Regeneration of Used Frying Palm Oil with Coffee Silverskin (CS), CS Ash (CSA) and Nanoparticles of CS (NCS)

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Abstract: The present investigation aimed to evaluate the efficiency of coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS) in regeneration the quality of used frying palm oil. The adsorbents were mixed individually with used frying palm oil at level 4% (w/v) for 60 min. The properties of CS, CSA and NCS adsorbents were studied using (SEM) scanning electron microscopy technique. Some of physicochemical characteristics of used frying palm oil (UFPO) and UFPO treated with adsorbents were determined. The results showed that the CS ash particles composed of irregular spherical and semispherical grains with deep cavities. The size of particles of CS ash ranged in diameter from 1.1 to 1.7 µm. The morphology of NCS consisted of cluster-type spherical nanoparticles and flakes. The particle size of NCS varies from 0.9 to 1.7 µm. Purification treatments caused marked ($p<0.05$) increases in the quality parameters of treated oil compared to untreated oil. The treatment of UFPO with 4% of adsorbents caused significant reductions in the content of free fatty acids ranged from 51.2 to 65.0%. The lowest level of peroxide (2.1 meq/kg) was recorded for UFPO treated with 4% of NCS. The highest reductions (72.8; 70.0%) in $p$-anisidine value were observed in UFPO treated with 4% of CSA and NCS, respectively. Treatment of UFPO with 4% of CS, CSA and NCS significantly lowered the polar content from 13.9% to 6.3, 4.8 and 3.9%, respectively. The results also indicate that CSA and NCS have nearly the same adsorption efficiency in lowering polymer content of UFPO. Filtration treatment of UFPO with 4% of CS, CSA and NCS markedly lowered the viscosity and colour values of treated UFPO.

Key words: coffee silverskin, nanoparticles, deterioration, used frying oil, palm oil

1 Introduction

Management of resources is one of the major concepts and policies which play a vital role of the lifestyles. Nowadays, one of the major global concerns is how to guarantee food security for a world growing population whilst ensuring long-term sustainable development. According to the FAO statistics, food production will have to grow by 70 percent to satisfy the needs of world population which will reach 9.2 billion in 2050\(^1\). Oils and fats play a crucial role as a source of nutrients for each of humans and animals. The use of oils and fats for producing biodiesel fuel poses a threat to food security, which also led to a increase in prices on the market, making it unaffordable for poor and low-income people. Oils and fats are also used to produce cosmetics, polymers, pharmaceuticals, and oleochemical intermediates\(^2\). Deep-fat frying is a process in which foods submerged in the hot oil with a contact between oil, air and food at a high temperature from 150 to 190°C\(^3\).

During frying process, through the effects of temperature, air, and moisture promote a multitude of physicochemical changes, such moisture loss, oil uptake, colour change, flavour improvement, gelatinization of starch and oxidation of oil\(^4,5\). Oxidation, polymerization and hydrolysis, which in turn lead to generation of a considerable number of chemical compounds that negatively affect human health\(^6,7\). Therefore, regeneration of used frying
2 Materials and Methods

2.1 Materials

Coffee silver skin sample was obtained from Brazilian coffee exhibition, El Koom El Akhdar, Faisal, Giza, Egypt. Used frying palm oil was obtained from one of potato French fries manufacturing plant, Sadat city, Menoufia Governorate, Egypt. The physicochemical properties of used frying palm oil are tabulated in Table 1. Ferric chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) and ferrous chloride tetrahydrate ($\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$) were obtained from Sigma-Aldrich (St Louis, MO, USA).

2.2 Preparation of coffee silverskin ash (CSA)

Coffee silverskin (CS) was washed with tap water for removing the dust particles, then dried in an air oven at 100°C for 48 h. The dried CS was sintered at 800°C for 2 h. The obtained ash was cooled in desiccator to room temperature and stored for further analysis.

2.3 Preparation of nanoparticles of coffee silverskin

Nanoparticles of coffee silverskin were produced according to the previously reported procedures by Khandanlou et al. Coffee silverskin (CS) was separated by centrifugation at 10,000 rpm for 20 min. The obtained CS was washed twice with ethanol and deionized water and dried in oven at 60°C. All the experiments were conducted at ambient temperature.

