony with those obtained by (Dana *et al.*, 2003). Interestingly, TBA value increased linearly with a significantly correlation between frying time and TBA value. The positive correlation coefficient between TBA values and frying time was high ( $r = 0.939$ ). Thereafter, the linear regression equation for prediction the TBA values of oil was:

$$Y_{(TBA)} = 2.4864 + 0.1191 X_{(FT)}$$

On the other side, the correlation coefficient between TBA value and TPC content was ( $r = 0.937$ ). Consequently, the linear regression equation for prediction the TPC content of oil was:

$$Y_{(TPC)} = 0.3740 + 2.935 X_{(TBA)}$$

Thus, consequently the results suggest that determination of TBA test is also good marker of TPC content in deep fat frying. The aforementioned findings of TBA test are in line with those obtained by Shaker (2014). Concerning the changes in ultra-violet absorption, the absorbance values reflect the presence of conjugated double bonds in the structure of oil molecule. These bonds are probably resulting of the formation of peroxides and other by products of oil oxidation. When unsaturated fatty acids are oxidized, to form hydroperoxides, the double bonds in the oils become conjugated, conjugated diene (CDs) may result from decomposition and

absorption bond at about 232 nm which measures the degree of the primary oxidation products, while absorption bond at about 268 nm measures the secondary oxidation products formed from the initial compounds detected at 232 nm. Both of conjugated diene (CDs) and conjugated triens (CTs) have been

used as a good successful index for detecting the formation degree of conjugated fatty acids diens (CDs) and conjugated fatty acids triens (CTs), respectively and they have been used to assess the changes during deep fat frying (Ahmad *et al.*, 2013; El-Naggar, 2007; Tompkins and Perkins, 1999).

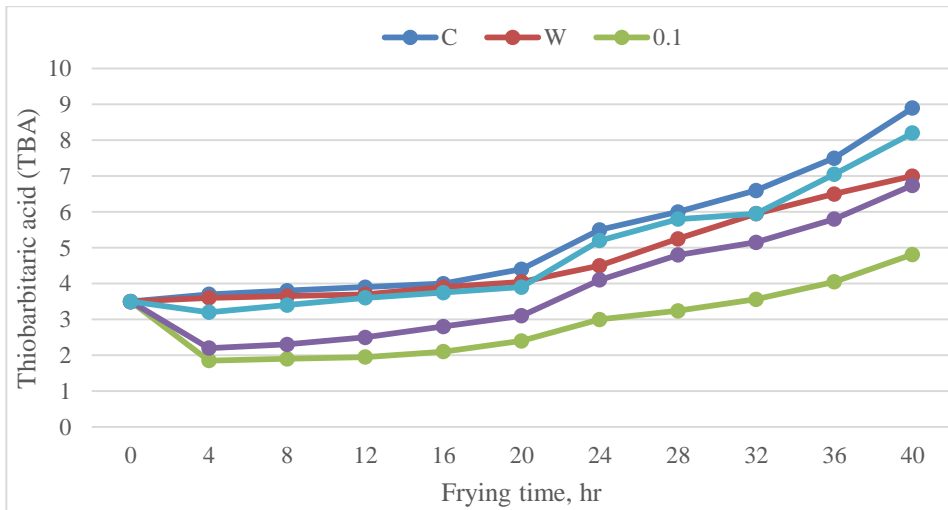


Figure (5): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on thiobarbituric acid (TBA).

Data given in Figure (6) indicated that the water injection reduced CDs concentrations. A water injection level of 0.1 ml/20 min. reduced the CDs from 8 to 5.59. Increasing the water injection to 0.3 ml/20 min. was not effective in reducing the CDs in sunflower oil after 40 hrs at 170°C of frying compared with the 0.1 ml/20 min. water injection. These results are in agreement with a similar decrease in CDs due water dispersion in corn and canola oil after frying for 20 hrs

at 180°C (Dana *et al.*, 2003). The same trend was observed in CTs. As shown in Figures (6) and (7) indicated that the CDF design samples contained a higher absorbance values at 232 nm (8) and at 268 nm (1.9) of oil than MDF design treatments. Meanwhile, absorbance values at 232 and 268 nm decreased ( $P \geq 0.05$ ) dramatically in the first level of water injection (5.59) and (1.33) in oils respectively as water injection level decreased.

