

COMPARATIVE ASSESSMENT OF THERMAL RESISTANCE OF PALM STEARIN AND HIGH OLEIC BLENDED OIL WHEN SUBJECTED TO FRYING PRACTICE IN FAST FOOD RESTAURANTS

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ABSTRACT

In this study, the thermal stability of palm frying oil (palm stearin, POs) and a formulated high oleic frying oil (high oleic blended oil, HOBO) in China was evaluated under simulated frying protocol in fast food restaurants. A series of physico-chemical properties of the oils were measured including change of colour, acid value (AV), peroxide value (PV), p-anisidine value (p-AV), total oxidation (TOTOX=2PV+p-AV), fatty acids composition (FAC), iodine value (IV), carbonyl group value (CGV), total polar compounds (TPC), oxidative stability index (OSI) and vitamin E content. The frying experiments were conducted at $170 \pm 5^\circ\text{C}$ for five consecutive days where French fries were fried in five cycles hourly for 12 hr a day. The results indicated that POs gave higher physical and chemical stability than HOBO under extended frying conditions, considering its relatively lower increase in TPC, p-AV, TOTOX and CGV, lesser decrease in C18:2/C16:0 and IV, and longer induction period. Based on the results, it can be conjectured that POs is a more preferred choice for deep fat frying with lower deterioration rate.

Keywords: palm stearin, high oleic oil, frying performances, deep fat frying.

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INTRODUCTION

Deep fat frying is one of the most well-accepted methods in food preparation, owing to the fact that

fried food provides unique aroma, taste, golden colour and crispy texture that cannot be found in other cooking techniques (Aladedunye, 2015). Essentially, deep fat frying involves immersion of food in hot oil at temperatures from 150°C to 190°C (Aniolowska and Kita, 2016; Yu *et al.*, 2016). During the frying process, oil undergoes a series of reactions which can produce unwanted breakdown compounds (Del Re and Jorge, 2006). These reactions mainly comprised of oxidation, hydrolysis and polymerisation, giving rise to generating myriad of degradation products including various volatile and non-volatile compounds (Nayak *et al.*, 2015). These generated

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process-developed contaminants can deteriorate the functional, sensory attributes and nutritional value of the oils (Hua *et al.*, 2016).

In general, there are many selections of vegetable oils available for deep-frying applications depending on their availability, traditional habits, and thermal resistance. Palm oil and soybean oil are mostly used for domestic cooking and frying worldwide, while canola oil is commonly used in European countries and Canada (Hosseini *et al.*, 2016). In China, palm oil is often used in fast food restaurants, *i.e.* Kentucky Fried Chicken (KFC), McDonald's and Dicos. This is due to palm oil's excellent thermo-oxidative stability, long shelf-life, abundant phytonutrients (tocotrienols and carotenoids) and reliable supply (Kushairi *et al.*, 2018). In 2018, Malaysia produced 19.52 million tonnes of palm oil, with annual productivity of 3.73 t ha⁻¹ yr⁻¹ (Kushairi *et al.*, 2019). Recently, unsaturated oils have received much attention, and among them, oil rich with monounsaturated fatty acids (MUFA) are increasingly received a broader spectrum of functionality and health benefits (Gillingham *et al.*, 2011), with an inherently higher thermal-oxidative stability compared to oils with higher polyunsaturated fatty acids (PUFA). Utilisation of high oleic oils such as high oleic rapeseed oil (canola oil), high oleic sunflower oil, high oleic peanut oil and high oleic soybean oil continues to increase in China, especially in fast food restaurants.

Oil stability indicates the ability of oil to resist elevated temperatures during frying, as a result, the degree of saturation has become a considerable criterion for choosing suitable frying oil. A great many studies have demonstrated that oil with higher amount of saturated fatty acids and lower amount of unsaturated fatty acids exhibits better stability on frying performance irrespective of the nutritional standpoint of oil (Matthäus, 2006; Aladedunye and Przybylski, 2014). Furthermore, the number of unsaturated bonds in fatty acids plays a decisive role in the oxidation rate of oil. It is reported that the relative oxidation rate of stearic acid (18:0) to oleic acid (18:1) to linoleic acid (18:2) to linolenic acid (18:3) was 1:10:100:150 (Ahmad Tarmizi *et al.*, 2016). Saturated fatty acid has no double bond in its fat molecule which gives the higher stability property as compared with unsaturated fatty acid. However, oil stability does not depend on the degree of saturation absolutely (Normand *et al.*, 2006). Factors like the presence of minor components such as phytosterols, tocopherols and tocotrienols and the positioning of fatty acid in the triacylglycerols could also affect the stability of the oil (Abuzaytoun and Shahidi, 2006; Ahmad Tarmizi *et al.*, 2016).

Therefore, the aim of the present work was to evaluate the frying performance of two commercial frying oils, which are refined, bleached and

deodourised palm stearin [POs, iodine value (IV) 49] and high oleic blended oil (HOBO) consisting of a blend of high oleic sunflower oil and canola oil under following frying protocol in fast food restaurants in China. The main focus was the quality changes occurring in the two frying oils which included colour, iodine value (IV), acid value (AV), peroxide value (PV), *p*-anisidine value (*p*-AV), total oxidation (TOTOX), carbonyl group value (CGV), fatty acids composition (FAC), total polar compounds (TPC), oxidative stability index (OSI) and tocols.

MATERIALS AND METHODS

Materials

Commercial-grade POs (IV 49) was purchased from Wilmar Co. Ltd (Shanghai, China) while HOBO consisting of a blend of high oleic sunflower oil and modified canola oil were purchased from Cargill Co. Ltd (Shanghai, China). Pre-fried French fries were provided by Inner Mongolia Lamb Weston Potato Co. Ltd (Ulanqab, China). Benzene, n-hexane, n-heptane, tetrahydrofuran were chromatographic grade and purchased from Sinopharm Chemical Reagent Co. Ltd (Shanghai, China). The internal standard α -, β -, γ -, δ -tocopherols were obtained from Sigma-Aldrich (St Louis, MO, USA) and α -, β -, γ -, δ -tocotrienols samples were gifts from Sime Darby Plantation Company, Malaysia with purity greater than 97% by high performance liquid chromatography (HPLC). Other reagent-grade chemicals were purchased from Sinopharm Chemical Reagent Co. Ltd (Shanghai, China).

Frying Protocol

The present work was designed to simulate frying practice of fast food restaurants according to Li *et al.* (2019) with slight modifications, heating the oils for 12 hr daily, with frying cycles every 12 min over five consecutive days. Each frying experiment was carried out using a 13-litre capacity stainless deep fryer Model OFE-28 (Yixi, Shanghai, China) with a set temperature of 170 \pm 5°C. Each frying cycle, a batch of 200 g of pre-fried French fries was fried for 3 min, and 9 min for the oil to remain idle before executing next frying cycle. The filtration with 60 g filter powder (Dallas Special Adsorbent Co., Qingdao, China) and paper (Yixi, Shanghai, China) was conducted every 6 hr of frying. After filtering, fresh frying oil was added to replenish the used oil to the initial level in the fryer. At the end of daily frying operation, 350 ml of each oil was collected and placed in a dark amber bottle, purged with nitrogen and kept at -20°C for subsequent analyses.

