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Effects of adulterated palm cooking oil on the quality of fried chicken nuggets

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Abstract:
Introduction. There is a rising concern over food safety caused by an increasing trend towards adulterating fresh cooking oil with used cooking oil in Malaysia. Recent decades have seen more cases of high-quality edible cooking oil adulteration with reused oil, driven by high market demand and profit margins. In this study, we aimed to analyze the properties of vegetable oils and their effect on the quality of fried chicken nuggets.
Study objects and methods. We determined free fatty acid contents and characterized the properties of fresh palm olein, used cooking oil, and adulterated oil. We also compared the sensory quality attributes of chicken nuggets fried in fresh and adulterated oils.
Results and discussion. The content of free fatty acids consistently increased with rising adulteration levels. The FTIR spectral analyses revealed significant differences between fresh, used, and adulterated oils at 3006, 2922, 2853, 2680, 1744, 1654, 987, 968, and 722 cm^{-1}. The oil samples with high adulterant concentrations demonstrated a linear increasing trend in K_{232} and K_{270} values, where higher absorbance values indicated severe deterioration in the oil quality. The sensory evaluation showed no significant effect ($P > 0.05$) of adulteration with used cooking oil on the quality of fried chicken nuggets.
Conclusion. Our findings filled in a gap in the previous studies which only focused on the effects of adulteration on the oil properties. The study also provides valuable information to regulatory authorities on the reliability of quality parameters and modern instruments in edible oil adulteration detection.

Keywords: Adulteration, fresh palm olein, used cooking oil, food safety, sensory evaluation, frying, chicken

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INTRODUCTION

Vegetable oils are a group of fats that are extracted from different parts of a plant, such as seeds, nuts, cereal grains, and fruits [1]. They play a significant role in our diet as the main source of dietary fat and nutrients, as well as a flavor enhancer. In Malaysia, palm oil has been widely employed in the frying process, particularly in deep frying, owing to its high stability [2, 3].

Deep-fried foods have become popular due to the ease and speed of thermal treatment, as well as unique flavor, taste, and texture induced during the frying process [4]. The quality of oil has become a major concern to the deep frying industry since it affects the sensory quality of fried food, such as fried chicken nuggets [5].

However, the authenticity of cooking oil has been a serious issue since old times [6, 7]. According to statistics, 26.5% of all food fraud incidents (n = 1648) in 1980–2012 were associated with cooking oils [8]. Vegetable oil adulteration can be defined as an addition of cheaper, inferior, harmful, or unnecessary substances to oil that could affect its nature and quality [9]. High profit often drives this kind of fraudulent practice. Lim *et al.* and Alagesh reported a rising concern over food

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safety in light of the increasing trend of fresh cooking oil adulteration in Malaysia [10, 11].

Used cooking oil (UCO), also known as waste cooking oil or yellow grease, is the oil that has already been used in food preparation processes [10]. In order to reduce expenses, most food business operators and caterers tend to reuse the oils repeatedly, toping them up with fresh oil to mask the effects of degraded oil. Moreover, by using a series of simple and low-cost processes, including preliminary filtration, boiling, and refining, they are able to recover the quality of waste cooking oil to a certain extent to make it resemble that of fresh oil [12]. Since the past decade, cooking oil adulteration with refined waste oil has been rampant in Asian countries, particularly in mainland China, followed by other countries [13–16]. The situation is worsened by the low purchase cost of UCO, its wide availability, and high profit gain over the price difference.

Various analytical techniques and parameters have been developed to determine cooking oil adulteration. The most common of them is a free fatty acid (FFA) test [3, 17]. However, this test only measures the overall levels of titratable acids, without identifying the profiles of FFAs. In recent years, many sophisticated analytical methods have been studied intensively, including the FTIR fingerprint spectroscopic method. They have proven fit to unravel the menace of adulteration in high quality fresh oil [10, 18–20]. According to Amereih *et al.* and Hashem *et al.*, the UV-Vis spectrophotometric method is also effective enough in adulteration detection and quantification [20, 21].

Therefore, we aimed to study the properties and quality of palm cooking oil adulterated with used cooking oil. Palm oil was chosen as the most common frying medium in Malaysia. In addition, we determined the effects of adulteration on the sensory quality of fried chicken nuggets, adding to former studies that mainly report its effects on the oil properties.

STUDY OBJECTS AND METHODS

Oil sample collection. Fresh palm olein (FPO) and frozen chicken nuggets were purchased from the local market in Pagoh Jaya, Johor, Malaysia. Pre-filtered used cooking oil (UCO) was collected from a local feedstock trading company.

Formulation and preparation of adulterated oil (AO). Sets of pure FPO and UCO samples were prepared without any adulteration. A set of AO samples was prepared by mixing FPO with 20, 40, 60, and 80% (v/v) of UCO. The mixtures were vortexed to ensure complete homogenization.

