Application of oil replenishment and mixed adsorbents technology to enhance the shelf life of frying oil used in chicken drumsticks processing

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ABSTRACT

The effects of mixed adsorbents (bentonite: activated clay: diatomaceous earth in a ratio of 3:4:1 + 1% citric acid) and fresh oil replenishment (10, 20, and 30%) on the physicochemical properties of recycled soybean oil while deep-fat frying chicken drumsticks for 3 days were studied. The used oil with 1% acid value was used as the initial frying medium. Free fatty acid (FFA), peroxide value (PV), dielectric constant (Food Oil Sensor (FOS) reading), and color (L^*, a^*, b^*) were continuously monitored. Using fresh oil replenishment processes with mixed adsorbents significantly resulted in lower FFA, PV, and FOS readings compared to the control. The L^*, a^*, and b^* values of the treated oils were also improved. Application of mixed adsorbents without fresh oil replenishment was not effective in enhancing the physico-chemical qualities of the used oil. Higher replenishment levels resulted in improved oil quality. Replenishment levels at 20 and 30% potentially retarded deterioration of frying oil.

Keywords: oil adsorbents; oil replenishment; recycled oil; oil life-cycle; fried chicken

1. INTRODUCTION

Frying is an everyday thermal process (Moreira et al., 1999) used both domestically and industrially. During frying, the frying medium is repeatedly heated to high temperatures (about 160-180°C) and is also affected by moisture, oxygen, and substances from what is being fried. This results in lipid oxidation, hydrolysis, and the polymerization of the frying medium which have been ascribed to primary and secondary chemical products that include polymer components, aldehydes, free fatty acids (FFA), and ketones (Zhang et al., 2012; Urbančič et al., 2014). These reactions cause the organoleptic and nutritional characteristics of fried products to deteriorate (Santos et al., 2018). In addition, the repeated use of oil has been shown to be a significant health risk. The desire among consumers for more nutritious and healthier foods and economic concerns among food processors have forced the industry to evaluate the quality of frying medium (Bou et al., 2012).

Under industrial frying, the frying oil is daily used to cook large amount of poultry products and then frying oil is regularly replaced, treated, or discarded to maintain oil quality (Song et al., 2017). However, a certain amount of oil residue is left in the fryer and went through a high deterioration in a longer period. To extend the life of the frying oil and reduce the negative effects, several scientific findings have sought to address the safety limit of the used oils and have claimed that frequently cleaning and maintaining equipment, using a premium-quality frying medium, and suitable frying processes would help (Stevenson et al., 1984).

Reducing the numbers of insoluble particles in frying medium by using a filter paper (passive filtering) or a muslin cloth can retard oil deterioration (Akoh et al., 2001). Although these coarse particles can be separated by this method, many toxic compounds still remain in the oil. Therefore, active filtrations such as natural and synthetic adsorbents have been introduced to maintain the quality of frying oil. The adsorbents, such as activated carbon, magnesium oxide, diatomaceous earth, bleaching earth, calcium silicate, and other forms of silica, have shown their ability in bleaching and removing surfactants and some polymers in the frying oil. Jacobson (1967), for example, reported that synthetic calcium silicate and synthetic magnesium silicate had a potential to reduce the FFA and color in frying oil. Mancini-Filho et al. (1986) showed that using bleaching clay and charcoal significantly improved the dielectric constant changes (DCC). McNeill et al. (1986) also tested the efficiency of mixed activated carbon and silica in improving the quality of used canola oil. They found that mixed adsorbents reduced levels of acid values (AV), saturated and unsaturated carbonyl contents, total polar components (TPC), PV, and photometric color in the treated oil more than the untreated control. Bhattacharya et al. (2008) also showed that the binary and quaternary adsorbent treatments were more effective than using single adsorbents in enhancing the life cycle of palm oils during deep-fat frying of legume-based snacks for 36 h. Furthermore, Lin et al. (2001) reported that the FFA was reduced by 64%, TPC 19.1%, dielectric constant (FOS reading) 32.6%, and a color difference of 4.4% when a mixture of synthetic 3% Hubersorb600, 2% Frypowder, and 3% Magnesol was applied for 4 days.