Methods of Oil Analyses

AV, PV and TPC were determined using the AOCS Official Methods Cd 3d-63, Cd 8b-90 and Cd 20-91, respectively (AOCS, 2017). The IV and *p*-AV of oil samples were assayed according to the ISO methods 3961:2018 and 6885:2016, respectively. The OSI of oil was measured at 110°C using a Metrohm 743 Rancimat (Metrohm, Switzerland) according to ISO Method 6886:2016. Determination of oil colour was carried out using a Lovibond Tintometer Model-F (Salisbury, England) following the ISO Method 27608:2010.

Determination of FAC

According to the AOCS Official Method Ce 1a-13 (2017), the FAC was analysed using gas chromatography (Agilent Technologies, Shanghai, China), coupled with a FID and polar capillary column model varian cp 7489 (100.0 m × 250 µm × 0.20 µm, VARIAN, Shanghai, China). The injection temperature was kept at 250°C. The oven temperature was held for 5 min at 160°C and subsequently programmed to 210°C at 10°C min⁻¹. Ultrahigh-purity helium was used as the carrier gas at a flow rate of 1.3 ml min⁻¹ and the split ratio was 50:1.

Analysis of Tocol Homologues in Oil

The concentration of tocols (tocopherols and tocotrienols) in oil was quantified following to the ISO Method 9936:2016 using a normal-phase HPLC (Agilent Technologies 1200, Shanghai, China) fitted with a fluorescence detector (Agilent Technologies, Shanghai, China) by setting excitation and emission wavelengths at 292 nm and at 394 nm, respectively. A LiChrospher 100 DIOL column (250 mm × 4 mm, i.d. 5 µm) was used as the stationary phase at a column temperature of 30°C. The mobile phase used in the analysis was a mixture of 96.15:3.85 ratio of n-hexane and tetrahydrofuran at a flow rate of 1 ml

min⁻¹. Tocopherols and tocotrienols were identified using external calibration for their individual homologue.

Statistical Analyses

All samples were analysed in triplicate, and data are presented as means ± standard deviations (SD). Data were evaluated by single factor analyses of variance (ANOVA) using the statistical package IMB SPSS Statistics (Version 20). Statistically significant differences between means were determined by Duncan's multiple range tests for p<0.05. Pearson correlations among the selected quality parameters were also calculated.

RESULTS AND DISCUSSION

FAC

FAC of the fresh oils used in the frying experiment are shown in *Table 1*. The most prominent fatty acids in fresh POs were palmitic acid (47.92%), oleic acid (37.49%) and linoleic acid (9.07%), while HOBO contained much higher amount of oleic acid (66.79%) and lesser amount of palmitic acid (4.54%). Besides, the level of saturated fatty acids (SFA) in POs (53.44%) was almost 10 times as high as that of HOBO (5.73), whereas only a third of the content of PUFA in HOBO was observed in POs. Oils with high amount of SFA and low amount of unsaturated fatty acids, especially PUFA, has higher oxidative stability (Ahmad Tarmizi and Ismail, 2014).

Figure 1 shows that FAC of all oils changed with frying time. Considering that linoleic acid (C18:2) is more susceptible to oxidation than palmitic acid (C16:0), the ratio of C18:2/C16:0 is used as the indicator for oxidative deterioration in used oils (Bansal *et al.*, 2010; Aniołowska and Kita, 2015; Li *et al.*, 2017). As shown in *Figure 1*, the C18:2/C16:0 dropped progressively in HOBO while remained almost unchanged in POs over the frying period.

TABLE 1. FATTY ACIDS COMPOSITION (%) OF FRESH OILS

FAC	POs	HOBO
C14:0	1.44 ± 0.11a	ND
C16:0	47.92 ± 1.19a	4.54 ± 0.15b
C18:0	4.08 ± 0.14a	1.19 ± 0.12b
C18:1	37.49 ± 0.45a	66.79 ± 1.34b
C18:2	9.07 ± 0.04a	18.70 ± 0.08b
C18:3	ND	8.78 ± 0.09b
SFA	53.44a	5.73b
MUFA	37.49a	66.79b
PUFA	9.07a	27.48b

Note: POs - palm stearin; HOBO - high oleic blended oil; SFA - saturated fatty acids; MUFA - monounsaturated fatty acids; PUFA - polyunsaturated fatty acids; FAC - fatty acids composition; ND - not detected. Different letters are significant in the same row at P < 0.05.

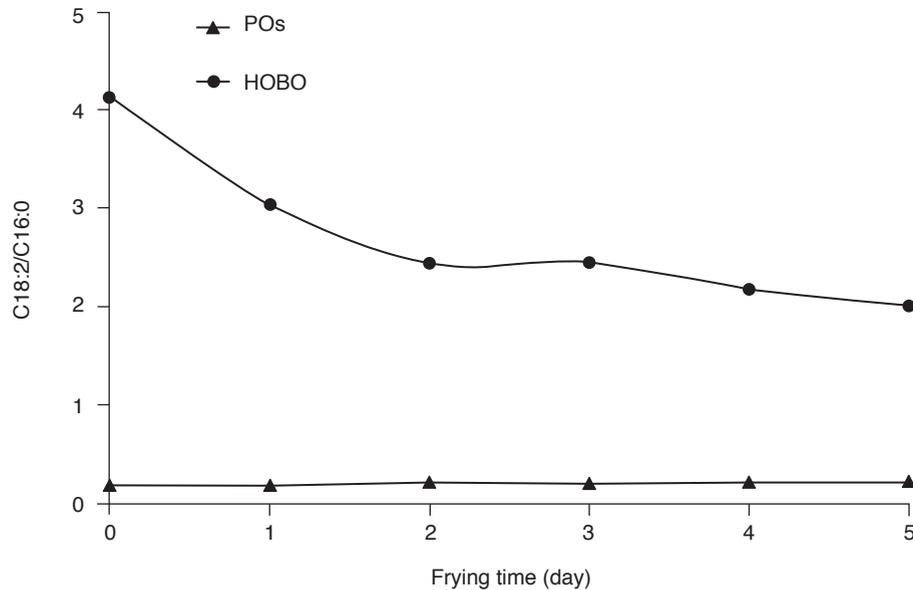


Figure 1. Changes in the ratio of C18:2/C16:0 during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

In addition, the C18:2/C16:0 decreased by 51.46% for HOBO, at the end of frying session. This ratio was significantly higher ($P < 0.05$) than that of POs (15.79%), which indicates that HOBO was susceptible towards changes in FAC when the unsaturation degree in the oil degraded due to oxidation during frying.