Determination of free fatty acid (FFA) content. The FFA content was determined using a conventional acid-base titration method developed by the Malaysian Palm Oil Research Institute, as previously reported by Abdul Wahab *et al.*, with slight modification [22, 23]. A 500 mL volumetric flask was filled with 50 mL of 1.0 M sodium hydroxide solution that was diluted with distilled water to the graduation mark. The solution was standardized by titrating with a standard KHP solution. Then, 2-propanol solution was heated to approximately 80°C and mixed with 1 mL of phenolphthalein indicator. The heated alcohol solution was then neutralized by adding the 0.1 M sodium hydroxide solution drop by drop until the first permanent light pink color was obtained. Subsequently, an oil sample was mixed with the neutralized alcohol solution and shaken vigorously to ensure an even mixture. Finally, the still hot mixture was titrated against the 0.1 M sodium hydroxide solution until another permanent light pink color was obtained. The amount of sodium hydroxide consumed during titration was recorded and used to determine the FFA content (Eq.(1)). The results were expressed in mean ± standard deviation in triplicate.

$$\text{FFA}\,\% = \frac{28.2\text{VM}}{\text{W}} \tag{1}$$

where V is the volume of NaOH, mL; M is the molarity of NaOH, M; W is the weight of the oil sample, g.

Measurement of ATR-FTIR spectra. The procedure followed the method described by Poiana *et al.* [19]. The ATR-FTIR spectra of each oil sample were scanned and recorded using a Spectrum Two FT-IR spectrometer (PerkinElmer, United States) equipped with an ATR accessory. A drop of each oil sample was placed on the crystal at room temperature (25°C). All the spectra were measured at the mid-infrared region ranging from 4000 to 650 cm^{-1} with a scanning time of 60 s and 4 cm^{-1} resolution. The ATR-FTIR spectra were obtained against the air background spectrum. After every scan, a new reference air background spectrum was performed. The ATR plate surface was gently wiped with a soft tissue soaked in acetone to remove any residues of the previous oil sample before placing a new one. The FTIR spectra of all the oil samples were recorded as an absorbance value in triplicate.

Measurement of UV-Vis absorption at 232 and 270 nm (K_{232} and K_{270}). The procedure was based on the method reported by Amereih *et al.* and Chong, with slight modification [21, 24]. The absorption spectra of all the oil samples were obtained at 200 to 800 nm using a U-3900H UV-Vis spectrophotometer (Hitachi High-Tech Corp., Japan). A quartz cuvette (1 cm path) was filled with 1% of an oil sample in isooctane solution. The absorption was measured against a blank of isooctane. The maximum absorption values obtained at 232 nm and 270 nm were subsequently used to determine the specific extinction coefficients, K_{232} and K_{270} respectively, as outlined in Eq. (2).

$$K_{\lambda} = \frac{A\lambda}{\text{cL}} \tag{2}$$

where K_{λ} is the specific extinction coefficient at wavelength λ; A_{λ} is the absorption measured at wavelength λ; c is the concentration of the oil sample in solvent, g/100 mL; L is the path length of the cuvette, cm.

Deep frying and sensory evaluation. The frozen chicken nuggets were weighed and made into batches of 300 g. FPO was added into an EF-102T electric dual tank deep fryer (Wibur, China) to reach its minimum capacity of about 4 kg of oil. The FPO was heated for about 20 min up to 175 ± 5°C. After pre-heating, the first batch of frozen chicken nuggets was deep-fried for 3 min until the nuggets turned golden brown. The subsequent frying cycles started at an interval of 20 min. At the end of a frying cycle, the nuggets fried in FPO were taken for sensory evaluation. Due to health concerns regarding reused oil, the use of AO in preparing fried chicken nuggets for sensory evaluation was limited to 60%. It simulated the AO that could be commonly found in the local night market. The new frying cycles began by replacing the FPO with AO containing 60% UCO (w/w). Similarly, the fried chicken nuggets prepared in 60% AO were then evaluated for sensory acceptance.

The fried chicken nuggets prepared in FPO and 60% AO were evaluated for sensory attributes such as color, flavor, juiciness inside, crispiness outside, taste, and overall acceptability. The 9-point hedonic scale was employed differently for each attribute, namely for flavor, taste, and overall quality: 1 = extremely dislike, 5 = neither like nor dislike, and 9 = extremely like; for crispiness outside: 1 = soft and 9 = crispy; for juiciness inside: 1 = dry and 9 = juicy; and for color: 1 = dark brown and 9 = golden yellow.

Statistical analysis. All the tests were conducted in triplicate. The volume of titrant and % FFA were recorded and expressed in mean ± standard deviation in triplicate. The functional groups and their vibration modes, as shown in the IR spectra, were matched to the respective characteristic bands in FPO, AO, and UCO. The absorbance intensities of the bands were evaluated by comparing the peak heights. Each spectrum and maximum absorbance at 232 nm and 270 nm were reported in mean ± standard deviation. An independent t-test was performed using Microsoft Excel to examine the differences between the oil samples ($P < 0.05$). ANOVA was used to analyze the sensory evaluation data to determine significant effects between the fried chicken nuggets prepared in different oils.