Oil turnover is one of the methods that have been used for extending the life frying oil for industrial use. By their nature, industrial fryers are used for long periods at a time, thus the recommended turnover is below than 8 h, but. this depends on type of food and fryer (Lawson, 1995; Stauffer, 1996). This is in an agreement with Romero et al. (1998) who exhibited that frequent addition of fresh oil throughout the deep-frying process minimized thermo-oxidation and hydrolytic changes in the frying oils and extended the frying life of the oils. While Totani et al. (2012) reported that the use of lard-containing canola oil without oil replenishment in the eating house increased color values rapidly.

Although potential of adsorbents in slowing down the rate of oil deterioration have been shown in many findings, they do not give us enough information about how they will react under commercial conditions where oil is used repeatedly (Boki et al., 1989; Yates and Cardwell, 1992; Zhu et el., 1994). In our previous study, the combination of adsorbents in the form of bentonite, activated clay, and diatomaceous earth in a ratio of 3:4:1 with the addition of 1% (w/v) of citric acid has indicated a potential to improve the physico-chemical quality of oil used to fry poultry (Udomkun et al., 2018). Therefore, the aim of this study was to investigate the result of oil replenishment together with mixed adsorbents for enhancing quality of used oil in commercial poultry processing.

2. MATERIALS AND METHODS

2.1 Preparation of chicken drumsticks

Breaded chicken drumsticks for commercial use were obtained from Better Foods Co., Ltd., Lopburi province, Thailand for use in this study. The drumsticks were prepared in uniform shape and size (about 10 × 13 × 3 cm) and each weighed approximately 140±5.5 g. The initial moisture content of the breaded drumsticks was 62.5±0.5% and fat content was 45.1±0.2%; they were kept at 45°C before being fried in used soybean oil at 1% of acid value (AV), following the frying instruction of company. The initial quality of the oil was monitored in batches.

2.2 Adsorbents preparation

Four adsorbents (Table 1) were selected to study the potential in improving quality of used oils. The selection of adsorbents and their appropriate ratio of 3:4:1 with 1% of citric acid was based on our preliminary study.

2.3. Frying processes

The experiment comprised five treatments. The “control” referred to oil without adsorbents but was filtered regularly with paper (pore size 30 µm) to remove particles at the end of each day. Treatment I was oil plus mixed adsorbents and using a filtration system but without fresh oil replenishment. Treatments II, III, and IV were similar to treatment I but with fresh oil replenishment every 2 h at three different levels (10, 20, and 30%).

A commercial dual-unit electric batch fryer (model H 114-2 CSC, Fry-master, Shreveport, LA, USA) with a capacity of 21 liters of oil was used for the frying process. To simulate usual frying conditions, fresh soybean oil was preheated at 175±5°C for 30 min and the temperature was monitored by a thermocouple. Fresh oil was not added during frying, however, about 200 mL/day of fresh oil might be added daily to keep the oil level constant.

Four chicken drumsticks weighing about 560±5 g per batch were fried at a temperature of 175°C in 13 kg of heated used oil. Each time, the chicken samples were submerged in the oil in a stainless-steel basket and fried for 150 s. The fried samples were then lifted out of the oil and left to cool in room temperature. The oil was kept at 175°C for the duration of the experiment.

Each batch was fried at 10 min intervals and each frying treatment was continuously performed for 3 days in an attempt to imitate industrial commercial frying of chicken drumsticks production. The fryer was operated for 6 h/day. In total, 36 batches per frying experiment were monitored and the frying experiment was done in triplicate.