Changes in IV

The IV is used as the indicator to measure the degree of oil unsaturation. A decrease in IV can be due to the destruction of unsaturated bonds of oil by oxidation and polymerisation (Abdulkarim *et al.*, 2007). Figure 2 shows the changes in IV during five consecutive days of frying. The initial IV for POs (49.42) was almost unchanged over five days of frying, while HOBO showed gradual decrease in the IV (from 105.63 to 95.36) during the frying period, which was in good agreement with its reduction in unsaturated fatty acids (data not shown). This meant that POs was less susceptible to oxidation than HOBO.

Colour

Figure 3 shows the changes of oils colour across five days of frying. POs and HOBO darkened with frying time. Palm oil showed a similar and moderate rate of colour darkening with that of HOBO during the first three days before starting to accelerate for the remaining frying days (Figure 3). Darkening of oils during frying is due to the formation of non-volatile decomposition products (Abdulkarim *et al.*, 2007). However, colour is recognised as a prejudiced parameter used for rapid monitoring

of the quality of frying oil in the food industry. As the trace pigments and tocopherols, particularly tocotrienols are prone to formation of red-brown quinone polymers which may also affect the colour of frying oils. Formation of some carotenoid oxidation products and polymerised acylglycerols may also contribute to the higher colour observed for POs (Aladedunye and Przybylski, 2014). This may be a good explanation why the initial and end of POs colour was higher despite the rate of colour darkening was comparable to that of HOBO.

Changes in AV

AV principally measures the level of FFA in oil is usually used to indicate the degree of oil deterioration owing to hydrolysis of triglyceride and/or degradation of hydroperoxide (Matthäus, 2006). Figure 4 shows changes in AV for all oils during five days of frying. Increase in AV for both POs and HOBO was observed across frying time. However, the AV of both frying oils met the standards in China and Netherlands of no greater than 4.5-5.0 mg KOH g⁻¹ even after at the end of frying session (Day 5), mainly attributed by systematic filtering and replenishing of fresh oil during frying (Aladedunye and Przybylski, 2009). At the end of frying, the AV for POs was relatively higher compared to HOBO.

Generally, the degree of FFA through hydrolysis is too low, and poorly correlated with the quality of the food, thus, AV is not suitable to be used alone as quality indicator for frying oils (Matthäus, 2006; Aladedunye and Przybylski, 2014). However, it can be a good indicator of the extent of oil adulteration if used in combination with other methods (Abdulkarim *et al.*, 2007).

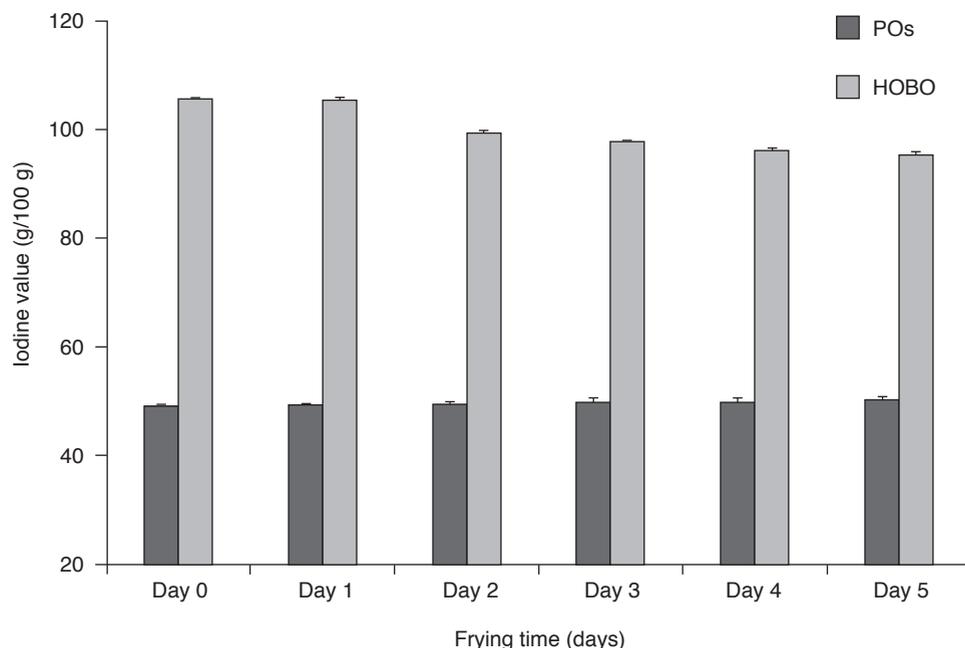


Figure 2. Changes in iodine value (IV) during five days of frying in palm stearin (POs) and high oleic blended oil (HOB0).

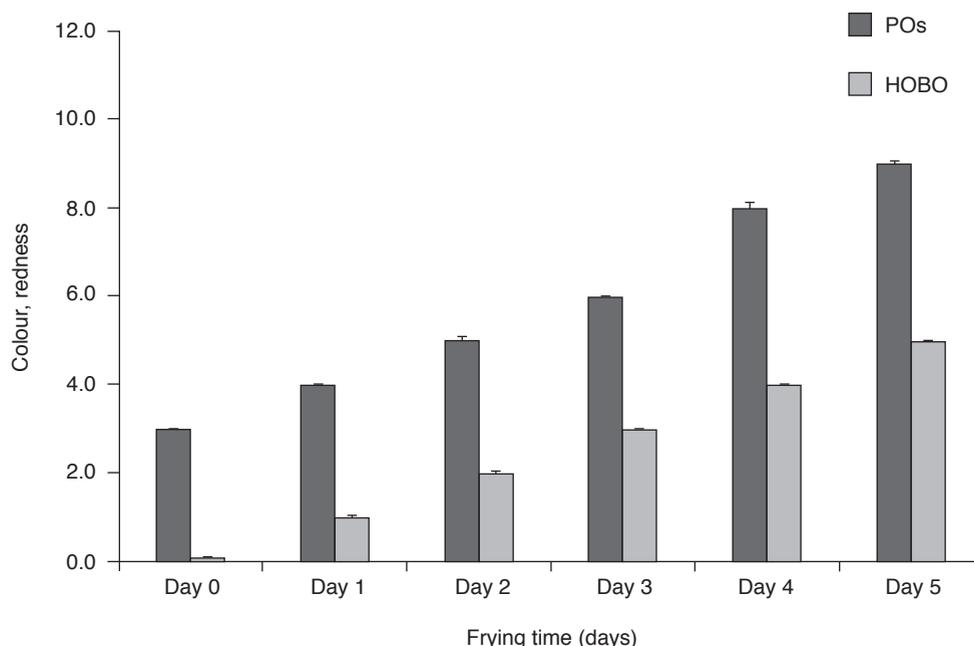


Figure 3. Changes in colour during five days of frying in palm stearin (POs) and high oleic blended oil (HOB0).