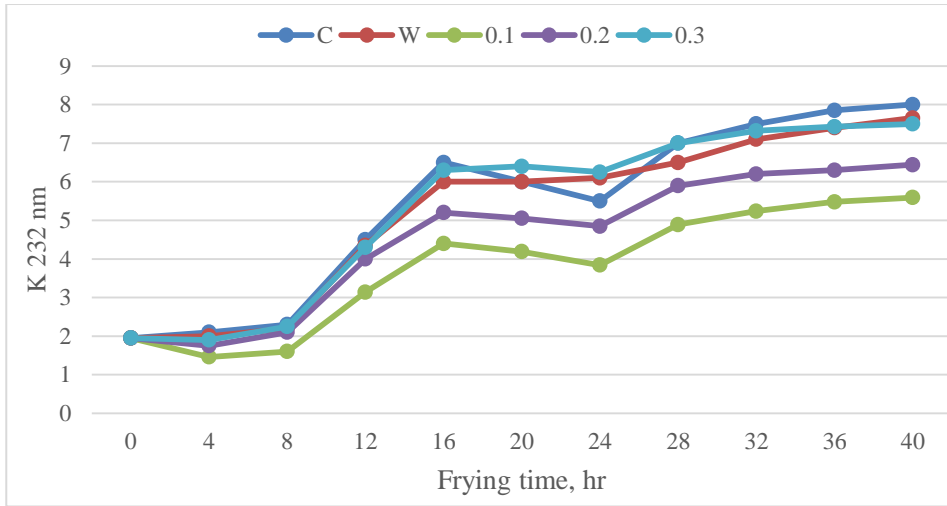


Figure (6): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on K 232 nm.

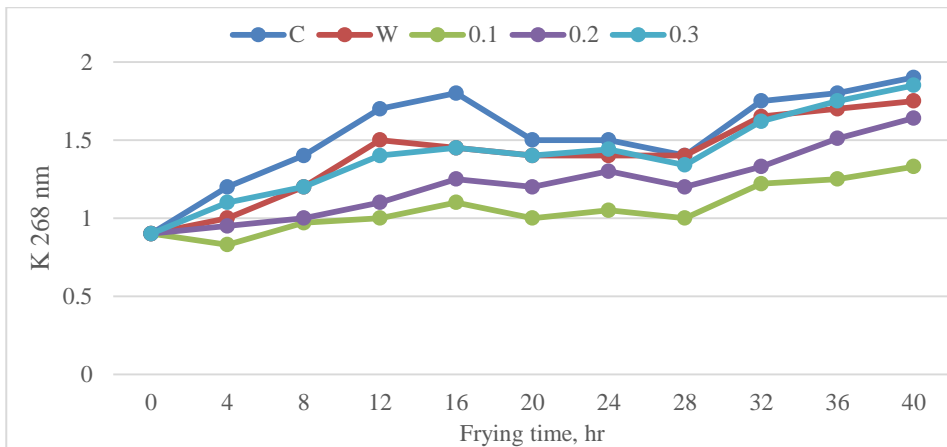


Figure (7): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on K 268 nm.

Hence, the first level of water injection had the highest ( $P \geq 0.05$ ) inhibitory effect on absorbance values at 232 and 268 nm in oil compared to another water injection levels and CDF design samples. The reduction effect of the first level of water injection on absorbance values at 232 and 268 nm in oils may be owing to generating a steam (blanket) over the oil

and preventing contact between oxygen and oil, caused small surface area of modified stainless steel vessel. Similar results are very close to those reported by (Dana *et al.*, 2003; Delgado *et al.* 2014). It is interesting to notice that the positive correlation coefficient between CDs, CTs and TPC contents and both of CDs ( $r = 0.937$ ) and CTs ( $r = 0.908$ ). The linear

regression equation for prediction the TPC contents of oils were:

$$Y_{(TPC)} = 0.961 + 2.4X_{(CDs)}$$

$$Y_{(TPC)} = -12.5654 + 20.069X_{(CTs)}$$

Thereafter, the data suggest that determination either CDs or CTs is also good marker of TPC content in deep fat frying.