Table 1 Type and surface area of adsorbents used in the study

Adsorbents	Characteristics	Surface area (µm)	Source
Diatomaceous earth (Celite® coarse 545)	White and odorless powder	<10 m^2/g	Flukachemical, Buchs, Switzerland
Activated clay	Gray granules, odorless, and insoluble in water	~824 m^2/g	Power Dry Co., Ltd., Thailand
Bentonite	Odorless and light-brown powder	~294 m^2/g	Sigma Aldrich Chemica, GmbH, Germany
Citric acid	Odorless and colorless crystals with an acidic taste	No data	Sigma Aldrich Chemica, GmbH, Germany

2.4 Filtration system

At the end of each day, the oil was firstly filtered by the gravity filtration method. The hot oil was collected from the fryer and then put into a container prior recirculated and filtered to remove the sediment by vacuum with filter paper obtained from Noonsfeer Co., Ltd., Thailand. Similarly, oils in treatments I, II, III, and IV were filtered by gravity, treated with 1% (by weight) of mixed adsorbents, before being recirculated and passed through filter paper. After continuously pouring and stirring the recirculated oil for 5 min, the adsorbent particles were gathered and separated from the used oil using a vacuum filtration system.

2.5 Collection of frying oil

The oil samples were kept in the closed containers and sealed to prevent oxidation. Then the samples were cooled in cold room at a temperature of 7°C for 1 h. Afterwards, the samples were kept at ambient temperature about 1 week until further physical and chemical analyses. FFA, PV, FOS reading, and color (L^*, a^*, b^*) characteristics were taken to measure the deterioration of the frying oil.

2.6. Analyses of quality

2.6.1. Free fatty acid (FFA)

The AOCS procedure Ca 5a-40 (AOCS, 1990) was used to analyze FFA content. One gram of oil sample was weighed and then 10 mL of 95% ethanol and 10 drops of phenolphthalein indicator were added to the Erlenmeyer flask. The mixture was shaken and immediately titrated with 0.1 N NaOH solution until a consistent pink color remained for 30 s. The test was done in triplicate.

2.6.2. Peroxide value (PV)

The AOCS procedure Cd 8-53 (AOCS 1990) was also used to analyze PV content in frying oil. In brief, about 1 g of sample was dissolved with 30 mL of chloroform: acetic acid (3:2, v/v). Subsequently, 1 mL of saturated potassium iodide solution was added to react with the sample for 3 min. The sample was then titrated with 0.1 N standard sodium thiosulfate using starch solution as an indicator. The PV test was repeated 3 times.

2.6.3. Dielectric constant

The Food Oil Sensor (model NI-2C, Northern Instrument Co., MN, USA) was used to measure changes in the dielectric properties of the frying oil. The dielectric properties of oil usually vary owing to fluctuations in source and temperature, so it is vital for all readings to be taken at the same temperature. The test was repeated 3 times.

2.6.4. Color

A Tintometer (model PFX190, Lovibond, England) was used to measure the L^*, a^*, and b^* values of the degraded oil and the reading was taken 3 times for each sample.

2.6.5. The efficiency of adsorption process

The efficiency of adsorbent combinations and oil replenishment in enhancing oil quality was calculated as

$$\text{Percentage Improvement (PI)} = \frac{|\text{Value of untreated oil} - \text{Value of treated oil}|}{\text{Value of treated oil}} \times 100$$

2.7 Statistical test

Statistical analyses were performed using General Linear Model Program (GLM) to test the effects of adsorbents on the physico-chemical qualities of frying oil. Least Significant Difference (LSD) was used to estimate the significant differences among the means of each treatment at 5% the probability level using SAS program (Ver. 8.1, SAS Inst., Cary, NC, USA).

3. RESULTS AND DISCUSSION

3.1 Free fatty acid content

Many fried poultry producers use the FFA value as to indicate the degree of hydrolysis of frying oil. The results of the study showed that FFA content was gradually elevated over time during frying (Table 2). This can be explained by the hydrolysis reaction in which water vapor released from chicken drumsticks consequently reacted with triacylglycerols and formed

FFA. In addition, the secondary products such as hydroperoxides, conjugated dienoic acids, epoxides, hydroxides, and ketones can be continuously oxidized during frying and it can lead to a higher content of FFA (Kun, 1990).