Changes in PV

Figure 5 shows the changes in PV of both oils for five days of successive frying. It was found that the PV of both oils increased drastically during the first day of frying and started to exhibit slight fluctuation thereafter. PV is considered as primary oxidation constituents of heated oil. Increase in the PV during frying period indicates the formation

of hydroperoxides due to early stage of oxidation. However, the hydroperoxides are unstable and prone to decompose into carbonyl and aldehyde compounds during elevated frying temperature. At frying temperatures, hydroperoxides decompose to form carbonyl and aldehydic compounds resulting in PV increment (Abdulkarim *et al.*, 2007). Therefore, PV appeared fluctuant throughout the frying process. However, PV alone is not a sole

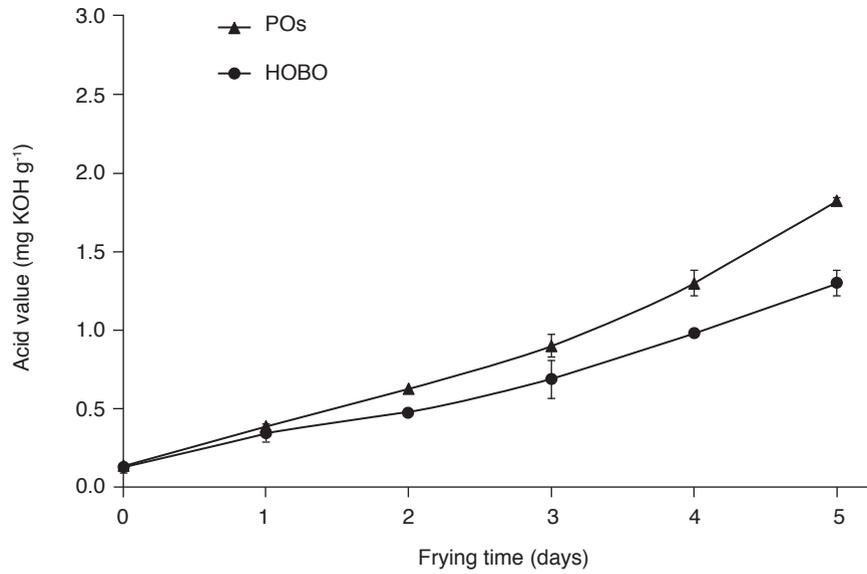


Figure 4. Changes in acid value (AV) during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

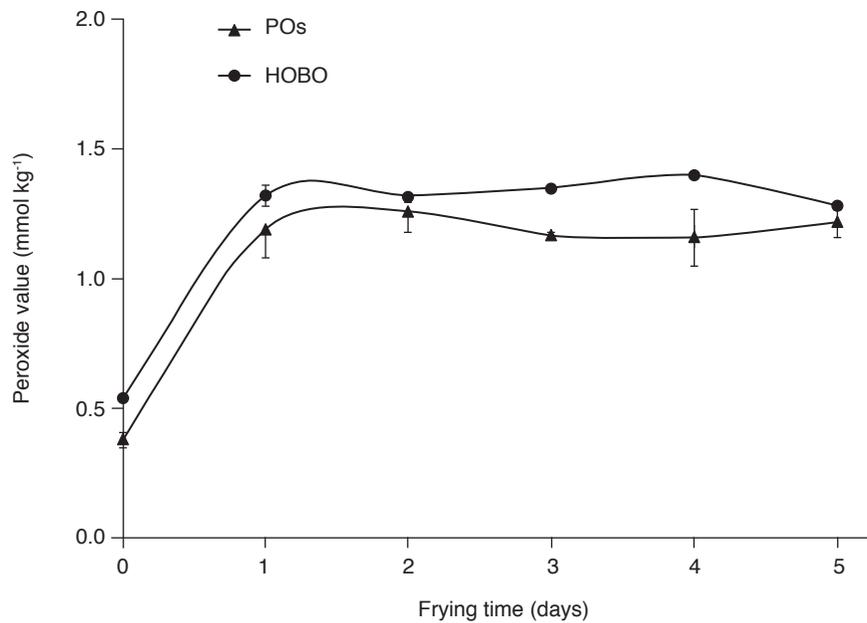


Figure 5. Changes in peroxide value (PV) during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

parameter to assess the extent of oil deterioration. In this respect, the amount of hydroperoxides in the oil cannot be fully used to estimate oil deterioration.

Changes in *p*-AV

Thermal decomposition of hydroperoxides during frying will further generate a considerable amount of secondary oxidation components of which carbonyl compounds being the most prominent among others (Nayak *et al.*, 2016).

Thus *p*-AV is a good indication of the level of nonvolatile aldehydes in the frying oil (Aladedunye and Przybylski, 2014). As shown in Figure 6, this observation can be supported by the trend of *p*-AV with frying time where it remained plateaued and stayed within 24-28 unit for POs and 39-45 unit for HOBO after a sharp increase for the first two days of frying. These results were similar to the study done by Ahmad Tarmizi *et al.* (2019), where the *p*-AV of vegetable oils including palm olein, soyabean oil, canola oil and sunflower oil reached a plateau after the third day of frying.

Changes in TOTOX Value

While PV evaluates the primary oil oxidation, *p*-AV measures the secondary oil oxidation. Therefore, *p*-AV is often used in the industry in conjunction with PV to calculate the total oxidation or TOTOX ($2PV + p\text{-AV}$) value (Shahidi and Wanasundara, 2002). The transient of *p*-AV is shown in Figure 7. After the fifth day of frying, the increment in TOTOX value for POs (22.61 unit)

was almost two-fold lower than HOBO (44.16 unit), which further confirmed that POs is more resistant against oxidation compared to HOBO. Higher TOTOX value in HOBO can be explained by their high percentage of unsaturation, especially PUFA. HOBO contains higher amounts of linoleic and linolenic acids, while POs has higher degree of saturation (palmitic acid) and MUFA, which gives the latter to pose better oxidative stability and lower TOTOX value.

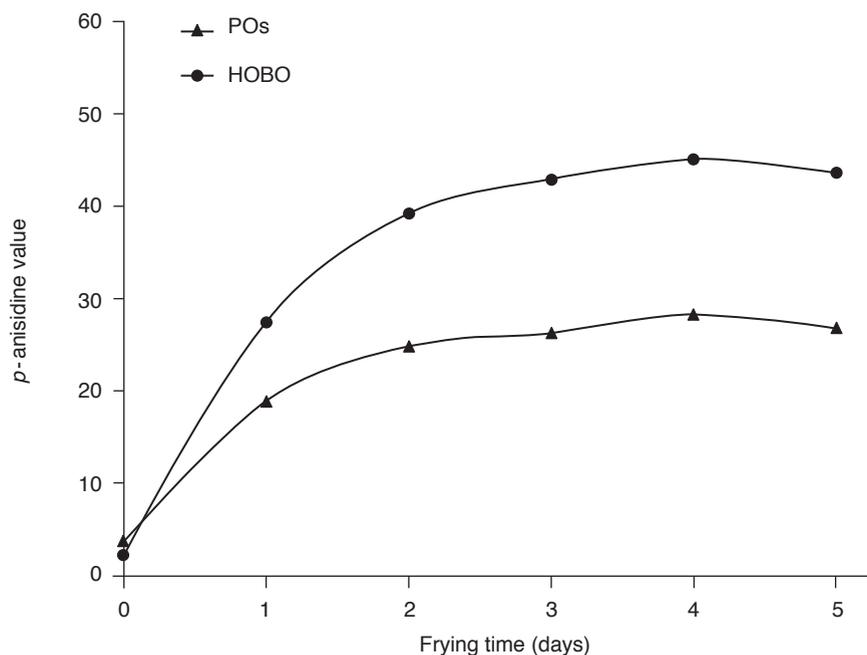


Figure 6. Changes in p-anisidine value (p-AV) during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