2.4 Microstructure Analysis Test

Scanning electron microscopy (SEM) was performed using a SEM JSM-6460 LA JEOL, Japan to analyze the microstructure of the coffee silverskin (CS), CS ash and nanoparticles of CS (NCS).

2.5 Purification process of used frying palm oil (UFPO)

The adsorbents (coffee silverskin (CS), CS ash and nanoparticles of CS) were mixed individually with 1500 mL of used frying palm oil (UFPO) at level 4% (w/v). The optimum level of adsorbent was determined after three of initial standardization trials (Unpublished data). The mixture was stirred at 105°C with a magnetic stirrer for one hour as a contact time. Treated oil samples (1000 mL) was reheated at 80°C and hot water (85°C) was added (1:1, v/v). The mixture was mixed by glass rod for 15 min, then left at room temperature for cooling. The upper oil phase was separated by centrifugation at 10,000 rpm for 20 min. The centrifuged oil was vacuum filtered through a cotton filter cloth. The untreated used frying palm oil (UFPO) was vacuum filtered through a cotton filter cloth as a control sample.

2.6 Analytical methods

2.6.1 Moisture content

The moisture content was determined as described in AOAC method (950.46). The AV was determined according the previous techniques described in AOAC method (969.17). Acid value is expressed as mg KOH per g of oil.

Table 1  Physicochemical properties of used frying palm oil.

| Properties             | Used frying palm oil |
|------------------------|----------------------|
| Moisture content (%)   | 0.38                 |
| Acid value (mg KOH / g)| 2.3                  |
| Peroxide value (meq/kg)| 26.9                 |
| Total polar components (%)| 13.9               |
| Polymer content (%)    | 7.3                  |
| $\rho$-Anisidine value | 59.6                 |
| Viscosity (centipoises)| 56.6                 |
| Colour (Red slide)     | 14.8                 |
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2.6.3 Peroxide value (PV).

The PV was determined according to AOAC method (965.33)\(^{17}\). PV is expressed as the milliequivalent of peroxides per kg of oil sample.

2.6.4 Total polar compounds

The total polar compounds content in oil samples was assayed according to the methods described in AOCS method (Cd 20- 91)\(^{19}\).

2.6.5 Insoluble polymer content

The content of insoluble polymers was determined using the previously reported method by Wu and Nawar\(^{19}\).

2.6.6 \(p\)-Anisidine value (\(p\)-AnV)

The content of aldehyde was assayed by determination of the \(p\)-anisidine value (\(p\)-AnV). \(p\)-AnV was determined according to the previous techniques described in AOCS Official Method Cd 18-90 1992\(^{20}\).

2.6.7 Colour

Colour was determined using Lovibond tintometer. The yellow glass filter was fixed at 30 and the intensity of the red glass colour was measured\(^{8}\).

2.6.8 Viscosity

Brookfield LV viscometer Model TC-500 (Brookfield Engineering Laboratories Stoughton, MA, USA) was used to measure the viscosity of the oil samples at 45°C, according to the method described by Saguy et al.\(^{21}\).

2.7 Statistical analysis

Data are expressed as mean ± SD. Data were statistically analyzed according to the procedures described by Gomez and Gomez\(^{22}\). SPSS Version 18.0 (SPSS Inc., Chicago, IL, USA) was used to analyze data.

3 Results and Discussion

3.1 Morphological analysis

Figures 1-7 show scanning electron microscopy (SEM) images of coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). The images obtained by SEM revealed significant morphological differences among CS, CSA and

![Fig. 1](image1.png)  
Fig. 1 SEM image of coffee silverskin (CS).

![Fig. 2](image2.png)  
Fig. 2 SEM image shows the average of particle size of CS.

