Feasibility of Continuous Frying System to Improve the Quality Indices of Palm Olein for the Production of Extruded Product

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Abstract: Comparative frying studies on the processing of extruded product were conducted under intermittent and continuous frying conditions using two separate frying systems i.e batch and pilot scale continuous fryers, respectively. Thermal resistance of palm olein were assessed for a total of 5 days of frying operation at 155°C – the unconventional frying temperature gave the product moisture content of 3% after intermittent and continuous frying for 2.5 min and 2 min, respectively. The formation of free fatty acid in palm olein in the case of intermittent frying was more than 2-fold higher compared to its counterpart (0.66%). Smoke point inversely evolved with oil acidity: the value dropped progressively from 215 to 177°C and from 219 to 188°C when extruded product was intermittently and continuously fried, respectively. In the light of induction period, repeated frying exhibited a gradual decrease in the value after 5 days of frying (12.2 h). Interestingly, continuous frying gave somewhat similar induction period, as demonstrated by fresh palm olein, across frying time. Frying at lower temperature, to some extent, provides opportunity for palm olein to retain 74% of its initial vitamin E during continuous frying. This benefit, however, is somehow denied when extruded product was processed under intermittent frying conditions – only 27% of vitamin E was remained at the end of frying session. Regardless of frying protocols, transient in polar compounds was minimal and hence comparable. The colour in the case of continuous frying appeared to be darker due to higher degree of oil utilisation for frying. The data obtained will provide useful information for food processors on how palm olein behaves when frying is undertaken under different frying protocols.

Key words: comparative frying, extruded product, intermittent frying, continuous frying, thermal resistance

1 INTRODUCTION

Frying is one of the ancient methods in cooking food since it has been extensively practiced for more than 4000 years1. It essentially involves rapid heat and mass transfer when food is immersed in edible oil at temperatures above the boiling point of water in the presence of air and water emission. This cooking technique is likely to be the most preferable way to process food because of its versatility, convenience and economic viability that enable to produce fried products with unique sensory attributes2. Frying may have similar fundamental as in baking – a brownish crust layer is formed on the food surface that contributes to a distinctive fried flavour – but it generally cooks faster due to higher efficiency of heat transfer3.

In spite of all this, the benefits of frying process seem to be meaningless if the quality aspects of the oil are not considered. Exposure of oil to excessive heating in the presence of air and moisture stimulates complex pattern of thermolytic, oxidative and polymeric reactions4. Such deleterious reactions are becoming more complicated when oil degradation components interact with food during the frying process. It is anticipated that the compositions of the food (e.g. proteins, carbohydrates and lipids) determine the degree of oil breakdowns5. Destructive changes in oil not only affect the usability and fry life of the oil, but may also initiate health hazards in human body6.

Many studies were undertaken to investigate the strategies on how to protect and hence minimise frying oil deterioration. The strategies include alteration of fatty acids composition through blending, hydrogenation, plant breeding, and incorporation of additives and antioxidants. Nonetheless, the rate of oil degradation relies not only to oil properties alone but also the process conditions or protocols of which the oil being applied4, 7. Exposure of frying
oil with air is minimal when the oil surface area to volume ratio is relatively small\(^1\). Flushing the frying oil with inert gases like carbon dioxide and/or nitrogen helps to reduce the concentration of dissolved oxygen\(^2,3\). Frying at elevated pressure\(^1\) and under vacuum\(^2\) protects frying oil against deterioration. Ahmad Tarmizi et al.\(^1\) observed that the shelf life of frying oil can be improved when applying vacuum during the post-frying stage. It is also worth noting that the initial quality of oil also plays a significant role in oil stability during frying\(^4\).

The performance of vegetable oils during frying is extensively discussed in the literatures. Most of these studies, however, were carried out under intermittent (batch) frying, and many of which involved frying of potato products (e.g. potato chips and French fries) and coated products (e.g. fillets and nuggets). In fact, research works that simulate industrial (continuous) frying, are rather scanty, and only restricted to frying potato chips and/or pre-fried French fries\(^12\,18\). It is believed that higher operation cost and/or trade policy of food industry are the main reasons for scanty publications related to continuous frying\(^13\).

By considering all this, it is essential to investigate on how the oil behaves when frying is undertaken for other products. This study, therefore, was designed to compare the physical and chemical changes occurring in palm olein products. This study, therefore, was designed to compare how the oil behaves when frying is undertaken for other products. This study, therefore, was designed to compare the physical and chemical changes occurring in palm olein products. This study, therefore, was designed to compare how the oil behaves when frying is undertaken for other products. This study, therefore, was designed to compare the physical and chemical changes occurring in palm olein products. This study, therefore, was designed to compare how the oil behaves when frying is undertaken for other products. This study, therefore, was designed to compare the physical and chemical changes occurring in palm olein products.