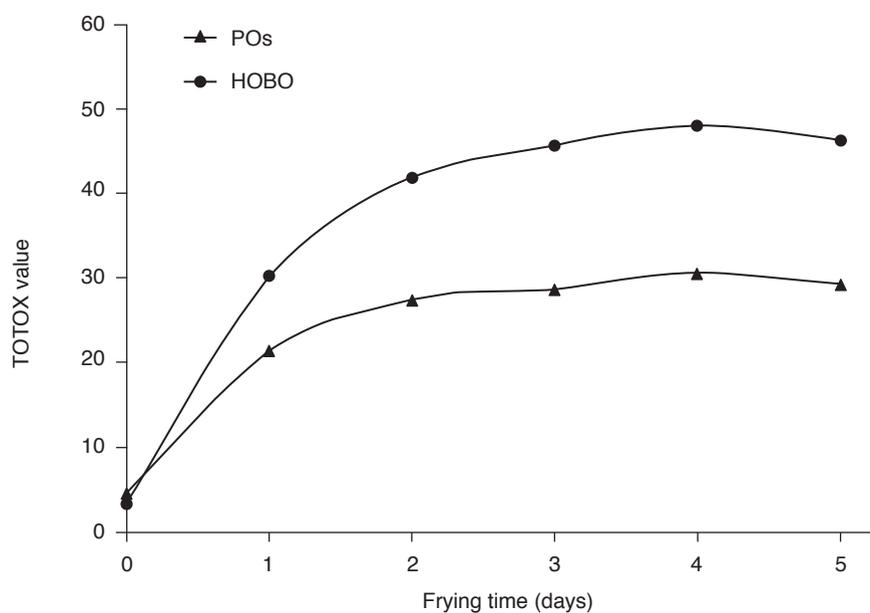


Figure 7. Changes in total oxidation (TOTOX) during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

Changes in CGV

CGV is useful to evaluate the quality of frying oils as it indicates the quantity of total carbonyl compounds from thermal oxidation, hydrolysis, and polymerisation during frying (Zhang *et al.*, 2015). These compounds often result in unpleasant and rancid flavours and reduce the nutritional value of fried foods (Farhoosh and Moosavi, 2008). As shown in *Figure 8*, a fluctuant increase in CGV with the rising frying time was found for the two frying oils. However, the CGV of POs and HOBO still kept low level with a maximum value of 15.52 meq kg⁻¹ and 18.35 meq kg⁻¹, respectively during frying. This levelling of CGV can be due to the addition of fresh oil every day after filtering and transfer of these carbonyl compounds into fried fries; however, their degradation should not be ignored. Moreover, the CGV in POs was significantly lower than that in HOBO, indicating that lesser total carbonyl compounds were produced in POs.

Changes in TPC

Measurement of TPC is recognised as one of the most accurate assessments of the thermo-oxidative degradation of frying oils since the measured components are non-volatile and are representative of the major reactions occurring during frying (Li *et al.*, 2019; 2017). As shown in *Figure 9*, the amounts of TPC increased linearly with frying time irrespective of oil type. The level of 24%-27% TPC has been suggested as the maximum limit for frying oil to

be edible in many European countries (Waghmare *et al.*, 2018). Both frying oils met the requirement and exhibited good frying stability. In addition, the rate of TPC formation in POs was lower than that of HOBO despite a significant higher TPC was observed in POs during the whole frying period mainly due to its higher level of diglyceride (Li *et al.*, 2019). Ahmad Tarmizi *et al.* (2019) have also revealed that dependency to TPC measurement alone in arbitrating the quality and safety of oils can be misleading especially for those oils including palm oil and rice bran oil that are rich of significant level of natural diacylglycerols. Further studies on the analysis of polar compound fractions are needed to avoid deceptive perception on the state of oil deterioration by judging from the amount of TPC alone.

Changes in OSI

The OSI or induction period, an expression of the stability of oils to resist oxidation, provides dynamic measures of oil stability during storage and heating (Ahmad Tarmizi and Ismail, 2008). As shown in *Figure 10*, the induction period of POs decreased rapidly for the first two days of frying before remaining constant thereafter. This may be attributed to the significant level of tocotrienols in POs that accounts for almost 80% of the total tocols content. Tocotrienols with three double bonds at the side chain was more susceptible to deterioration compared to their tocopherols counterpart when exposed to excessive heat (Ahmad Tarmizi *et al.*, 2016).

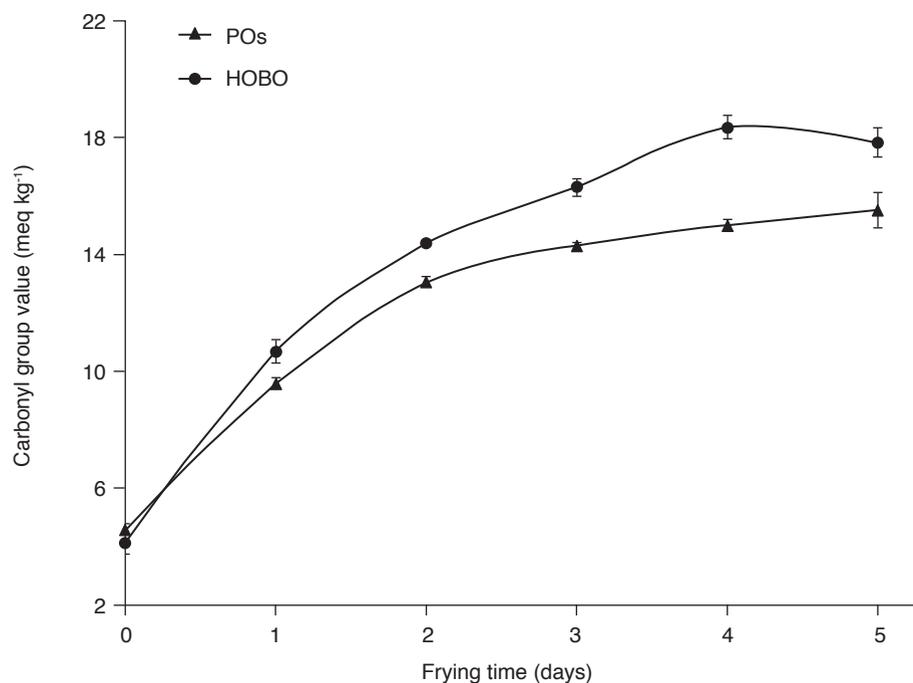


Figure 8. Changes in carbonyl group value (CGV) during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