![Fig. 3](image3.png)  
Fig. 3 SEM image shows the spherical and semispherical grains with deep cavities of CS ash particles.
Particles of CS are denser morphology than those of particles CSA and NCS. CS particles are composed of thin sheets of material that resembles sawdust\(^{15}\). Particle size of CS ranged from 14.1 to 16.2 \(\mu m\) (Fig. 2). Figures 3, 4 and 5 show the SEM of CS ash. Subjecting coffee silverskin to ashing temperature caused significant changes in aggregation of particles of CSA (Fig. 3). The image 4 shows that the CS ash particles are mainly composed of irregular spherical and semispherical grains with deep cavities formed due to the thermal decomposition of coffee silverskin matrix during ashing process (Fig. 4). These cavities provide binding areas for the ash of coffee silverskin. CS ash has agglomerated particles with some pores on the structure. The size of particles of CS ash ranged in diameter from 1.1 to 1.7 \(\mu m\) (Fig. 5). Figures 6 and 7 show SEM image of nanoparticles of CS (NCS). The morphology of NCS consisted of cluster-type spherical nanoparticles and flakes. Figure 6 also indicates that a uniform surface morphology has been formed. The particle size of NCS varies from 0.9 to 1.7 \(\mu m\) (Fig. 7).

3.2 Effect of treatments with adsorbents on the quality attributes of used frying palm oil

3.2.1 Acid value

Figure 8 illustrates the changes in acid value (mg KOH / g oil) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). The acid values of oil samples under investigation ranged from 0.8 to 2.3 mg KOH / g oil. UFPO has significantly \((p < 0.05)\) the highest acid value (2.3 mg KOH / g oil). This finding suggests that the triacylglycerol molecules were subjected to hydrolytic degradation process\(^{23}\). According to the United States Department of Agriculture (USDA) the level of free fatty acid (FFA) in frying oil greater than 2.5 mg KOH / g of oil cannot be acceptable\(^{24}\). The treatment of UFPO with 4% of CS, CSA and NCS for

![Fig. 5](image)

**Fig. 5** SEM image shows the average of particle size of CS ash.

![Fig. 6](image)

**Fig. 6** SEM image of CS nanoparticles (NCS).

![Fig. 7](image)

**Fig. 7** SEM image shows the average of particle size of NCS.

NCS. Figures 1 and 2 illustrate the SEM of coffee silverskin (CS), these figures show that the CS has agglomerated particles and some of these particles are stuck to each other. Values with different letters are significantly different \((p < 0.05)\).

![Fig. 8](image)

**Fig. 8** Changes in acid value (mg KOH/g oil) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Values with different letters are significantly different \((p < 0.05)\).
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60 min contact time caused significant reductions in acid values. These reductions varied from 51.3 to 65.0%. The highest decrease (65.0%) was recorded for UFPO treated with 4% NCS followed by that of UFPO treated with 4% CSA (64.2%). The lowest reduction was observed for UFPO treated with 4% CS. The acid values of UFPO treated with 4% of CS, CSA and NCS were 2.1, 2.8 and 2.9 times lower than that of UFPO without treatments. These findings indicate that the adsorption capability of NCS and CSA is greater than that of CS. These reductions in FFA levels may be attributed to the specific adsorption affinity of CS, CSA and NCS to small molecules, such as FFAs and monoacylglycerol.

3.2.2 Peroxide value

Figure 9 demonstrates the influence of adsorption treatments on peroxide value (meq/kg) of UFPO. The peroxide value of used frying palm oil without applying treatments was 26.9 meq/kg, which is higher than the peroxide maximum (10 meq/kg) for vegetable oil deterioration. Oxidation after deep-fat frying process results in the formation of hydroperoxide molecules. Several studies suggest the necessity to remove peroxides compounds from deteriorated fried oils. In this part of study, the adsorption capacity of CS, CSA and NCS were assessed by measuring their ability to reduce the levels of peroxide in UFPO. The results show that the adsorption treatments with 4% of CS, CSA and NCS significantly reduce the levels of peroxides in UFPO. The adsorption capacity of these filter aids varied from 77.2 to 91.8%. The lowest level of peroxide (2.1 meq/kg oil) was recorded for UFPO treated with 4% of NCS for 60 min. This finding indicates that nanoparticles of CS has the highest adsorption capacity (91.8%). In this respect the treatment of UFPO with 4% of CS, CSA for 60 min induced significant reduction in the peroxide value. The peroxide value of used frying palm oil was about 4.4 and 8.7 times as great as that in UFPO treated with 4% of CS, CSA, respectively. Generally, the filter aids of the current investigation can be effectively used to reduce the peroxides of used frying oils. These findings indicate that the peroxide values of oils treated with adsorbents under study meet the limits of peroxide value specified by the Codex Alimentarius.