RESULTS AND DISCUSSION

Effect of adulteration with reused oil on FFA content. In all the oil samples under analysis, FFA contents increased with higher adulterant concentrations (Table 1). The FFA level was the lowest in FPO (0.90 ± 0.16) and the highest in UCO (3.25 ± 0.06). Banani *et al.* and Alias *et al.* reported that used or waste cooking oil had high FFA values, which subsequently led to high acidity and viscosity values [25, 26]. This finding was similar to those by Abdul Wahab *et al.* and Panadare and Rathod, who found higher FFA contents (2.33–6.42%) in waste cooking oil compared to fresh cooking oil [23, 27].

Table 1 FFA content in oil samples with different adulteration levels

Oil sample	Adulterant concentration, %	Free fatty acid, %
Fresh palm olein	0	0.90 ± 0.16
20% adulterated oil	20	1.34 ± 0.14
40% adulterated oil	40	1.69 ± 0.00
60% adulterated oil	60	2.12 ± 0.05
80% adulterated oil	80	2.58 ± 0.04
Used cooking oil	100	3.25 ± 0.06

The relatively higher FFA content in UCO, which was attributed to darker oil color, might be due to the exposure to prolonged heating and moisture from food, which induced the hydrolysis reaction of triglycerides [23]. Since the FFA content in UCO was less than 15%, it was classified as yellow grease. This finding was similar to the results reported by Abdul Wahab *et al.*, Panadare and Rathod, and Rosnelly *et al.* [23, 27, 28]. All the findings indicated the deteriorating quality of the UCO subjected to repeated heating cycles. As a result, it was no longer suitable for frying or human consumption due to increased oil acidity, which is potentially harmful to human health. This observation was in agreement with the results reported by Ahmad Tarmizi *et al.*, Maskan and Bagci, and Chong [3, 29, 30].

Used or waste frying oil is an end product of frying. It is subjected to harsh frying conditions and prolonged exposure to excessive heat and atmospheric air due to repetitive use. The chemical changes induced by frying, such as hydrolysis and oxidation, generate reactions in its by-products, such increasing FFA values, which gives rise to off flavors and odors. This justifies the high FFA content in the UCO in our study. We also found that increasing adulterant concentrations corresponded to high FFA values, which makes the adulterated oils unsafe for frying or human consumption.

Characterization of oil properties using FTIR spectra. We found no significant differences between the spectral features, despite slight changes in the absorbance of some bands and a few shifts in their exact position. Figure 1 shows the FTIR spectra of the FPO and UCO samples at ambient temperature. Both the FPO and UCO displayed some typical spectral features associated with oils. Both spectra were similar in terms of shape, position of the characteristic bands, and the presence of peaks. These similarities can be explained by the same origin of the oils and the presence of identical principle components in their composition, which are triglycerides [10, 31].

However, variation in the oil composition is an important factor that influences the exact position of the bands, as well as shifts in the spectra [19, 31–33]. The variation in both spectra could be due to the quality degradation caused by adulteration. Table 2 summarizes the significant aberrations observed in the FTIR

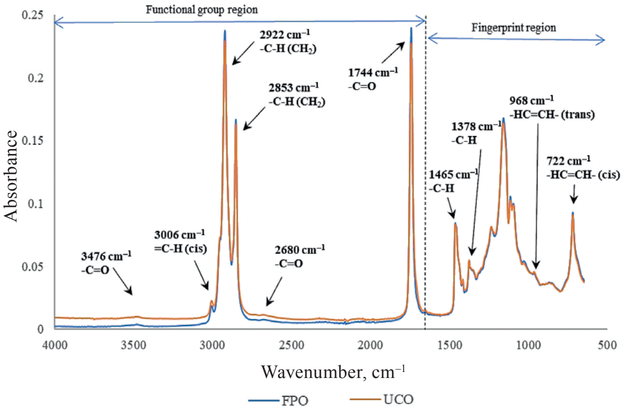


Figure 1 FTIR spectra for fresh palm olein (FPO) and used cooking oil (UCO) at 4000–650 cm^{-1}

spectra of all the oil samples in response to adulteration with UCO.

The FTIR spectrum is divided into two distinctive regions. They are functional group and fingerprint regions corresponding to 4000–1650 and < 1650 cm^{-1}, respectively. The entire spectra that we obtained for all the oil samples were seemingly identical because of their similar fatty acid compositions.