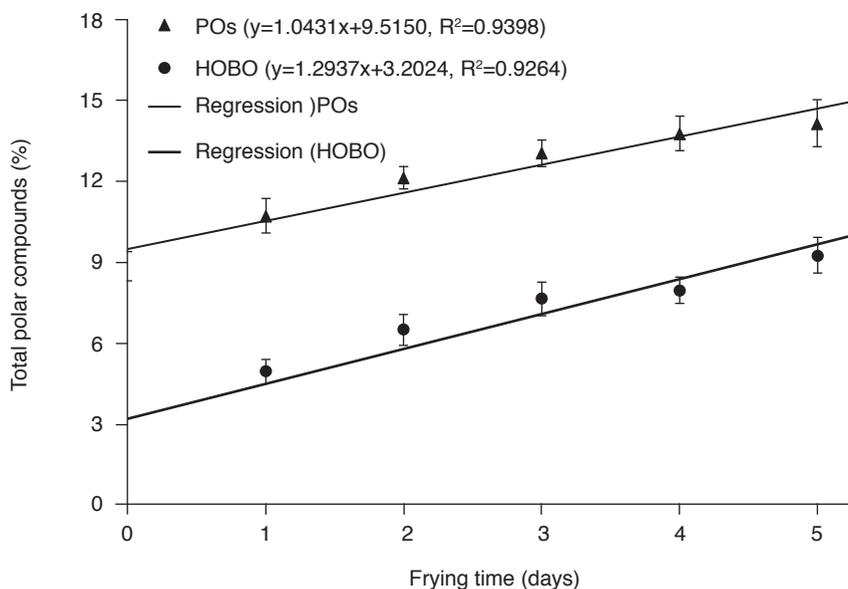


Figure 9. Changes in total polar compounds (TPC) during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

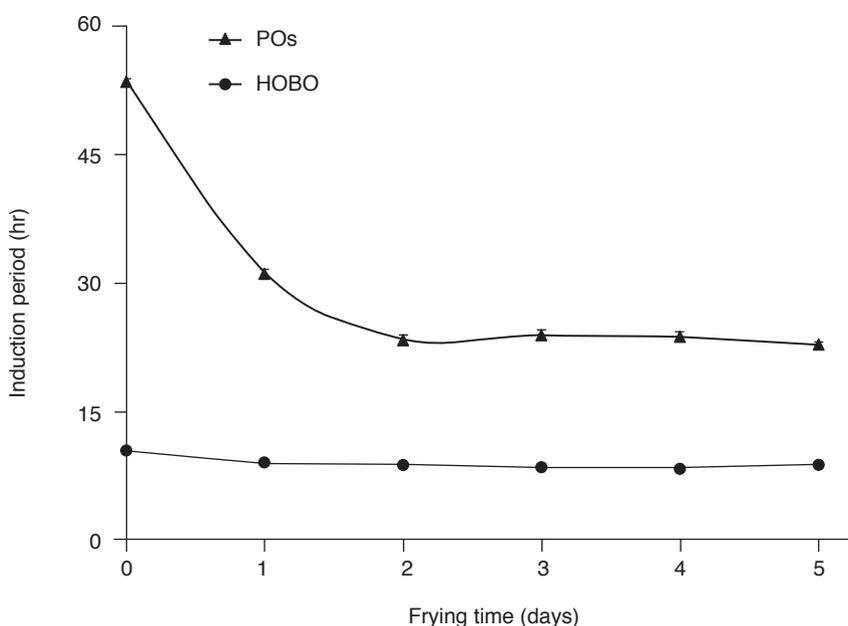


Figure 10. Changes in oxidative stability during five days of frying in palm stearin (POs) and high oleic blended oil (HOBO).

However, POs consistently displayed significantly higher induction period than HOBO, regardless of the frying time, indicating that POs exhibited better resistance against oxidation than HOBO. Moreover, after the fifth day of frying, the induction period of POs was still above 22 hr, which was more than three times as high as that of HOBO (averaging at 7 hr). OSI is strongly associated to FAC before frying but highly related to the synergistic properties of antioxidants during frying (Ahmad Tarmizi and Ismail, 2014). Lower induction period in HOBO was due to the high percentages of unsaturated fatty acids, especially PUFA.

Changes in Tocol Homologues

Tocols which comprise of tocopherols and tocotrienols, act as antioxidants. The tocols level and isomeric constituents have been reported to influence the stability of frying oils (Warner and Moser, 2009; Romero *et al.*, 2007). The changes in the amounts of tocopherols and tocotrienols during frying are shown in Table 2. The initial tocols content in POs was 618 mg kg⁻¹, almost the same as HOBO (624 mg kg⁻¹), and different isomeric constituents were observed in POs and HOBO. HOBO contained only three tocopherols, while POs contained more than

three-quarter of tocotrienols from the total tocopherols. Different forms of tocopherols exhibited different degrees of antioxidant effectiveness (Karmowski *et al.*, 2015). Previous study has reported that the order of antioxidant activity of different tocotrienol isomers *in vitro* was $\delta > \gamma > \beta > \alpha$ (Normand *et al.*, 2001). The tocotrienols are better antioxidants than the corresponding tocopherols, devoid of double bonds in the side chain, which is helpful to the stability of frying oil (Rossi *et al.*, 2007).

Tocopherols and tocotrienols exhibited different stabilities for the two oils during frying. The order of degradation rate of tocopherol homologues after five days of simulated deep fat frying was γ -tocotrienol (69.71%) > α -tocotrienol (46.50%) > δ -tocotrienol (38.20%) > α -tocopherol (19.14%) > β -tocotrienol (16.79%) for POs, and γ -tocopherol (44.27%) > α -tocopherol (25.02%) > δ -tocopherol (19.57%) for HOBO. Interestingly, it appeared that frying severely affect on γ -, α -, δ -tocotrienols and γ -tocopherols but lesser impact on α -, δ -tocopherols and β -tocotrienol, which is consistent with the study conducted by Ahmad Tarmizi *et al.* (2008) and Aladedunye and Przybylski (2014), where tocotrienols depleted faster than tocopherols when exposed to frying temperatures. It is plausible that tocotrienols are susceptible to thermal and oxidative degradations in the presence of three double bonds in the side chain (Ahmad Tarmizi *et al.*, 2016).

Correlation between Different Parameters

A Pearson correlation coefficients (PCC) analysis was carried out to investigate the relationships

between all quality parameters in deep-fried oils (Table 3). The results showed that PV, *p*-AV, TOTOX and CGV were positively correlated between one to another ($r = 0.859$ to 0.998). TPC presented positive correlation with colour, but correlated negatively with IV, tocopherols and C18:2/C16:0 ($r = -0.870$ to -0.932). These findings agree with the study conducted by Aladedunye and Przybylski (2009) that TPC correlated well with colour and tocopherol reduction with a correlation coefficient of 0.9302 and 0.9540, respectively for canola oil used in seven successive days' fryings of French fries. A strong negative linear correlation between 18:2/16:0 and TPC were also observed by Bansal *et al.* (2010) for palm olein in repeated deep frying of French fries and chicken nuggets. In addition, it is also noted that there was an apparent correlation between IV and C18:2/C16:0 ($r = 0.960$).