### 3.2 Potato chips properties

Data given in Figures (8, 9 and 10) indicated the changes in moisture content, oil uptake and shrinkage percentages of potato chips of different levels of water injection and their comparative with control samples. It is worthy to mention that a linear decrease with a significantly correlation between moisture content and frying time (Ahmad *et al.*, 2013). The correlation coefficient between moisture content and frying time was ( $r = -0.59$ ) for control samples. The linear regression equations for prediction the frying time (FT) were:

$$Y_{(FT)} = 3.1309 - 0.0229X_{(MC)} \quad (r = -0.590) \quad (\text{Control})$$

$$Y_{(FP)} = 3.4318 - 0.02477X_{(MC)} \quad (r = -0.647) \quad (WI = 0.1)$$

$$Y_{(FP)} = 3.3864 - 0.01459X_{(MC)} \quad (r = -0.474) \quad (WI = 0.2)$$

$$Y_{(FP)} = 76.1792 - 17.606X_{(MC)} \quad (r = -0.483) \quad (WI = 0.3)$$

On the other side, the positive correlation coefficient between oil uptake percentage and frying time was very high ( $r = 0.905$ ) for control samples. The linear regression equation for prediction the oil uptakes were:

$$Y_{(OU)} = 29.8073 + 0.19436X_{(FT)} \quad (r = 0.905) \quad (\text{Control})$$

$$Y_{(OU)} = 25.066 + 0.046023X_{(FT)} \quad (r = 0.968) \quad (WI = 0.1)$$

$$Y_{(OU)} = 25.057 + 0.0688X_{(FT)} \quad (r = 0.996) \quad (WI = 0.2)$$

$$Y_{(OU)} = 26.761 + 0.04352X_{(FT)} \quad (r = 0.714) \quad (WI = 0.3)$$

It is worth mentioning that, the weak

correlation coefficient between shrinkage percentage and frying time was very low ( $r = -0.174$ ) for control samples. Similar results are very close to those reported by (Delgado *et al.*, 2014).

$$Y_{(SH)} = 14.7796 - 0.0006X_{(FT)}$$

While, the correlation coefficient between shrinkage percentage and frying time was moderate ( $r = -0.44$ ) at water injection level (0.1) and linear regression equation for prediction the shrinkage percentage was:

$$Y_{(SH)} = 10.2591 - 0.0007X_{(FT)}$$

The correlation coefficient between shrinkage percentage and frying time was very low ( $r = -0.139$ ) at water injection level (0.2) and linear regression equation for prediction the shrinkage percentage was:

$$Y_{(SH)} = 11.04 - 2.9544X_{(FT)}$$

While, the correlation coefficient between shrinkage percentage and frying time was low ( $r = -0.187$ ) at water injection level (0.3) and linear regression equation for prediction the shrinkage percentage was:

$$Y_{(SH)} = 13.1341 - 0.0006X_{(FT)}$$

The negative correlation coefficient between oil uptake (OU) and moisture content percentage (MC) was strong and linear regression equations for predication the oil uptake were:

$$Y_{(OU)} = 37.3355 - 1.3623X_{(MC)} \quad (r = -0.246) \quad (\text{control})$$

$$Y_{(OU)} = 28.685 - 0.9191X_{(MC)} \quad (r = -0.74) \quad (WI = 0.1)$$

$$Y_{(OU)} = 29.9642 - 1.1415X_{(MC)} \quad (r = -0.508) \quad (WI = 0.2)$$

$$Y_{(OU)} = 34.1064 - 2.029X_{(MC)} \quad (r = -0.915) \quad (WI = 0.3)$$

The positive correlation coefficient

between shrinkage (SH) and moisture content percentages (MC) were high and linear regression equations for predication the oil uptake were:

$$Y_{(SH)} = 12.66 + 0.7702X_{(MC)} \quad (r = 0.866) \quad (\text{Control})$$

$$Y_{(SH)} = 9.0794 + 0.3521X_{(MC)} \quad (r = 0.815) \quad (\text{WI} = 0.1)$$

$$Y_{(SH)} = 9.01691 + 0.5855X_{(MC)} \quad (r = 0.85) \quad (\text{WI} = 0.2)$$

$$Y_{(SH)} = 9.376 + 1.1287X_{(MC)} \quad (r = 0.939) \quad (\text{WI} = 0.3)$$

The negative correlation coefficient between oil uptake (OU) and shrinkage (SH) percentages was moderate and linear regression equations for predication the oil uptake were:

$$Y_{(SH)} = 13.807 + 0.02529X_{(OU)} \quad (r = -0.157) \quad (\text{Control})$$

$$Y_{(SH)} = 15.807 - 0.2123X_{(OU)} \quad (r = -0.61) \quad (\text{WI} = 0.1)$$

$$Y_{(SH)} = 12.3585 - 0.05212X_{(OU)} \quad (r = -0.169) \quad (\text{WI} = 0.2)$$

$$Y_{(SH)} = 24.7943 - 0.4265X_{(OU)} \quad (r = -0.779) \quad (\text{WI} = 0.3)$$

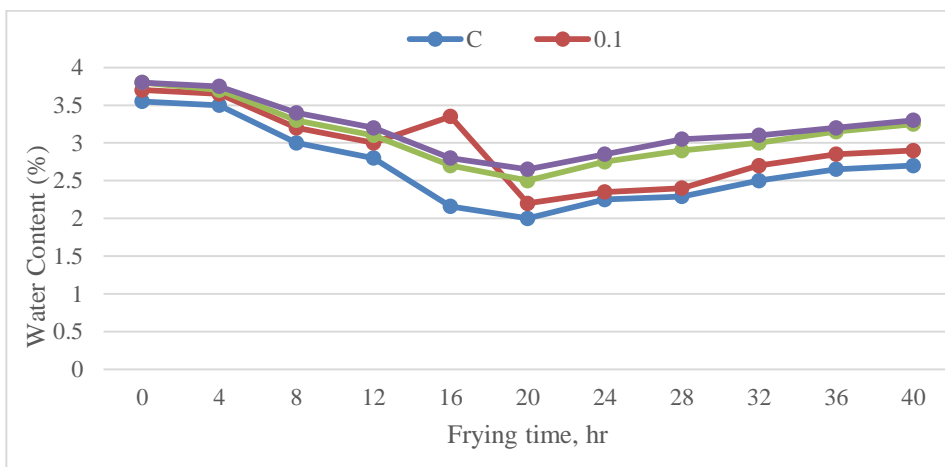


Figure (8): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on water content (%).

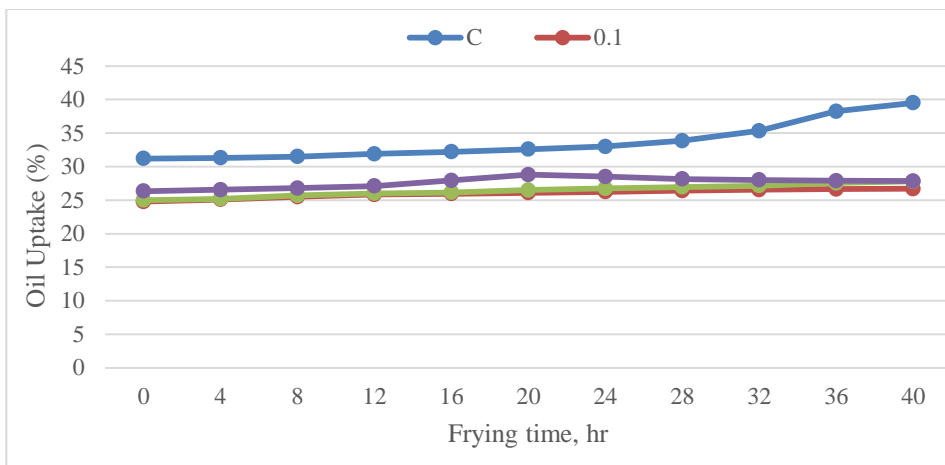


Figure (9): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on oil uptake (%).