Nevertheless, we found that the UCO and AO samples with increasing adulteration levels demonstrated a slight aberration at 3006, 2922, 2853, 2680, 1744, 1654, 987, 968, and 722 cm^{-1} in terms of absorption bands and absorbance intensity. The adulteration of FPO with UCO resulted in a shift of the 3006 cm^{-1} band (Fig. 2a). This finding was in agreement with [19, 32, 34, 35] showing that the exact band position was determined by oil composition and unsaturation level. FPO recorded its highest absorbance at 3007 cm^{-1}, while AO reached its maximum at 3006 cm^{-1} due to reduced unsaturation. This suggested that exposure of frying oil to high heat had an effect on its unsaturation degree. Compared to FPO, the AO and UCO samples, which had been heated repeatedly, showed higher absorbance at 3006 cm^{-1}. This observation was consistent with a previous study by Alshuiael and Al-Ghouti, which proved that high heat application caused oil to become more unsaturated by losing hydrogen atoms [35].

We also observed strong and sharp absorption bands at 2922 and 2853 cm^{-1} due to the symmetric stretching vibration of aliphatic groups (-CH). The bands are attributed to the presence of aliphatic fatty acid chains. The high absorption peak of FPO at around 2922 cm^{-1} was determined by its unique fatty acid composition.

Apart from that, we identified a weak absorption band at around 2680 cm^{-1}, which could be attributed to carbonyl ester (-C=O) caused by Fermi resonance (Fig. 2b). The absorption band at 2680 cm^{-1} indicated the presence of aldehyde containing the O=C-H group. The increment of carbonyl aldehyde correlated with the adulteration incidence. As we can see in Fig. 2b, the concentration of aldehydes in the UCO samples and in most AO samples was far higher than that in FPO, except for 80% AO.

The concentration of volatile aldehydes is associated with a degree of oxidative degradation of oil, as aldehydes are major volatile compounds emitted upon heating as thermal degradation products [36, 37]. Volatile compounds such as aldehydes, ketones, alcohols, and acids are generated during oil degradation. They create unfavorable aroma and flavor, shorten the oil's shelf life, and may induce health problems [38]. We found that the UCO exposed to repeated frying gave high absorbance intensity at 2680 cm^{-1}, which might be attributed to an increment of volatile aldehydes due to lipid oxidation that consequently degrades the oil quality.

In relation to that, we observed a strong and sharp absorption band at 1744 cm^{-1} (Fig. 2c) due to the presence of the C=O group of triglycerides caused by stretching vibration. This was due to the decomposition of unstable primary hydroperoxides, which formed upon oxidation, into stable secondary oxidation products such as aldehydes and ketones, which cause an absorbance

Table 2 Significant aberrations in the FTIR spectra for oil samples in response to adulteration

Description of spectra feature	Significance
Slight shift of band near 3006 cm^{-1}	Reduced degree of unsaturation caused by diminution of *cis*- olefinic double bonds (=CH)
Strong band at 2922 and 2853 cm^{-1}	Presence of aliphatic methylene (-CH$_2$) group indicative of saturation level
Weak band at 2680 cm^{-1}	Presence of saturated aldehydes as a marker of advanced oxidation
Strong band at 1744 cm^{-1}	Appearance of carbonyl compounds and other secondary oxidation products
Increased absorbance of band at 1680–1630 cm^{-1} (or decreased absorbance of band at 1654 cm^{-1})	Presence of *trans*- and *cis*- isomers due to *cis*-*trans*- isomerization upon thermal stress
Maximum absorption at 987 and 968 cm^{-1}	Formation of *trans*- isomers (conjugated *trans* and non-conjugated *trans*- respectively) induced by conjugation and *cis*-*trans*- isomerization due to heat
Appearance of band at 968 cm^{-1}	Possible presence of secondary oxidation products (aldehydes, ketones) with isolated *trans*- double bond indicative of advanced oxidation
Progressive decrease in absorbance of band at 700–725 cm^{-1} (or at 722 cm^{-1})	Disappearance of *cis*- double bonds indicative of reduced unsaturation