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## 2 MATERIALS AND METHODS

### 2.1 Raw materials

Refined, bleached and deodorised (RBD) palm olein was provided by MOI Foods Sdn. Bhd. (Pulau Indah, Malaysia). Ingredients for dough formulation were purchased from local suppliers. Dough for the preparation of extruded product contained chickpea and tapioca flours, chicken and chilli powders, salt, icing sugar, palm olein and water.

### 2.2 Frying procedures and oil sampling

Interruption frying experiments were conducted using 23-L capacity stainless steel electrical open fryer (Frymaster Corporation, Shreveport, USA) with two split pots; each pot has the capacity of 11.5 L. Oil was poured into the fryers and conditioned at 155°C for 30 min prior to frying. For each pot, a batch of 100 g of dough was manually kneaded into noodle-like strands and fried for 2.5 min. Every 100 g of dough produced an average of 90 g of extruded product. The extruded product was processed for every 20 min cycles across 8 h day\(^{-1}\) for 5 consecutive days. About 1 L of oil was sampled at the end of each day using two 500-mL dark amber bottles. The samples were flushed with nitrogen and stored at −20°C for subsequent physico-chemical analyses. The lid was placed on the fryer and left overnight. Necessary amount of fresh oil (1.2 L) was added into the fryer on the next day of frying operation to keep a constant level of 11.5 L.

Contrariwise, continuous frying was conducted for 8 h daily over 5 consecutive days using a 200-L capacity pilot plant continuous fryer (Heat and Control Inc., Brisbane, Australia). Oil was transferred from the fresh oil tank into the fryer and heated gradually until the oil temperature reached 155°C. The dough strands were allowed to fry for 2 min. By taking the oil turnover time of 10 h as a benchmark, 80 kg of dough was automatically kneaded on hourly basis to yield 60 kg of extruded product. Fresh oil was continuously compensated at the rate of 18 kg h\(^{-1}\) throughout the process. About 1 L of oil was collected at predetermined time intervals, and treated in identical manners upon storage. At the end of each frying day, the oil inside the fryer was pumped into the used oil tank and stored overnight before use on the next day of operation. Summary of the process conditions underpinning intermittent and continuous frying is tabulated in **Table 1**.

It is important to note that the establishment of dough formulation and process conditions for the above frying protocols were initially carried out prior to execution of this study. Despite the frying temperature used was considerably low (155°C) as compared to the typical frying temperatures, the time needed for the product to achieve 3% moisture content (which is generally the final moisture content of commercial extruded products) was shorter (2.5 min for intermittent frying and 2 min for continuous frying).

### 2.3 Analytical methods for fresh and heated oils

Identification of fatty acid composition was performed with reference to the AOCS Official Methods Ce 2-66 and Ce 1a-13\(^{30}\) whereas lipid component was determined using a method described in AOCS Official Methods Ce 5c-89 and Ce 5c-93\(^{31}\). Free fatty acid (FFA), smoke point, peroxide value (PV) and p-anisidine value (AnV) were analysed by the AOCS Official Methods Ce 9a-48, Cd 8b-90 and Cd 18-90, respectively\(^{32}\). Total oxidation or Totox correlates with PV and AnV according to the following equation: \(\text{Totox} = 2\text{PV} + \text{AnV}\). Tocols content, induction time (measured at 110°C) and colour were evaluated using AOCS Official Methods Ce 8-89, Cd 12b-92 and Cc 5a-40 respectively\(^{33}\).
Quantification of polar compounds (TPC) was determined gravimetrically using silica column chromatography following IUPAC 2.50720.

### 2.4 Statistical analysis

Intermittent frying and continuous frying sessions were conducted in triplicate and duplicate, respectively (reproducibility) while the physico-chemical measurements of each oil sample were done in triplicate (repeatability). One-way analysis of variance (ANOVA) was carried out using Minitab Version 14 (Minitab Inc., State College, USA) at confident level of 95%. Results in tables and figures are presented as means ± standard deviation, calculated across frying period.