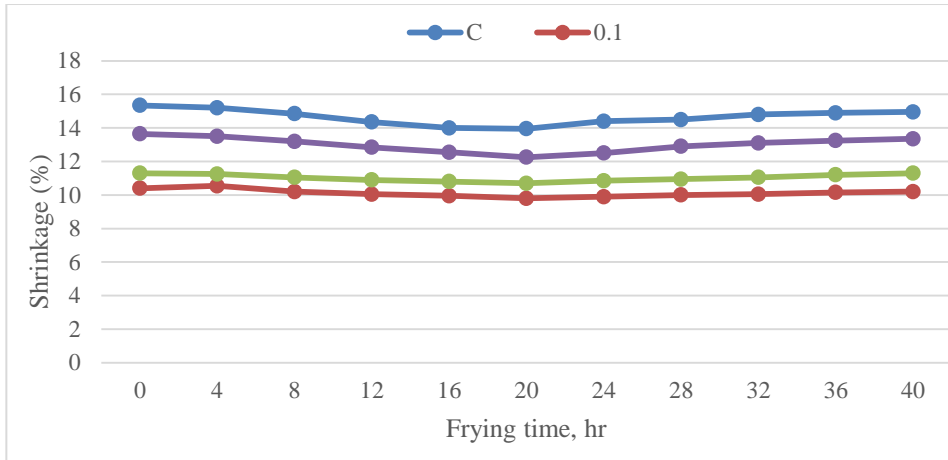


Figure (10): Effect of injecting water to sunflower oil during prolonged frying of potato chips at 170° c for 40 hrs on shrinkage (%).

Thereafter, the influence of water injection level during deep fat frying process on moisture content, oil uptake and shrinkage percentages of potato chips, it could be noticed that water injection level of 0.1 showed considerably improved the further potato properties (Garayo and Moreira, 2002). Table (1)

shows the evaluation of fatty acid composition of fried oil properties during CDF and MDF designs. There were significant differences ( $P \geq 0.05$ ) between the fried oil properties during CDF and MDF design samples. Total unsaturated fatty acids at MDF gave the highest values.

Table (1): Effect of injecting water to sunflower seed oil after deep fat frying of Potato chips at 170°C for 40 hrs on fatty acid composition.

Treatment	Control		Without water injection	Water injection level after 40 hrs		
	Zero time	After 40 hrs		0.1	0.2	0.3
C <sub>12:0</sub>	0.36	0.65	0.60	0.54	0.55	0.57
C <sub>14:0</sub>	0.50	0.15	0.20	0.33	0.30	0.25
C <sub>16:0</sub>	17.04	30.00	28.00	24.70	24.69	26.01
C <sub>16:1</sub>	0.30	0.35	0.34	0.30	0.33	0.34
C <sub>18:0</sub>	3.80	3.50	3.38	3.29	3.32	3.20
C <sub>18:1</sub>	23.10	33.00	30.03	25.72	27.88	29.00
C <sub>18:2</sub>	55.50	32.20	37.30	45.12	42.80	40.50
C <sub>18:3</sub>	0.1	0.15	0.14	0.12	0.13	0.13
Total sat. fatty acids	20.98	34.30	32.18	28.86	28.86	30.03
Total un sat. fatty acids	79.00	65.70	67.81	71.14	71.14	69.97
C <sub>18:2</sub> C <sub>16:0</sub>	3.25	1.07	1.33	1.82	1.73	1.55

Meanwhile, total unsaturated fatty acid values increased in the first and second levels of water injection (71.14) against

(67.81) for MDF design without water injection and (65.7) for CDF design after 40 hrs at 170°C. Linoleic and palmitic

acids are usually used as indicators of the extent of oil deterioration, because linoleic acid is more susceptible to oxidation, whereas, palmitic acid is more stable toward oxidation. Consequently, the ratio of C18:2/C16:0 was used to indicate the degree of oxidation deterioration of frying oil. The ratio of C18:2/C16:0 was reduced during CDF and /or MDF while, first level of water injection contained the highest value of these ratio (1.82) followed by the second level of water injection (1.73) and then the third level of water injection (1.55) compared with (1.33) for MDF design without water injection and/or (1.07) for CDF after 40 hrs at 170°C.