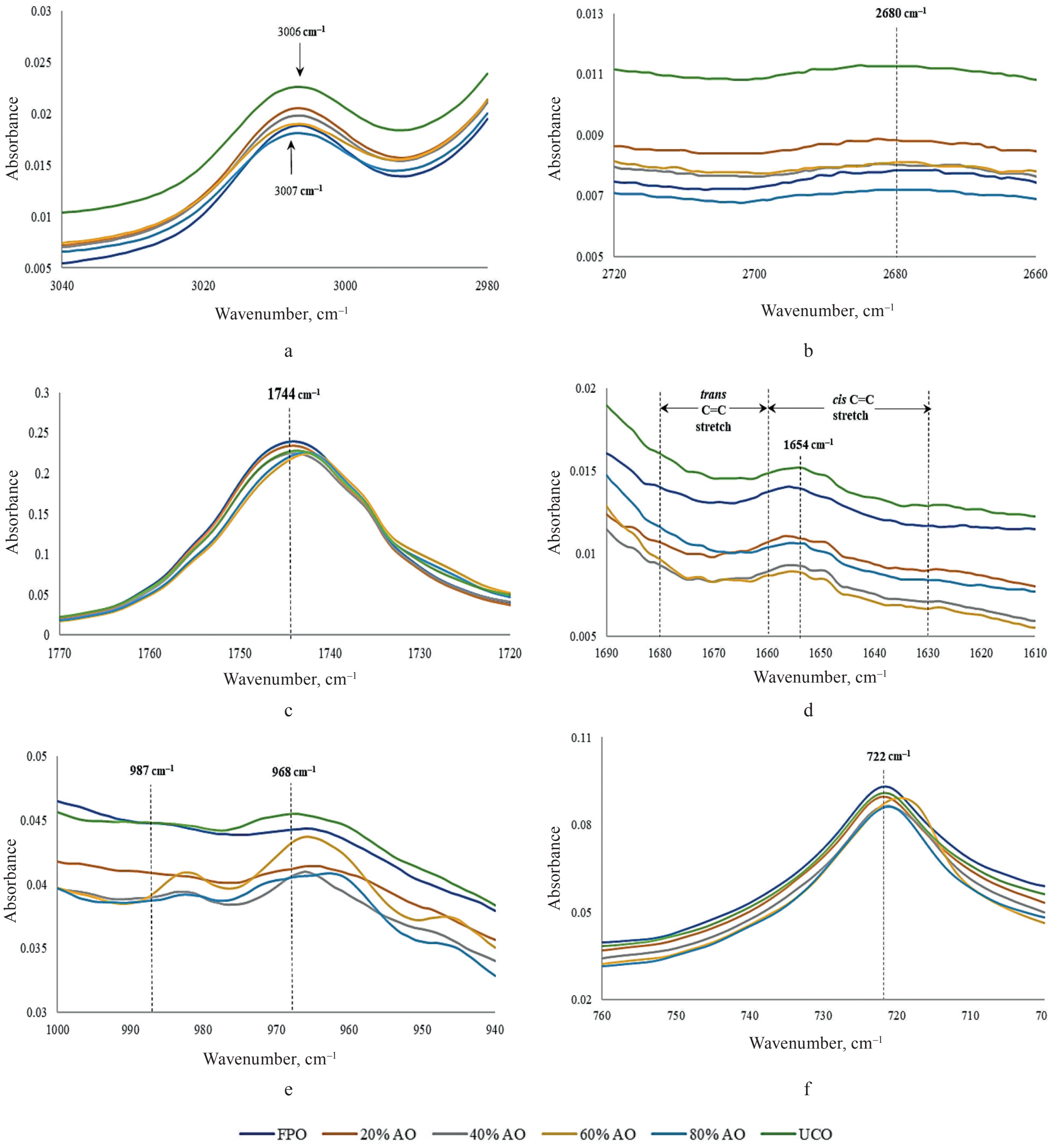


Figure 2 Significant aberrations in fresh palm olein (FPO), used cooking oil (UCO), and adulterated oil (AO) spectra at: (a) 3006, (b) 2680, (c) 1744, (d) 1680–1620, (e) 987–968, and (f) 722 cm^{-1}

near 1744 and 1728 cm^{-1}. High absorbance of FPO at this band could be explained by prolonged storage, which intensified the oxidative reaction [39].

The absorption band near 1680–1620 cm^{-1} could be assigned to the C=C stretch (Fig. 2d). The peak at 1654 cm^{-1} showed a general declining trend in absorbance with increasing adulteration levels, implying the disappearance of the *cis*- carbon-carbon double bond within the molecular structure. This could be due to the thermal and/or oxidative degradation of the oil samples.

The accumulation of *trans*- fatty acids in all the samples was further evident through an increasing trend in absorbance from the *cis*- C=C stretch band region (1660–1630 cm^{-1}) to the *trans*- C=C stretch band region (1680–1660 cm^{-1}). This might be explained by the occurrence of *cis-trans*- isomerization induced by thermal stress, changing the initial *cis*- geometric configuration into *trans*- and resulting in *trans*- fatty acids accumulation [19, 40, 41]. This finding was further reinforced by the absorption bands at 968 and 722 cm^{-1}, corresponding to bending vibration of -HC=CH- in *trans*- and *cis*- configuration, respectively (Fig. 2e and 2f).

The UCO generally demonstrated a higher absorbance intensity than the FPO at 968 cm^{-1}. This observation related to the increment of *trans*-composition caused by *cis-trans*- isomerization, resulting in deteriorated oil quality. Meanwhile, the band near 722 cm^{-1} was responsible for the *cis*- double bonds of disubstituted olefins. The UCO showed lower absorbance values compared to the FPO, which was probably due to the reduction of *cis*- C=C double bonds of unsaturated fatty acids. This observation was consistent with a previous study [19] that showed a progressive decline in absorbance at 722 cm^{-1} indicative of *cis-trans*- isomerization in unsaturated fatty acids, which subsequently resulted in double bonds vanishing from the *cis*- conformation.