3.2.3 p-Anisidine value

During the oxidation of lipids, hydroperoxides decompose to produce secondary oxidation products (aldehydes, ketones, acids and hydrocarbons) which are more stable during deep fat-frying process, responsible for off-flavors of oil. p-AnV is a measurement for determining the levels of secondary oxidation products in oils. Figure 10 shows the changes in p-AnV of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). p-AnV value of used frying palm oil was 59.6. This finding indicates that used frying palm oil underwent further oxidation during frying process. Oxidation is one of the main degradation reactions that occur during deep-fat frying leading to the formation of aldehydes and ketones. The purification treatments with coffee silverskins (CS), CS ash (CSA) and nanoparticles of CS (NCS) caused significant (p<0.05) decreases in p-AnVs. These decreases vary according to adsorbent type, the decreases in p-AnV ranged from 50.6 to 72.7%. The highest reductions (72.7, 70.0%) in p-AnV were observed in UFPO treated with 4% of CSA and NCS, respectively. However, the lowest reduction (50.6%) was observed for UFPO samples, treated with 4% of CS. These findings indicate that CS, CSA and nanoparticles of CS have a strong affinity for aldehydes and ketene molecules.

3.2.4 Total polar compounds

The content of total polar compounds is one of the most predominant indicators for determination the quality of fats and oils and widely used in several regulations. The content of polar constitutes in frying oil was regulated to

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**Fig. 9** Changes in peroxide value (meq/kg oil) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Values with different letters are significantly different (p < 0.05).

**Fig. 10** Changes p-anisidine value (p-AnV) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Values with different letters are significantly different (p < 0.05).
be not more than 25%\(^{31}\). Figure 11 shows changes in polar content (%) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Values with different letters are significantly different (\(p<0.05\)).

Fig. 11 Changes in polar content (%) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Values with different letters are significantly different (\(p<0.05\)).

3.2.5 Polymer content

Figure 12 illustrates the changes in polymer content (%) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Used frying palm oil contains significantly the highest amounts of polymers (7.3%). During frying process the high temperatures (160-190°C) lead to produce high molecular cyclic fatty acid (FA) monomers, and triglyceride (TG) dimers as well as oligomers\(^{33-35}\). These oxidation products, such as monomers and polymers can cause clinically harmful effects\(^{36}\). Therefore, several researchers focused on the ability of adsorbents on lowering polymers from used frying oils\(^{5,12}\). The treatment of used frying palm oil (UFPO) with 4% of CS, CSA and NCS induced significantly (\(p<0.05\)) decreases in the polymer contents from 7.3% to 4.4, 2.0 and 1.6%, respectively. This finding indicates that CSA and NCS have nearly the same adsorption efficiency in lowering polymer content from used frying palm oil (Fig. 12).

3.2.6 Viscosity

Viscosity parameter is one of the most important physical properties, required to identify the quality and stability of vegetable oils\(^{37}\). Figure 13 shows the changes in viscosity values of used frying palm oil (UFPO) and UFPO treated with 4% of coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Used frying palm oil had significantly the highest value of viscosity (56.6 centipoises). Oxidation of oils during frying eventually leads to the formation of oil polymers which increase viscosity of the oils. This increase in viscosity may explain, at least in part, why oxidized oils tend to trap water vapor as foam. Another possible factor may be in the lowering the interfacial surface tension of the oil through oxidation\(^{8,10}\).