### 3.3 Organoleptic evaluation of fried potato chips by using the modified fryer

As shown in Table (2) the sensory evaluation revealed that fried potato chips were more acceptable with the best flavor, crispness and greasiness compared to CDF design samples. Whereas, overall acceptability scores for those samples were ranged from 3 and 4.8 against 3.8 of CDF method. Fried potato chips during the first level of water injection had the highest ( $p \geq 0.05$ ) flavor (4.6), crispness (4.5) greasiness (4.6) and the overall acceptability (4.8) compared to fried potato chips during another levels of water injection.

Table (2): Organoleptic evaluation during deep fat frying of potato chips at 170 °C for 40 hrs.

Properties	Frying time (hrs)	Flavour	Crispness	Greasiness	Overall acceptability	
Treatment						
Control	8	4.3	4.0	3.6	3.8	
	16	4.4	4.1	3.6	3.8	
	24	4.2	3.8	3.4	3.5	
	32	3.4	3.3	3.2	3.0	
	40	3.0	3.0	3.1	3.0	
Without water injection	8	4.5	4.2	4.2	4.5	
	16	4.5	4.4	4.0	4.4	
	24	4.3	4.0	3.8	4.0	
	32	3.8	3.7	3.5	3.6	
	40	3.5	3.5	3.3	3.4	
Injection water level (ml/batch) during frying of potato chips at 170C ° for 40 hrs.	0.1	8	4.5	4.2	4.6	4.8
		16	4.6	4.5	4.4	4.6
		24	4.5	4.3	4.0	4.2
		32	4.0	4.0	3.8	4.0
		40	3.6	4.0	3.6	4.0
	0.2	8	4.3	4.1	4.4	4.6
		16	4.4	4.4	4.3	4.2
		24	4.1	4.1	4.0	3.8
		32	3.6	4.0	3.6	3.6
		40	3.2	3.8	3.4	3.4
	0.3	8	4.1	3.9	4.1	4.2
		16	4.0	4.0	4.0	3.8
		24	3.8	3.8	3.8	3.4
		32	3.4	3.6	3.4	3.2
		40	3.0	3.4	3.2	3.0
LSD 5%		1.01	1.05	0.5	0.7	



From the overall acceptability rating, it was concluded that a MDF could be injected water up to 0.2 ml/20 min. per 1 liter without affecting their sensory quality. It is interesting to notice that sensory evaluation correlated significantly with the deterioration occur in quality attributes in oil during deep fat frying. Additionally, sensory evaluation data are providing us with the information about the thermal stability for quality properties of fried potato chips and oil frying media. The negative correlation coefficient between overall acceptability and *P*-anisidine values was high ( $r = 0.935$ ). For the third level of water injection followed by the first level of water injection ( $r = -0.832$ ) and then the second level of water injection ( $r = -0.795$ ), compared with CDF design. The linear regression equation for prediction the anisidine values of oil was:

$$Y (p - anisidine) = 59.913 - 11.383 X (\text{overall acceptability}) \quad r = (-0.935)$$

Same trend was noticed with the most another sensory attributes throughout the whole experiment period. These findings could be supported by Basuny *et al.* (2012) and Ahmad *et al.* (2013). Generally, it is worthy to mention that a linear decrease with a significantly correlation between sensory evaluation and oil deterioration parameters except acid value, the correlation coefficient was very weak. , the results suggest that determination of oil deterioration parameters are good marker of sensory evaluation during deep fat frying. These data are in the same line with those reported by El-Nagar (2007). Nevertheless, water spray injection may provide protection to the frying oil by

steaming out volatile oxidized substances and free radical, and reducing residual dissolved oxygen. It seems to play a crucial role as physical agent for steaming out the volatile oxidative products were found in vapor inhalation and enhancing their evaporation and condensation by steam blanketing design.

#### 4. Conclusions

Results indicate that, water injection can both a accelerate hydrolysis and furnish protection against oxidation. Thereafter, these data suggest that the evaporating water do indeed create a steam blanket above the oil surface. The additional properties role of the evaporating water is due to the steam out and distillation effect that reduces the concentration of dissolved oxygen, and drives out oxidized volatile compounds, and possibly also free radicals generated during the frying process MDF design can be applied as simple method to maintain oil quality during deep fat frying.

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