Table 2 Effects of mixed adsorbents and fresh oil replenishment on free fatty acid (FFA) of soybean oil during 3 days of frying

Time (h)	Control[1]	Treatment I[2]	Treatment II[3]	Treatment III[4]	Treatments IV[5]
0	0.96 ^{aJ} (0.01)	0.95 ^{aH} (0.01)	0.96 ^{aG} (0.01)	0.98 ^{aF} (0.04)	0.97 ^{aE} (0.01)
2	1.03 ^{aI} (0.01)	1.04 ^{aG} (0.02)	1.01 ^{aFG} (0.02)	1.01 ^{aF} (0.02)	1.00 ^{aDE} (0.01)
4	1.11 ^{aGH} (0.02)	1.11 ^{aF} (0.01)	1.08 ^{aEF} (0.03)	1.13 ^{aCD} (0.01)	1.12 ^{aC} (0.02)
6	1.27 ^{aF} (0.03)	1.26 ^{aE} (0.04)	1.17 ^{aD} (0.03)	1.16 ^{aBCD} (0.01)	1.18 ^{aB} (0.02)
6	1.15 ^{aGF} (0.06)	0.98 ^{bGH} (0.03)	0.97 ^{bG} (0.04)	1.03 ^{bEF} (0.02)	1.04 ^{bD} (0.01)
8	1.44 ^{aE} (0.01)	1.16 ^{bF} (0.05)	1.09 ^{bEF} (0.03)	1.12 ^{bCD} (0.01)	1.11 ^{bC} (0.01)
10	1.64 ^{aC} (0.02)	1.29 ^{bDE} (0.01)	1.20 ^{cCD} (0.01)	1.12 ^{dCD} (0.01)	1.13 ^{dC} (0.03)
12	1.87 ^{aB} (0.03)	1.38 ^{bC} (0.01)	1.26 ^{cC} (0.01)	1.22 ^{dcB} (0.03)	1.20 ^{dB} (0.01)
12	1.56 ^{aD} (0.01)	1.01 ^{cGH} (0.04)	1.04 ^{cbF} (0.01)	1.10 ^{bDE} (0.03)	1.10 ^{bC} (0.03)
14	1.93 ^{aB} (0.01)	1.33 ^{bDC} (0.05)	1.15 ^{cDE} (0.06)	1.16 ^{cBCD} (0.05)	1.17 ^{cB} (0.03)
16	2.07 ^{aHI} (0.01)	1.72 ^{bB} (0.04)	1.35 ^{cB} (0.01)	1.19 ^{dBC} (0.03)	1.21 ^{eB} (0.02)
18	2.32 ^{aA} (0.01)	1.99 ^{aA} (0.02)	1.66 ^{bA} (0.02)	1.44 ^{cA} (0.09)	1.28 ^{cA} (0.01)

Data are expressed as mean (standard deviation)

Means within a column by the different superscript are significantly different ($P \leq 0.05$).

Means within a row by the different superscript are significantly different ($P \leq 0.05$).

[1]Control: The oil was filtered.

[2]Treatment I: No fresh oil replenishment and the oil was treated with mixed adsorbent and filtered.

[3]Treatment II: 10% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[4]Treatment III: 20% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[5]Treatment IV: 30% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

FFA in the control sample was 0.96% and reached 2.32% after 18 h of frying. When compared with the control, it could be observed that the FFA was significantly lower (P<0.05) in treatments I, II, III, and IV. The average percentage improvement (PI) was 14.22% for treatment I, 28.45% for II, 37.93% for III, and 44.83% for IV. It could be deduced that applying active adsorbents daily to frying oil reduced the build-up of FFA. In general, activated clay has an ability to remove impurities through occlusion and adsorption processes, while diatomaceous earth - a form of silica oxide (SiO_2) - can adsorb FFA compounds by interacting with the exposed silinol group. The use of fresh oil replenishment could improve the oil quality owing to the dilution effect. Romeo et al. (1998) reported that frequently replacing frying oil with fresh oil decreases the formation of FFA, polar compounds, and diacylglycerols. This agreed with Saguy and Dana (2003) who observed that oil turnover rate every 8 h could control FFA level within the range of 0.6-0.8%

for 500 h of frying. Following Thai regulations, most poultry-frying manufacturers usually set FFA value at 2.0% for discarding the used oil. However, this percentage could differ, depending on the ingredients used. For example, using spices may lower the discard point to less than 2.0%.