In addition, we found a very weak absorption band at 987 cm^{-1}, which indicated the presence of *trans*-, *trans*- and/or *cis*-, *trans*-conjugated diene groups of hydroperoxides. Oil oxidation causes *cis*- double bonds to disappear, also leading to the isomerization of *cis*- fatty acids to *trans*- isomers and hydroperoxide (primary oxidation products) generation [42]. Unstable hydroperoxides decompose into aldehydes, ketones, and other secondary oxidation products, which are more stable. These volatile compounds are responsible for the off-odor of the oxidized oils.

According to Guillen and Cabo, the absorption band at 967 cm^{-1} indicates the possible presence of secondary oxidation products such as aldehydes and ketones, which contain isolated *trans*- double bonds [43]. As can be seen in Fig. 2e, the UCO showed a relatively higher absorbance at 987 and 967 cm^{-1} compared to the FPO. This was due to the generation of *trans*- isomers that contributed to conjugated *trans*- isomers caused by the exposure of UCO to harsh frying that advanced oxidation.

This observation was in agreement with the studies by Lim *et al.* and Poiana *et al.* [10, 19]. Nevertheless, we also used the UV-Vis spectroscopy as an exceptional alternative to the FTIR spectroscopy in detecting the presence of primary (232 nm) and secondary (270 nm) oxidation products, which will be discussed later.

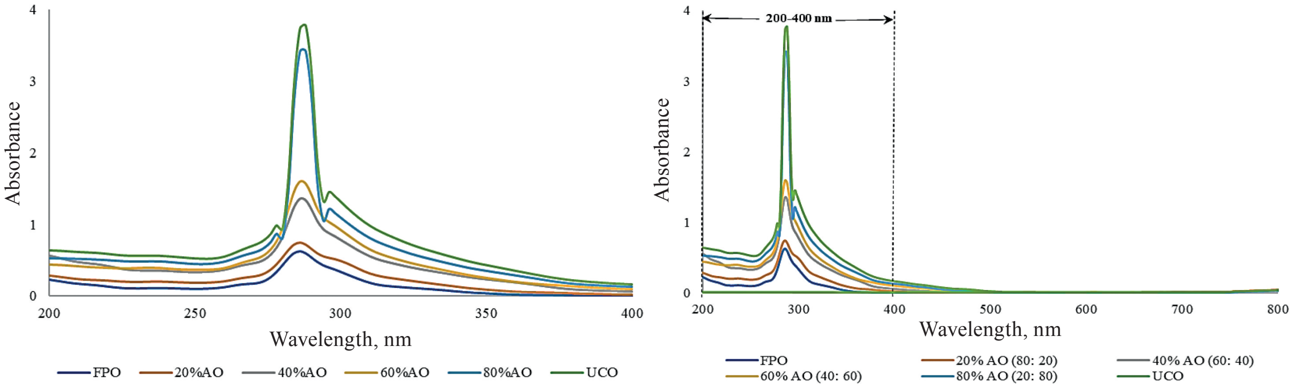
Detection and quantification of FPO adulteration using UV-Vis spectrophotometry. The UV-Vis spectrophotometry is a simple analytical method to detect and quantify oil adulteration incidence. This method evaluates the authenticity of oils by measuring absorption bands between 200 and 400 nm [21]. The UV-Vis spectra from 200 to 400 nm are considered to be directly related to oil quality [20, 21].

Figure 3a illustrates a significant peak that we observed within this range, from 200 to 400 nm. This finding was consistent with the previous studies [20, 21], which detected oil adulteration incidence by observing the molecular absorption of UV-Vis spectra within the designated range.

Figure 3b shows an enlarged view of the UV-Vis spectra. We found that the maximum absorption at 232 and 270 nm was related to the presence of conjugated dienes and trienes, which served as the best indicator of oil quality. This is because conjugated dienes and trienes are substances that form at an advanced oxidation stage, indicative of degraded oil quality.

Oxidation products absorption at 232 and 270 nm (K_{232} and K_{270}). As mentioned above, the maximum absorption at 232 and 270 nm correlate with the presence of oxidation products that are exceptionally powerful in determining the adulteration incidence in oil. These absorptions are typically expressed as specific extinctions at 232 and 270 nm denoted by K_{232} and K_{270}, respectively [20].