Filtration treatment of UFPO with 4% of coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS) significantly lowered the polar content from 13.9\(\pm\) to 6.3, 4.8 and 3.9% respectively. No significant differences in the adsorptive capacity were observed between each of CS ash (CSA) and CS nanoparticles of CS in lowering the content of polar compounds from used frying palm oil. In this regard, the treatment of purified oils with hot water (at the end of filtration process) significantly lowered the content of polar compounds in used frying palm oil (Fig. 10). Polar substances dissolve best in polar solvents\(^{8,12}\). The obtained levels of polar compounds after applying filtration treatments are in good agreement with those of oil quality regulations of International Union of Pure and Applied Chemistry\(^{25}\). Polar constitutes produced during the deterioration of edible oils and fats have been removed by the adsorbents materials due to van der Waals forces\(^{26}\). Values with different letters are significantly different (\(p<0.05\)).

Fig. 12 Changes in polymer content (%) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Values with different letters are significantly different (\(p<0.05\)).

Fig. 13 Changes in viscosity (centipoises) of used frying palm oil (UFPO) and UFPO treated with coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). Values with different letters are significantly different (\(p<0.05\)).
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Regeneration of used frying oil with coffee silverskin caused a lowering effect on the viscosity values and being patterns greatly depend on the periods of frying and corresponding impacts in removing oil oxidation products from used frying oils. Several studies proved the ability of adsorbents materials or their combination to adsorb the impurities such as oxidized compounds and colour substances from used frying oils. The reduction in polymers and oxidized compounds of treated oil under investigation contributes positively to enhance colour values of treated - used frying oil. CS ash (CSA) and CS nanoparticles have exhibited much higher efficiency and greater rates in purification of used frying palm oil than coffee silverskin (CS) due to high specific surface area and occupy a large number of unsaturated atoms on the surfaces. These specific advantages enhance adsorption capacity for the removal of organic and inorganic substrates.

3.2.7 Colour

The colour of oil samples under study was measured on fixed yellow glass slide (30) and variable red glass slides. Figure 14 shows the changes in colour values of used frying palm oil (UFPO) and UFPO treated with 4% of coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS). The colour of used frying palm oil was 14.8 (red glass slides). The colour of palm oil changed from low red value to high red value at the end of frying period (12 h) .

Colour darkening is a complicated process involving interaction with fatty acids, dimers, polymers and other minor compounds present in the oil. Dark colour of used frying oil is an indication of oxidation, polymerization and formation of carbonyl compounds. The dark colour patterns greatly depend on the periods of frying and correlated with time of deep fat-frying process. UFPO treated with adsorbents under study exhibited (p < 0.05) lighter colours than UFPO without purification treatments. The treatment of used frying palm oil with 4% of coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS) caused significant (p < 0.05) decreases in the values of the red-coloured glasses. The percentage reduction of colour in used frying palm oil after purification treatments varied from 34.6 to 54.8%. The highest reduction (54.8%) was recorded for used frying palm oil sample treated with 4% NCS followed by the reduction of those samples treated with 4% CSA (42.6%). The lowest (34.6%) reduction was observed for UFPO samples treated with 4% CS. These findings indicate that the efficiency of the adsorbents under study in lowering the values of colour was in the decreasing order: NCS > CSA > CS. Adsorbent materials or their combinations were found to effectively useful for the control of colour of used frying oils.

4 Conclusion

The results of the present investigation suggest that filtration treatments of used frying palm oil (UFPO) with 4% of coffee silverskin (CS), CS ash (CSA) and nanoparticles of CS (NCS) regenerated the quality of UFPO and have positive impacts in removing oil oxidation products from used frying oils.