3.2 Peroxide value

PV is normally used as an indicator to measure the number of hydroperoxides produced from FFA radicals through processes of rancidity reaction during frying and storage (Che Man and Jaswir, 2000; Zahir et al., 2017). As predicted, the frying time greatly influenced the build-up of PV that developed during 18 h of frying. After 18 h, PV was 25.77. Only treatments III (approximately 40.16%) and IV (37.33%) showed a significant reduction of PV when compared with the control (Table 3). Although fresh oil replenishment and mixed adsorbents were applied, it could be seen that the PV raised and fallen in all treatments because the peroxides formed are unstable at the frying temperature and these substances can be broken down, forming many thermo-oxidative compounds such as hydroperoxides, alcohols, conjugated dienoic acids, epoxides, hydroxides, and ketones (Moreira et al., 1999; Romero et al., 2000). Moreover, Lynch et al. (2001) and Srivastava and Semwal (2015) reported that the presence of protein in meat can react with the free radicals and aldehydes in frying oil, affecting the accuracy to estimate PV.

After 18 h of frying, the major products of oxidation, the extremely unstable lipid hydroperoxides, quickly reacted and produced secondary products that disintegrated to an alkoxy free radical (Hamiton, 1999). According to Blumenthal (1991) there are not many mono- and di-acylglycerols when frying starts. During frying, the increased interfacial tension breaks the steam bubbles and covers the oil surface like a blanket. This steam blanket diminishes the contact between the frying medium and the oxygen, reducing oxidation reaction. Furthermore, higher temperatures were more likely to decompose the peroxides (Tyagi and Vasishtha, 1996). However, Cuesta et al. (1993) noted that a greater oxidative reaction occurred more than hydrolytic reaction when oil frequently changed during frying potato. Stevenson et al. (1984) recommended that a high turnover can reduce the use of antifoaming agents such as silicones by 15 to 25% of the capacity of the fryer.

3.3 Dielectric constant

In terms of dielectric constant (FOS reading), the quality parameter was gradually elevated in all treatments during frying. The FOS reading of the control rose more quickly than in the other treated oils from an initial difference of 3.35 to 6.21 after 18 h of frying (Table 4). The quality of treated oil from treatments I-IV was improved by 11.76% for I, 10.30% for II, 17.39% for III, and 18.36% for IV. In general, the main decomposed products in the frying process are nonvolatile polar compounds, triacylglycerol dimers, polymers, and cyclic compounds (Choe and Min, 2007). An increment in dielectric properties of oil is a result of the accumulation of TPC during frying (Hein et al., 1998; Shyu et al., 1998; Innawong et al., 2004a; 2004b). Fritsch et al. (1979) also reported that a statistically significant correlation existing between the FOS reading and an increment of TPC was recognized as the best oil quality index to indicate the degree of lipid oxidation. The reduction of TPC after the fresh oil replenishment and mixed adsorbents process can be attributed to its dilution effect as well as the polarity and surface area of adsorbents. Due to a high non-polar surface of 824 m^2/g, activated carbon can absorb various polar materials through van der Waals forces (McNeill et al., 1986), whereas diatomaceous earth has a surface area less than 10 m^2/g, thus it does not reduce polar materials (Bhattacharya et al., 2008).