### 3 RESULTS AND DISCUSSION

#### 3.1 Initial fatty acid and lipid compositions

Fatty acid and lipid compositions are among the few indicators used to establish the authenticity of edible oils. Table 2 showed that palm olein contained equal levels of saturated and unsaturated fatty acids, and therefore imparts to the stability of the oil. Palm olein also exhibited trace amount of linolenic acid (C18:3), which is well below the maximum allowance of 2% linolenic acid for use in the industrial frying3. Higher level of linolenic acid not only releases unpleasant smell throughout the frying operation but also gives bitter taste to the fried product13.

In general, palm olein contains about 93% of triacylglycerols (TAG) (Table 3). The most abundant TAG are POP (29.1%) and POO (25.2%) with comparable amounts of...
PLO (10.5%) and PLP (9.9%). The remaining TAG are found to be no greater than 5%. It is also interesting to note that equivalent concentrations between mono- and di-saturated TAG – which are 40.5% and 45.1%, respectively – were somewhat similar to that of saturated and monounsaturated fatty acids (Table 2), and thus reflects the stability of palm olein. Appreciable amount of diacylglycerols (DAG) in palm olein of nearly 7% contributes to inherently higher level of polar compounds when compared to conventional liquid oils such as soybean, canola and sunflower oils (2 to 3%)\(^\text{30}\).

### 3.2 Free fatty acid

Determination of oil acidity – which measures the formation of free fatty acid (FFA) – is one of the principle markers used by many food manufacturers to monitor the oil quality during frying. The FFA is generally developed when frying oil interacts with the leached water from food, and partly through alteration of oil triacylglycerols (TAG) as a result of oxidative reaction\(^\text{31}\).

Figure 1 illustrates the evolution of FFA in palm olein throughout the course of intermittent and continuous frying. As expected, a linear increase in FFA (from 0.12 to 0.66%) was observed when extruded product was repeatedly fried for 5 days. The FFA of oil samples collected during continuous frying, however, evolved exponentially with the function of frying time: the oil acidity increased gradually for the first two days before achieving an equilibrium state between 0.24 and 0.29%. It is also evidenced from Fig. 1 that the level of FFA was significantly lowered by more than two folds when frying is performed under continuous frying conditions. Similar trend is also obtained by Ahmad Tarmizi and Ismail\(^\text{13, 14}\) when produced potato chips under similar frying conditions. In this respect, it is plausible that the oil inside the fryer – which is taken up by the extruded product and/or loss during frying – is continuously compensated with the fresh oil of lower acidity and hence gives the consistency in FFA formation\(^\text{19}\).

Regardless of the frying protocols performed, the level of FFA in all oil samples was significantly below the maximum allowance defined by some countries: Czech Republic, Russia and Ukraine (1%); Austria, Turkey and Finland (1.25%); Poland (1.5%); Germany 2%; The Netherlands (2.25%); Belgium, Argentina and Chile (2.5%); and Panama (3%)\(^\text{21}\). Assuming 1% of FFA is taken as the benchmark, it is conjectured that palm olein, in the case of intermittent frying, can be utilised for another 4 days before discarded. Contrariwise, continuous frying, in a way, allows ‘infinite’ use of palm olein throughout frying operation.

### 3.3 Smoke point

Smoke point is a form of heating test that determines the temperature where consistent wisp of smoke starts to emanate from the oil. Theoretically, disintegration of triacylglycerols to low-molecular-weight constituents – e.g. FFA, monoacylglycerols (MAG), DAG and other volatile matters – quantifies to the amount of smoke release from the heated oil\(^\text{20}\). The results demonstrated in Fig. 2 indicate a progressive drop of smoke point across 5 days of frying, and this appears to inversely correlate with the acidity of palm olein. The smoke points were similar in both frying protocols for the first two days of frying before start to deviate significantly from one to another for the remaining days. At the end of frying session, continuous frying gave the smoke point of 11°C higher than the otherwise (177°C). Nonetheless, all the smoke point values were greater than 20°C above the frying temperature (155°C) and exceeded the lower limit of smoke point (170°C) allowed by many countries\(^\text{10}\). Despite being one of the internationally recognised indicators to discard used oil, the implementation of smoke point to be one of the oil quality

Fig. 1 Development of free fatty acid in palm olein during intermittent and continuous frying of extruded product. Means within the same frying interval marked with asterisks (*) are significantly different \((p < 0.05)\).

Fig. 2 Transient of smoke point in palm olein during intermittent and continuous frying of extruded product. Means within the same frying interval marked with asterisks (*) are significantly different \((p < 0.05)\).
parameters is hardly reported in the literatures.