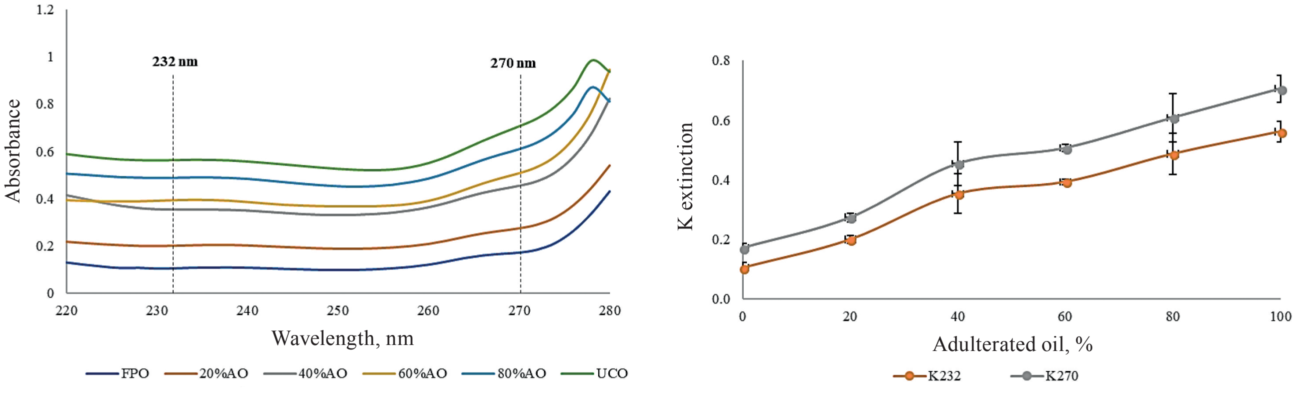
Traditionally, the peroxide value and the anisidine value are often used together to measure the oxidative status of edible oils. They reflect the concentration of primary (hydroperoxides) and secondary (aldehyde



a

b

Figure 3 (a) UV-Vis spectra of fresh palm olein (FPO), adulterated oil (AO), and used cooking oil (UCO) at 200–800 nm; (b) enlarged view of UV-Vis spectra of oil samples at 200–400 nm



a

b

Figure 4 (a) Maximum absorption of fresh palm olein (FPO), used cooking oil (UCO), and adulterated oil (AO) with increasing adulterant concentrations at 232 and 270 nm, (b) Direct relationship between adulterant concentrations and UV absorbances at 232 and 270 nm

and ketones) oxidation products, respectively [44, 45]. Repeated frying accelerates the accumulation of oxidative products, thus contributing to higher peroxide and anisidine values indicative of deteriorated oil quality [46].

Xu *et al.* reported that palm olein exhibited a significant increment in the peroxide and anisidine values with increasing frying cycles [47]. Therefore, in counterfeit oil, their significant increase could be considered a result of quality degradation. Nevertheless, these chemical analyses are lengthy, expensive, and involve hazardous chemicals [48]. Thus, we preferred to use spectrophotometry to determine oxidative products in the oil samples.

Figure 4a shows maximum absorption of all the oil samples at 232 and 270 nm, while Fig. 4b shows an increasing trend of K_{232} and K_{270} values with adulterant concentrations. We found the absorbances at 270 nm to be significantly higher than those at 232 nm.

We found a linear relationship between adulterant concentrations and absorbances at 232 and 270 nm. The AO samples showed higher absorbances with increasing adulterant concentrations, while the FPO and the UCO samples had the lowest and highest values, respectively.

We also observed a tendency for all the samples to show much higher absorption at 270 nm, compared to 232 nm. This was due to the formation of relatively unstable hydroperoxides (primary oxidation products), which directly correlated with absorbance at 232 nm and could decrease in number over time [10]. They tended to decompose into more stable, complex forms of secondary oxidation products including aldehydes, ketones, and alcohols, which corresponded to the absorption at 270 nm.

This observation was in agreement with that reported by Lim *et al.*, Maskan and Bagci, and Jolayemi *et al.* [10, 29, 49]. This experimental finding also supported the application of specific absorbances in the ultraviolet region at 232 and 270 nm to detect adulteration. They can serve as an oil quality indicator through the measurement of primary and secondary oxidation indicative of oxidative deterioration [50]. This finding was consistent with that reported by Amereih *et al.*, where high absorbance at these particular wavelengths indicated oil adulteration [21]. Thus, high quality oil shows low absorbances at 232 and 270 nm and vice versa.

Effect of adulterated oil on the quality of fried chicken nuggets. In this study, chicken nuggets were fried in two sets of oil samples, FPO and 60% AO. Motivated by health concern, we only used 60% AO to simulate the adulterated palm cooking oil that was commonly found in the night market. Figure 5 compares the average scores of sensory attributes for the chicken nuggets fried in FPO (code 831) and 60% AO (code 524).