References

1) OECD/FAO, OECD-FAO Agricultural Outlook 2011e2020. OECD Publishing, Paris. FAO. http://dx.doi.org/10.1787/agr_outlook-2011-en.
2) Adewuyi, A.; Oderinde, R.A. Fatty acid composition and lipid profile of Diospyros mespiliformis, Albizia lebbeck, and Caesalpinia pulcherrima seed oils from Nigeria. Intern. J. Food Sci. doi: 10.1155/2014/283614 (2014).
3) Yamsangsumg, R.; Moreira, R.G. Modelling the transport phenomena and structural changes during deep fat frying. Part II: Model solution and validation. J. Food Eng. 53, 11-25 (2002).
4) Nelson, L.V.; Keener, K.M.; Kaczay, K.R.; Banerjee, P.; Jensen, J. L.; Liceaga, A. Comparison of the FryLess 100 K Radiant Fryer to oil immersion frying. LWT-Food Sci. Technol. 53, 473-479 (2013).
5) Lazarick, K.; Aladedunye, F.; Przybylski, R. Effect of breadings and battering ingredients on performance of frying oils. *Eur. J. Lipid Sci. Technol.* **116**, 763-770 (2014).

6) Miyagi, A.; Nakajima, M. Regeneration of used frying oils using adsorption processing. *J. Am. Oil Chem. Soc.* **80**, 91-96 (2003).

7) Romero, A.; Bastida, S.; Sanchez-Muniz, F.J. Cyclic fatty acid monomer formation in domestic frying of frozen foods in sunflower oil and high oleic sunflower oil without replenishment. *Food Chem. Toxicol.* **44**, 1674-1681 (2006).

8) Ali, Rehab F.M.; El Anany, A.M. Recovery of used frying sunflower oil with sugar caneindustry waste and hot water. *J. Food Sci. Technol.* **51**, 3002-3013 (2014).

9) Ogata, F.; Kawasaki, N. Regeneration of waste edible oil by the use of virgin and calcined magnesium hydroxide as adsorbents. *J. Oleo Sci.* **65**, 941-948 (2016).

10) Farag, R.S.; El-Anany, A.M. Improving the quality of fried oils by using different filter aids. *J. Sci. Food Agric.* **86**, 2228-2240 (2006).

11) Turan, S.; Yalcuk, A. Regeneration of used frying oil. *J. Am. Oil Chem. Soc.* **90**, 1761-1771 (2013).

12) Ismail, S.A.A.; Ali, Rehab F.M. Physico-chemical properties of biodiesel manufactured from waste frying oil using domestic adsorbent. *Sci. Technol. Adv. Mater.* **16**, doi:10.1088/1468-6996/16/3/034602 (2015).

13) El Nemr, A. Organic hydrocarbons in surface sediments of the Mediterranean coast of Egypt: distribution and sources. *Egypt. J. Aquat. Res.* **34**, 36-57 (2008).

14) Mussatto, S.I.; Ballesteros, L.F.; Martins, S.; Teixeira, J.A. Extraction of antioxidant phenolic compounds from spent coffee grounds. *Sep. Purif. Technol.* **83**, 173-179 (2011).

15) Ballesteros, L.F.; Teixeira, J.A.; Mussatto, S.I. Chemical, functional, and structural properties of spent coffee grounds and coffee silverskin. *Food Bioproc. Tech.* **7**, 3493-3503 (2014).

16) Khandanbou, R.; Almad, M.; Shamel, K.; Kalantari, K. Synthesis and characterization of rice straw/FeO₃ nanocomposites by a quick precipitation method. *Molecules* **18**, 6597-6607 (2013).

17) AOAC. Official methods of analysis of the Association of Official Analytical Chemists, 17th edn. (Horwitz, W. ed.), Washington DC (2000).

18) AOCS. Determination of polar compounds in frying fats. AOCS Official Method Cd 20-91. American Oil Chemists' Society, IL, USA (1997).

19) Wu, P.F.; Nawar, W.W. A technique for monitoring the quality of used frying oils. *J. Am. Oil Chem. Soc.* **63**, 1363-1367 (1986).

20) AOCS. Official methods and recommended practices of the American Oil Chemists' Society, 4th edn., AOCS Press, Champaign, Additions and Revisions, Method Cd 18-90 (1992).

21) Saguy, I.S.; Shani, A.; Weinberg, P.; Garti, N. Utilization of jojoba oil for deep-fat frying of foods. *LWT-Food Sci. Technol.* **29**, 573-577 (1996).