3.4 Total oxidation value

Peroxide value (PV) is an expression of primary oxidation that measures the formation of hydroperoxides in oils. Despite being a useful tool in monitoring the initial stage of oxidation, PV is considered as unstable measurement for oils when they are subjected to excessive heat because peroxides have a tendency to decompose at high temperatures while the new ones are being produced during the cooling period. As expected, there was no apparent trend in the peroxides formation throughout the course of intermittent and continuous frying; PV was no greater than 9 meq O₂ kg⁻¹ in both cases even after 5 days of frying (Table 4). Fission of hydroperoxides further disintegrates into constituents such as aldehydes and ketones; this secondary oxidation stage is denoted as p-anisidine value (AnV). Total oxidation (Totox) value correlates both primary and secondary oxidations to provide adequate information pertaining to the oxidative state of oil. When palm olein is exposed to frying temperatures, AnV seems more prominent than PV and thus governing the Totox value.

Table 4 clearly shows that rapid increase in Totox value was demonstrated after first and second days of continuous and intermittent frying, respectively before starting to increase moderately thereafter. This could be due to the formation of higher molecular weight compounds with carbonyl group. Inevitably, the highest Totox value was registered during intermittent frying of nearly 40% more than the otherwise. This can be elucidated from the basis of the procedure involved during intermittent frying where hot oil was allowed to remain idle and exposed to air (oxygen) between frying cycles – the oil was heated without loading for a total of 52.5 min for each hour of operation.

3.5 Vitamin E

Vitamin E, which consists of tocopherols and/or tocotrienols, is one of the abundant natural antioxidants existing in oils and fats. Unlike majority of vegetable oils that define vitamin E as tocopherols, palm olein is one of the few that contains both tocopherols and tocotrienols homologues. Indeed, more than one third of vitamin E content in palm olein is sourced from tocotrienols. In this study, palm olein used for frying extruded product primarily contained 570 mg kg⁻¹ of vitamin E for which tocotrienols constitute about three quarters of the total share (423 mg kg⁻¹).

The qualitative synergistic effects of vitamin E, including tocopherols and tocotrienols, are displayed in Fig. 3(a), (b) and (c), respectively. Depreciation of vitamin E in the case of intermittent frying was the most significant because 73% of its original content had disappeared after 5 days. Similar reduction trend was also observed in tocopherol and tocotrienol homologues: only 42 mg kg⁻¹ of tocopherols and 98 mg kg⁻¹ of tocotrienols were retained in the oil. Inversely for continuous frying, palm olein only experienced one stage reduction of vitamin E by 29% at the first day of frying, and achieved consistency within a narrow range of 394 to 423 mg kg⁻¹ afterwards. This can be explained from the basis of the oil losses inside the fryer was continuously conditioned with fresh oil throughout the frying process. It is worth to mention that at least 70% of the initial vitamin E content (78% tocopherols and 67% tocotrienols) was still persisted in the oil upon completion of continuous frying session. Ahmad Tarmizi and Ismail observed that potato chips produced under continuous frying conditions have retained almost half of the initial vitamin E content in palm olein after 5 days of frying. In all the frying protocols performed, it is also noted from Fig. 3 that reduction in vitamin E content was predominantly caused by decomposition of tocotrienols. The presence of

![Table 4](image-url) Changes of peroxide, p-anisidine and Totox values, colour, and induction period in palm olein during frying.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Frying protocol</th>
<th>Frying time (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Peroxide value (meq O₂ kg⁻¹)</td>
<td>Intermittent</td>
<td>1.3 ± 0.0aA</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>1.0 ± 0.1aB</td>
</tr>
<tr>
<td>p-anisidine value (unit)</td>
<td>Intermittent</td>
<td>1.5 ± 0.2aA</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>1.3 ± 0.1aA</td>
</tr>
<tr>
<td>Totox value (unit)</td>
<td>Intermittent</td>
<td>3.9 ± 0.3A</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>3.3 ± 0.2aB</td>
</tr>
<tr>
<td>Induction period (h)</td>
<td>Intermittent</td>
<td>26.5 ± 0.3aA</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>27.4 ± 1.7aA</td>
</tr>
<tr>
<td>Colour (R)</td>
<td>Intermittent</td>
<td>3.0 ± 0.0aA</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>3.0 ± 0.1aA</td>
</tr>
</tbody>
</table>

Means within a row for each parameter marked with different lowercase letters are significantly different (p < 0.05). Means within a column for each parameter marked with different uppercase letters are significantly different (p < 0.05).
three double bonds at the side chain of tocotrienols is prone to degradation in comparison to their tocopherols counterparts. 