Table 3 Effects of mixed adsorbents and fresh oil replenishment on peroxide value (PV) of soybean oil during 3 days of frying

Time (h)	**Control[1]**	**Treatment I[2]**	**Treatment II[3]**	**Treatment III[4]**	**Treatments IV[5]**
0	8.64 ^{aG} (1.15)	8.00 ^{aG} (0.20)	8.05 ^{aI} (0.08)	7.43 ^{aF} (0.06)	7.66 ^{aE} (0.28)
2	12.89 ^{aF} (0.21)	12.27 ^{aF} (0.72)	11.80 ^{aH} (2.49)	12.16 ^{aE} (0.12)	13.41 ^{aDC} (0.17)
4	13.97 ^{aF} (1.52)	15.16 ^{aE} (0.85)	13.96 ^{aFG} (0.36)	12.94 ^{aDE} (1.24)	15.42 ^{aABC} (0.23)
6	17.86 ^{aE} (0.09)	17.63 ^{aD} (0.15)	15.99 ^{bE} (0.30)	14.12 ^{bBCD} (0.05)	15.95 ^{cAB} (0.33)
6	18.65 ^{aE} (1.18)	15.26 ^{bE} (0.68)	12.92 ^{cbGH} (1.30)	13.41 ^{cbCDE} (0.21)	12.47 ^{cD} (1.00)
8	21.21 ^{aD} (0.38)	17.80 ^{bD} (0.09)	15.84 ^{cbEF} (0.05)	13.54 ^{cCD} (0.37)	13.80 ^{cCD} (2.63)
10	21.85 ^{aCD} (0.27)	21.12 ^{aC} (1.46)	22.90 ^{aCD} (0.88)	14.87 ^{bAB} (0.17)	13.78 ^{bCD} (0.38)
12	23.56 ^{aB} (0.23)	24.73 ^{bAB} (1.27)	25.52 ^{abAB} (0.11)	14.72 ^{cABC} (0.09)	16.72 ^{dA} (1.03)
12	22.26 ^{aBCD} (0.68)	20.15 ^{bC} (0.80)	21.12 ^{abD} (0.58)	16.00 ^{cA} (0.48)	14.42 ^{dBCD} (0.36)
14	23.32 ^{aBC} (0.69)	23.70 ^{aB} (0.26)	23.93 ^{aBC} (0.18)	14.40 ^{bBC} (0.21)	14.36 ^{bBCD} (0.45)
16	23.81 ^{abB} (0.11)	25.54 ^{aA} (0.12)	23.51 ^{bC} (0.08)	15.04 ^{cAB} (0.99)	15.30 ^{cABC} (1.37)
18	25.77 ^{aA} (0.16)	26.28 ^{aA} (0.31)	26.04 ^{aA} (0.13)	15.42 ^{bAB} (1.18)	16.15 ^{bAB} (0.12)

Data are expressed as mean (standard deviation)

Means within a column by the different superscript are significantly different ($P \leq 0.05$).

Means within a row by the different superscript are significantly different ($P \leq 0.05$).

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[3]Treatment II: 10% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[4]Treatment III: 20% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[5]Treatment IV: 30% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

Table 4 Effects of mixed adsorbents and fresh oil replenishment on dielectric constant (FOS reading) of soybean oil during 3 days of frying

Time (h)	**Control[1]**	**Treatment I[2]**	**Treatment II[3]**	**Treatment III[4]**	**Treatments IV[5]**
0	3.35 ^{aF} (0.28)	3.08 ^{aG} (0.13)	3.11 ^{aF} (0.01)	3.16 ^{aF} (0.08)	3.07 ^{aH} (0.11)
2	3.45 ^{aF} (0.12)	3.66 ^{aF} (0.25)	3.58 ^{aEF} (0.11)	3.57 ^{aE} (0.16)	3.32 ^{aG} (0.16)
4	3.57 ^{aEF} (0.18)	3.78 ^{aEF} (0.15)	3.76 ^{aDE} (0.31)	3.61 ^{aE} (0.15)	3.56 ^{aF} (0.04)
6	3.63 ^{aEF} (0.24)	3.85 ^{aEF} (0.15)	3.96 ^{aCDE} (0.13)	4.04 ^{aCD} (0.16)	3.80 ^{aDE} (0.16)
6	3.60 ^{bEF} (0.13)	3.79 ^{abEF} (0.11)	3.82 ^{abE} (0.11)	3.89 ^{aD} (0.09)	3.70 ^{abEF} (0.07)
8	4.03 ^{aDE} (0.18)	4.15 ^{aDE} (0.05)	4.13 ^{aCD} (0.04)	4.13 ^{aC} (0.04)	3.92 ^{aD} (0.10)
10	4.70 ^{aBC} (0.39)	4.46 ^{aCD} (0.21)	4.39 ^{aBC} (0.06)	4.22 ^{aBC} (0.08)	4.20 ^{aC} (0.08)
12	4.37 ^{aCD} (0.37)	4.52 ^{aCD} (0.05)	4.78 ^{aB} (0.19)	4.41 ^{aB} (0.03)	4.37 ^{aC} (0.03)
12	4.17 ^{bD} (0.03)	4.40 ^{aCD} (0.02)	4.46 ^{aBC} (0.12)	4.20 ^{bBC} (0.09)	4.20 ^{bC} (0.01)
14	5.04 ^{aB} (0.12)	4.69 ^{bBC} (0.08)	4.89 ^{abB} (0.13)	4.40 ^{cB} (0.04)	4.37 ^{cC} (0.03)
16	5.82 ^{aA} (0.10)	5.01 ^{abB} (0.06)	5.45 ^{abA} (0.44)	4.92 ^{bA} (0.10)	4.60 ^{bB} (0.05)
18	6.21 ^{aA} (0.11)	5.48 ^{bcA} (0.48)	5.57 ^{abA} (0.55)	5.13 ^{bcA} (0.02)	5.07 ^{cA} (0.15)