CONCLUSION

In the present study, the physical and chemical characteristics of POs and HOBO were determined under simulated frying practice of fast food restaurants to evaluate their thermal stabilities. In general, POs is more stable than HOBO with lower values in TOTOX, ratio of linoleic acid to palmitic acid and IV. POs also showed better oxidative stability indicated by its longer induction period and lower TPC formation rate. The increase in CGV was much higher in HOBO than in POs. Colour and AV increased relatively faster in POs over frying time. It is interesting to investigate the relationship

TABLE 2. CHANGES IN TOCOPHEROLS AND TOCOTRIENOLS OF TWO FRYING OILS DURING FRYING

Frying time	Content/(mg kg ⁻¹)								
	α -T	β -T	γ -T	δ -T	α -T3	β -T3	γ -T3	δ -T3	Tocols
POs									
Day 0	132 ± 4a	ND	ND	ND	144 ± 11a	49 ± 6a	242 ± 12a	51 ± 4a	618
1	123 ± 9ab	ND	ND	ND	116 ± 8b	47 ± 3ab	165 ± 11b	44 ± 6b	494
2	116 ± 3bc	ND	ND	ND	98 ± 4c	46 ± 5ab	119 ± 7c	38 ± 2bc	417
3	110 ± 12bc	ND	ND	ND	86 ± 8cd	44 ± 4ab	93 ± 9d	35 ± 4c	368
4	107 ± 8c	ND	ND	ND	81 ± 2d	42 ± 3ab	80 ± 4e	32 ± 3c	341
5	106 ± 6c	ND	ND	ND	77 ± 9d	41 ± 2b	74 ± 3e	31 ± 3c	330
Degradation rate (%)	19.14	-	-	-	46.50	16.79	69.71	38.20	46.67
HOBO									
Day 0	381 ± 9a	ND	225 ± 7a	19 ± 1a	ND	ND	ND	ND	624
1	346 ± 18b	ND	196 ± 15b	18 ± 2ab	ND	ND	ND	ND	560
2	325 ± 14c	ND	172 ± 8c	17 ± 2ab	ND	ND	ND	ND	514
3	307 ± 8cd	ND	151 ± 11d	16 ± 3ab	ND	ND	ND	ND	474
4	292 ± 12de	ND	135 ± 9de	16 ± 1ab	ND	ND	ND	ND	443
5	285 ± 5e	ND	125 ± 8e	15 ± 1b	ND	ND	ND	ND	426
Degradation rate (%)	25.02	-	44.27	19.57	-	-	-	-	31.78

Note: ND - not detected; T - tocopherol; T3 - tocotrienol. Different letters are significant in the same column at $p < 0.05$.

TABLE 3. CORRELATION COEFFICIENTS OF THE PHYSICO-CHEMICAL PARAMETERS MEASURED IN FRYING OIL SAMPLES

Parameters	AV	PV	p-AV	TOTOX	IV	CGV	TPC	OSI	Colour	Tocols	C18:2/C16:0
AV	1	-	-	-	-	-	-	-	-	-	-
PV	0.492	1	-	-	-	-	-	-	-	-	-
p-AV	0.515	0.877**	1	-	-	-	-	-	-	-	-
TOTOX	0.516	0.886**	0.998**	1	-	-	-	-	-	-	-
IV	-0.255	0.176	0.360	0.355	1	-	-	-	-	-	-
CGV	0.750**	0.859**	0.938**	0.939**	0.100	1	-	-	-	-	-
TPC	0.677*	0.274	0.144	0.149	-0.848*	0.426**	1	-	-	-	-
OSI	-0.185	-0.607*	-0.637*	-0.639*	-0.796**	-0.515	0.433	1	-	-	-
Colour	0.868**	0.306	0.241	0.244	-0.690*	0.541	0.941**	0.249	1	-	-
Tocols	-0.888**	-0.576*	-0.491	-0.496	0.500	-0.753**	-0.870**	-0.050*	-0.932**	1	-
C18:2/C16:0	-0.363	0.016	0.120	0.116	0.960**	-0.116	-0.914**	-0.733	-0.757	0.603	1

Note: *p < 0.05; **p < 0.01.

AV - acid value.

PV - peroxide value.

p - AV - p-anisidine value.

TOTOX - total oxidation.

IV - iodine value.

CGV - carbonyl group value.

TPC - total polar compounds.

OSI - oxidative stability index.

between different parameters in deep-fried oils. The PCC results showed that significant correlation between PV, p-AV, TOTOX and CGV, and between TPC and colour, IV, tocols and C18:2/C16:0. Results from this study indicated that POs exhibited better thermo-oxidative stability during frying compared to HOBO. The result of this study can be used by the food processes to make their judgement in choosing the suitable oil for frying.

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REFERENCES

Abdulkarim, S M; Long, K; Lai, O M; Muhammad, S K S and Ghazali, H M (2007). Frying quality and stability of high-oleic *Moringa oleifera* seed oil in comparison with other vegetable oils. *Food Chem.*, 105(4): 1382-1389.

Abuzaytoun, R and Shahidi, F (2006). Oxidative stability of algal oils as affected by their minor components. *J. Agric. Food Chem.*, 54: 8253-8260.

Ahmad Tarmizi, A H; Ahmad, K; Sahri, M M and Choo, Y M (2016). Rancimat test for measuring the oxidative stability of cooking oils upon prolonged frying: Short communication. *J. Oil Palm Res. Vol.* 28(4): 531-535.

Ahmad Tarmizi, A H and Ismail, R (2008). Comparison of the frying stability of standard palm olein and special quality palm olein. *J. Amer. Oil Chem. Soc.*, 85(3): 245-251.

Ahmad Tarmizi, A H and Ismail, R (2014). Use of pilot plant scale continuous fryer to simulate industrial production of potato chips: Thermal properties of palm olein blends under continuous frying conditions. *Food Sci. Nutr.*, 2(1): 28-38.

Ahmad Tarmizi, A H; Hishamuddin, E and Abd Razak, R A (2019). Impartial assessment of oil degradation through partitioning of polar compounds in vegetable oils under simulated frying practice of fast food restaurants. *Food Control*, 96: 445-455.

Ahmad Tarmizi, A H; Ismail, R and Kuntom, A (2016). Effect of frying on the palm oil quality attributes - A review. *J. Oil Palm Res. Vol.* 28(2): 143-153.

Aladedunye, F and Przybylski, R (2009). Degradation and nutritional quality changes of oil during frying. *J. Amer. Oil Chem. Soc.*, 86: 149-156.

Aladedunye, F and Przybylski, R (2014). Performance of palm olein and modified rapeseed, sunflower, and soybean oils in intermittent deep-frying. *Eur. J. Lipid Sci. Technol.*, 116(4): 144-152.