3.6 Induction time

Induction time is among the alternative methods used to examine the extent of oil to resist oxidation at elevated temperatures. Unlike PV and AnV which provide static measures of oils stability, the determination of induction time is dynamic and thus gives an insight on the fate of oil during storage and heating. The results showed in Table 4 exhibit a clear distinct for oil samples collected throughout the two frying protocols. Induction time dropped sharply by 30% just after one day of intermittent frying, and followed by a slow decrease for the remaining days. Surprisingly, the induction time regardless to frying intervals seemed comparable with that of fresh palm olein when frying was undertaken under continuous frying conditions. It is plausible that the frying temperature applied in this study was considerably low (155°C) in contrast to the conventional frying temperatures. Producing potato chips at 180°C under continuous frying operation exhibited a decrease in the induction time during the first stage of frying before hovering within a constant value afterwards. In fact, Ahmad Tarmizi and Ismail even concluded that induction time has some relationship with the retention of vitamin E when palm olein is used for frying.

3.7 Polar compounds

Quantification of polar compounds is recognised as the most reliable and accurate route to assess thermo-oxidative degradation in frying oils. This can be elaborated from the spectrum of non-volatility of the polar compound fractions – i.e. polymerised and oxidised TAG, DAG and FFA – developed during excessive heat treatment. Oils containing high level of polar compounds are potentially toxic and can be easily absorbed by human body. As such, many countries have opted to establish regulatory limits for polar compounds varying from 25 and 30%.

The evolutions of polar compounds in palm olein across 5 days of intermittent and continuous frying are illustrated in Fig. 4. The level of polar compounds, in the case of the intermittent frying, increased linearly over frying time and the value was somewhat doubled at the end of frying session (12.3%). This trend, however, was only true for the first 2 days of continuous frying before the values plato
teaued between 9.2 and 9.3%, which are significantly lower than the results obtained from the otherwise. Irrespective of frying protocols, none of the oil samples superseded the threshold value. Continuous frying of potato chips gave similar trends in polar compounds formation; the value peaked after 24 h of frying and remained constant within 10 to 11.4% until the end of 56 h of frying operation \(^{13}\). It is also noted that fresh palm olein contained higher level of polar compounds because the oil is inherently enriched with DAG (Table 3). Since DAG is one of the components of polar compounds, it could be sometimes misleading for judging the quality of palm olein albeit the oil is not even being introduced to high temperatures.

3.8 Colour
Colour is a subjective and least preferred indicator for monitoring the quality of oils. Within all the frying protocols performed, oil colourisation was stimulated across frying times (Table 4). It came to surprise that the oil collected during intermittent frying was the least coloured compared to continuous frying considering good frying performance in the latter protocol especially when the frying temperature was considerably low (155°C). At the end of frying session, the rate of colour pigmentation in palm olein in the case of continuous frying was somewhat double than the otherwise. This occurrence can be explained from the basis of frying load during the operation: the ratio between the product and the amount of oil inside the fryer was relatively much higher for continuous frying (0.3 kg L\(^{-1}\)) as opposed to intermittent frying (0.02 kg L\(^{-1}\)). Of course, higher production rate is likely to lead for higher degree of scorched product being generated and diffused into the oil, which in turns accelerates oil darkening. Palm olein appeared to be darker (21.2 R) when potato chips were continuously fried for 56 h (Ahmad Tarmizi and Ismail, 2014). The incidence of colour reversion in palm olein can be explained from the perspective of its inherent antioxidants content; trace pigments, tocopherols and particularly tocotrienols are susceptible to the formation of red-brown quinone polymer which can further cause oil colourisation upon exposure at elevated temperatures\(^{20}\). Oral-Ulusoy \textit{et al.}\(^{20}\) relate colour reversion with the evolution of polarity in frying oil.

4 CONCLUSIONS
The present study shows that the performance of palm olein was more pronounced when extruded product is processed under continuous frying conditions. This frying protocol significantly reduced the free fatty acid content and vitamin E loss whereas the induction period seemed unchanged over frying time. Consistent replenishment of fresh palm olein containing lower free fatty acid content and significant amount of vitamin E (tocopherols and tocotrienols) enabled the oil to reach an equilibrium state soon after two days of continuous frying. Contrariwise, compensation of oil for intermittent frying only took place on the next day of operation. Of course, lowering the acidity would results in oil with higher smoke point. The level of polar compounds in both cases was more or less similar and none of them surpassed the legislative limit for used oil. In consideration of the results above, the snack food manufacturers – particularly from the small and medium industry – can opt to shift from the conventional batch fryer to continuous frying system for processing snack food.

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