22) Gomez, K.A.; Gomez, A.A. Statistical Procedures for Agricultural Research. 2nd ed. IRRI, New York. ISBN-10: 0471879312, p. 680 (1984).

23) Sebastian, A.; Ghazani, S.M.; Marangoni, A.G. Quality and safety of frying oils used in restaurants. *Food Res. Interna.* **64**, 420-423 (2014).

24) Aniolowska1, M.; Kita1, A. The effect of type of oil and degree of degradation on glycidyl esters content during the frying of French fries. *J. Am. Oil Chem. Soc.* **92**, 1621-1631 (2015).

25) Yates, R.A.; Caldwell, J.D. Regeneration of oils used for deep frying: A comparison of active filter aids. *J. Am. Oil Chem. Soc.* **70**, 507-511 (1993).

26) Bhattacharya, A.B.; Sajilata, M.G.; Tiwari, S.R.; Singh, R.S. Regeneration of thermally polymerized frying oils with adsorbents. *Food Chem.* **110**, 562-570 (2008).

27) Codex Alimentarius. Codex standard for named vegetable oils. Codex Stan 210-1999, pp. 5-13 (2003).

28) Melten, S.; Jafar, S.; Skyes, D.; Trigiano, M.K. Review of stability measurements for frying oils and fried food flavor. *J. Am. Oil Chem. Soc.* **71**, 1301-1308 (1994).

29) Fritch, C.W. Measurements of frying fat deterioration: a brief review. *J. Am. Oil Chem. Soc.* **58**, 272-274 (1981).

30) Firestone, D. Regulation of frying fat and oil. In *Deep Frying: Chemistry, Nutrition, and Practical Applications*. 2nd ed. (Erickson, M.D. ed.), AOCS Press, Urbana, USA, pp. 373-385 (2007).

31) Lee, C.H. The optimum maintain of frying oil quality and the rapid measurements of acid value and total polar compounds. *Taiwan Food News* **234**, 70-78 (2009).

32) IUPAC Standard Methods for the Analysis of Oils, Fats and Derivatives. 7th ed. Blackwell Scientific Publications. Oxford, UK. Methods 2.201, 2.202, 2.205, 2.401, 2.501 (1987).

33) Billek, G. Lipid stability and deterioration. in *Dietary Fats and Health* (Perkins, E.G.; Visek, W.J. eds.), AOCS Monograph. **10**, 70-89 (1983).

34) Henry, C.J.K.; Chapman, C. *The Nutrition Handbook for Food Processors*. Woodland Publishing Limited, United Kingdom (2002).

35) Sikorski, Z.E.; Kolakowska, A. eds. *Chemical and Functional Properties of Food Lipids*. CRC Press, United Kingdom (2002).

36) Paul, S.; Mittal, G.S. Regulating the use of degraded
Regeneration of used frying oil with coffee silverskin. Crit. Rev. Food Sci. Nutr. 37, 635-662 (1997).

37) Fasina, O.O.; Colley, Z. Viscosity and specific heat of vegetable oils as a function of temperature: 35°C to 180°C. Intern. J. Food Properties. 11, 738-746 (2008).

38) Mancini-Filho, J.; Smith, L.M.; Creveling, R.K.; Al-Shaikh, H.F. Effects of selected chemical treatments on quality of fats used for deep-frying. J. Am. Oil Chem. Soc. 63, 1453-1456 (1986).

39) Yates, R.A.; Caldwell, J.D. Adsorptive capacity of active filter aids for used cooking oil. J. Am. Oil Chem. Soc. 69, 894-897 (1992).

40) Chen, Y.H. Synthesis, characterization and dye adsorption of ilmenite nanoparticles. J. Non-Cryst. Solids 357, 136-139 (2011).

41) Ghaedia, M.; Sadeghiana, B.; Pebdania, A.A.; Sahraeib, R, Daneshfarb, A.; Duranc, C. Kinetics, thermodynamics and equilibrium evaluation of direct yellow 12 removal by adsorption onto silver nanoparticles loaded activated carbon. Chem. Eng. J. 187, 133-141 (2011).