Aladedunye, F A (2015). Curbing thermo-oxidative degradation of frying oils: Current knowledge and challenge. *Eur. J. Lipid Sci. Tech.*, 117: 1867-1881.

Aniołowska, M A and Kita, A M (2016). The effect of raw materials on thermo-oxidative stability and glycidyl ester content of palm oil during frying. *J. Sci. Food Agric.*, 96: 2257-2264.

- Aniołowska, M and Kita, A (2015). The effect of type of oil and degree of degradation on glycidyl esters content during the frying of French fries. *J. Amer. Oil Chem. Soc.*, 92(11): 1621-1631.
- AOCS (2017). *Official Methods and Recommended Practices of the American Oil Chemists' Society*. Seventh edition, American Oil Chemists's Society, Champaign, IL, USA. p. 1-7.
- Bansal, G; Zhou, W B; Barlow, P J; Lo, H L and Neo, F L (2010). Performance of palm olein in repeated deep frying and controlled heating processes. *Food Chem.*, 121: 338-347.
- Del Re, P V and Jorge, N (2006). Behavior of vegetable oils for frying discontinuous frozen pre-fried products. *Science Technology Aliment*, 26: 56-63.
- Farhoosh, S and Moosavi, S M R (2008). Carbonyl value in monitoring of the quality of used frying oils. *Anal. Chim. Acta*, 617: 18-21.
- Gillingham, L G; Harris-Janzen, S and Jones, P J H (2011). Dietary monounsaturated fatty acids are protective against metabolic syndrome and cardiovascular disease risk factors. *Lipids*, 46(3): 209-228.
- Hosseini, H; Ghorbani, M; Meshginfar, N and Mahoonak, A S (2016). A review on frying: Procedure, fat, deterioration progress and health hazards. *J. Amer. Oil Chem. Soc.*, 93: 445-466.
- Hua, H; Zhao, X; Wu, S and Li, G (2016). Impact of refining on the levels of 4-hydroxy-trans-alkenals, parent and oxygenated polycyclic aromatic hydrocarbons in soybean and rapeseed oils. *Food Control*, 67: 82-89.
- ISO 27608 (2010). Animal and vegetable fats and oils - Determination of Lovibond colour. 8 pp.
- ISO 3961 (2018). Animal and vegetable fats and oils - Determination of iodine value. 12 pp.
- ISO 6885 (2016). Animal and vegetable fats and oils - Determination of anisidine value. 7 pp.
- ISO 6886 (2016). Animal and vegetable fats and oils - Determination of oxidation stability (accelerated oxidation test). 13 pp.
- ISO 9936 (2016). Animal and vegetable fats and oils - Determination of tocopherol and tocotrienol contents by high-performance liquid chromatography. 16 pp.
- Karmowski, J; Hintze, V; Kschonsek, J; Killenberg, M and Böhm, V (2015). Antioxidant activities of tocopherols/tocotrienols and lipophilic antioxidant capacity of wheat, vegetable oils, milk and milk cream by using photochemiluminescence. *Food Chem.*, 175: 593-600.
- Kushairi, A; Soh Kheang Loh; Azman, I; Elina Hishamuddin; Meilina Ong-abdullah; Zanal Bidin Mohd Noor Izuddin; Razmah, G; Shamala Sundram and Ghulam Kadir Ahmad Parveez (2018). Oil palm economic performance in Malaysia and R&D progress in 2017. *J. Oil Palm Res. Vol. 30(2)*: 163-195.
- Kushairi, A; Meilina Ong-abdullah; Balu Nambiappan; Elina Hishamuddin; Mohd Noor Izuddin Zanal Bidin; Razmah Ghazali; Vijaya Subramaniam; Shamala Sundram and Ghulam Kadir Ahmad Parveez (2019). Oil palm economic performance in Malaysia and R&D progress in 2018. *J. Oil Palm Res. Vol. 31(2)*: 165-194.
- Li, X D; Li, J W; Wang, Y; Cao, P R and Liu, Y F (2017). Effects of frying oils' fatty acids profile on the formation of polar lipids components and their retention in French fries over deep-frying process. *Food Chem.*, 237: 98-105.
- Li, X; Wu, G C; Yang, F; Meng, L L; Huang, J H; Zhang, H; Jin, Q Z and Wang, X G (2019). Influence of fried food and oil type on the distribution of polar compounds in discarded oil during restaurant deep frying. *Food Chem.*, 272: 12-17.
- Matthäus, B (2006). Utilization of high-oleic rapeseed oil for deep-fat frying of French-fries compared to other commonly used edible oils. *Eur. J. Lipid Sci. Technol.*, 108: 200-211.
- Nayak, P K; Dash, U; Rayaguru, K and Krishnan, K R (2016). Physico-chemical changes during repeated frying of cooked oil: A Review. *J. Food Biochem.*, 40(3): 371-390.
- Normand, L; Eskin, N A M and Przybylski, R (2001). Effect of tocopherols on the frying stability of regular and modified canola oils. *J. Oil Chem. Soc.*, 78(4): 369-373.
- Normand, L; Eskin, N A M and Przybylski, R (2006). Comparison of the frying stability of regular and high-oleic acid sunflower oils. *J. Amer. Oil Chem. Soc.*, 83(4): 331-334.
- Romero, N; Robert, P; Masson, L; Ortiz, J; González K; Tapia, K and Dobaganes, C (2007). Effect of α -tocopherol, α -tocotrienol and Rosa mosqueta shell extract on the performance of antioxidant-stripped canola oil (*Brassica* sp.) at high temperature. *Food Chem.*, 104: 383-389.

Rossi, M; Alamprese, C and Ratti, S (2007). Tocopherols and tocotrienols as free radical-scavengers in refined vegetable oils and their stability during deep-fat frying. *Food Chem.*, 102(3): 812-817.

Shahidi, F and Wanasundara, U N (2002). Methods for measuring oxidative rancidity in fats and oils. *Food Lipids: Chemistry, Nutrition and Biotechnology*. Marcel Dekker, Inc., New York, USA. p. 465-482.

Waghmare, A; Patil, S; LeBlanc, J G; Sonawane, S and Arya, S S (2018). Comparative assessment of algal oil with other vegetable oils for deep frying. *Algal Res.*, 31: 99-106.

Warner, K and Moser, J (2009). Frying stability of purified mid-oleic sunflower oil triacylglycerols with added pure tocopherols and tocopherol mixtures. *J. Amer. Oil Chem. Soc.*, 86: 1199-1207.

Yu, L; Li J; Ding, S; Hang, F and Fan, L (2016). Effect of guar gum with glycerol coating on the properties and oil absorption of fried potato chips. *Food Hydrocoll.*, 54: 211-219.

Zhang, H; Ma, J; Miao, Y; Tuchiya, T and Chen, J Y (2015). Analysis of carbonyl value of frying oil by Fourier transform infrared spectroscopy. *J. Oleo Sci.*, 64(4): 375-380.