We observed no significant difference ($P > 0.05$) between the chicken nuggets fried in FPO and those fried in 60% AO in terms of sensory attributes including flavor, color, juiciness, taste, and overall acceptability. However, there was a significant difference ($P < 0.05$) in crispness. These observations concluded that adulterated oil with 60% UCO did not have a significant effect ($P > 0.05$) on the sensory perception of chicken nuggets

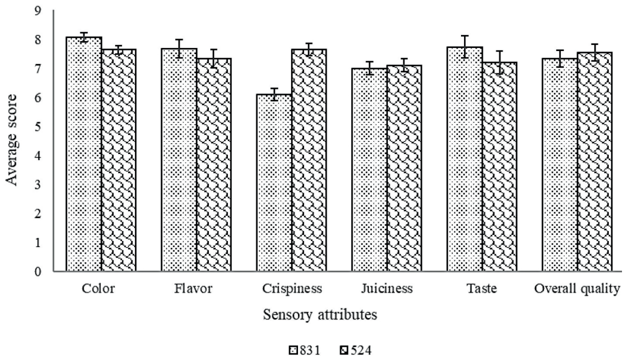


Figure 5 Comparison of sensory attributes for chicken nuggets fried in different sets of oil samples

fried in it, compared to FPO. Our findings were similar to those by Enriquez-Fernandez *et al.*, who reported an insignificant difference ($P > 0.05$) between the foods fried in used oil and fresh oil in terms of sensory evaluation [51].

Color differences were insignificant ($P > 0.05$) between the nuggets fried in FPO and those fried in 60% AO, both having a golden brown color. However, we observed that the 60% AO-fried nuggets were cooked faster and therefore turned golden brown in a shorter time than those fried in FPO. 60% AO was much darker and intense in color compared to FPO. Thus, our study showed a negligible effect of frying oil on the color of chicken nuggets. This finding was in line with the results by Ahmad, but opposite to those reported by Li, who emphasized that the color of frying oil influenced the color of fried foods [52, 53].

Although taste differences were insignificant ($P > 0.05$) between the chicken nuggets fried in FPO and those fried in 60% AO, we observed an appreciable gap in the scores. Some panelists mentioned an unpleasant rancid taste of the samples coded 524, which were fried in 60% AO. This rancid taste became more obvious and intense over time. This observation was further enhanced by Okparanta *et al.*, who reported that rancid oil led to abnormal rancid taste in fried foods [54].

However, there was a significant difference ($P < 0.05$) in crispiness, a desirable textural quality of fried foods. The chicken nuggets fried in 60% AO tended to be perceived with increased crispiness, compared to those fried in FPO. This observation might be due to a considerable time gap between the frying process of the samples and their sensory evaluation. The prolonged exposure to atmospheric air could have a noticeable influence on the sensory crispiness of both the FPO- and 60% AO-fried nuggets.

This finding was consistent with those by Antonova and Sung [55, 56]. In particular, Antonova reported a correlation between increased holding time under ambient conditions and decreased crispiness perceived by the panelists [55]. Holding time, which is defined as the minimum and maximum time after frying that a product can be used for sensory evaluation, should be determined for fried chicken nuggets to minimize variation in the test results. The previous studies suggested that breaded fried chicken nuggets should be served for sensory evaluation within 10 min after frying, under ambient conditions, to avoid variation in the test results [55]. Any longer than the suggested holding time can have an impact on the panelists' sensory perception.

However, it is worth noting that the chicken nuggets fried in adulterated oil with 60% used oil (7.53 ± 1.28) were found to be preferred in terms of overall quality, compared to those fried in fresh palm olein (7.33 ± 1.15). This finding can be supported by Bluementhal and Bordin *et al.*, suggesting that the optimum quality of fried food can be achieved with moderately altered and reused frying oil, instead of fresh oil [57, 58]. This is because of the role of surfactant compounds in the frying process. These compounds accumulate in increasingly abused oils and facilitate the contact between foods and oil, thus contributing to better characteristics of fried food products.

CONCLUSION

In conclusion, our study showed the effects of adulteration with used cooking oil on both the oil properties and the quality of fried chicken nuggets. We observed higher FFA contents in the oils as adulterant concentrations increased. Pure UCO recorded the highest FFA value and reached the discard point set by legislation.

The chemical characterization of oil properties by using the FTIR spectral analyses determined some differences between FPO, UCO, and AO in terms of the exact position of band appearance and absorbance intensities. Significant aberrations in the FTIR spectra were observed at 3006, 2922, 2853, 2680, 1744, 1654, 987, 968, and 722 cm^{-1}.

The UV-Vis spectral analysis used absorbances at 232 and 270 nm (K_{232} and K_{270}, respectively) as an indicator of oil adulteration. We found a linear increasing relationship between the adulterant concentrations and the K extinction values, which enabled the detection and quantification of adulteration with UCO.

The sensory evaluation of the chicken nuggets fried in FPO and AO showed no significant effects of adulteration with UCO on their quality.

CONTRIBUTION

The authors were equally involved in writing the manuscript and are equally responsible for plagiarism.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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