Data are expressed as mean (standard deviation)

Means within a column by the different superscript are significantly different ($P \leq 0.05$).

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[5]Treatment IV: 30% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

3.4 Color

Color is used as another indicator to discard the frying medium (Bheemreddy et al., 2002). The change of oil color occurs due to the Maillard reaction and the formation of decomposed products from oxidation, pyrolysis, polymerization, and other chemical reactions, (Lin et al., 2001; Kusucharid et al., 2009). The change of L^*, a^*, and b^* values of samples during frying are shown in Tables 5-7. Initial soybean oil displayed a color of 58.88 for L^*, 8.72 for a^*, and 36.43 for b^*. After 18 h, the L^* of the control sample decreased to 45.24, whereas the values of a^* and b^* were increased to 19.03 and 47.75. The high level of a^* and b^* values in frying oil could be due to the addition of ingredients such as paprika which would form reddish and yellowish substances. As the replenishment process is diluting chemical compounds in the frying oil and most adsorbents have a bleaching effect, it could be seen that the application of fresh oil replenishment and mixed adsorbents had a significant impact and improved the color of the oil, especially at high levels of fresh oil replenishment. In particular, the PI values rose by 19.56% for L^*, 31.74% for a^*, and 8.15% for b^*, in treatment III, but a better improvement of 18.85% for L^*, 36.78% for a^*, and 12.04% for b^* were observed in treatment IV.

Table 5 Effects of mixed adsorbents and fresh oil replenishment on lightness (L^*) of soybean oil during 3 days of frying

Time (h)	Control[1]	Treatment I[2]	Treatment II[3]	Treatment III[4]	Treatments IV[5]
0	59.57 ^{aA} (0.73)	58.60 ^{aABC} (1.27)	58.37 ^{aAB} (0.54)	58.85 ^{aA} (0.60)	59.00 ^{aA} (0.11)
2	57.49 ^{aABC} (3.02)	58.14 ^{aBCD} (1.09)	57.63 ^{aBC} (0.41)	57.12 ^{aBC} (0.44)	58.33 ^{aAB} (0.56)
4	55.87 ^{aBCD} (1.30)	56.00 ^{aE} (1.02)	56.36 ^{aDE} (0.24)	56.07 ^{aCD} (0.21)	57.38 ^{aCD} (0.37)
6	55.41 ^{abCD} (0.91)	55.33 ^{abEF} (0.20)	55.09 ^{bF} (0.31)	55.40 ^{abDE} (0.62)	56.60 ^{aEF} (0.33)
6	57.94 ^{bAB} (0.42)	59.66 ^{aAB} (0.53)	57.06 ^{bDC} (0.83)	58.34 ^{abAB} (0.74)	57.69 ^{bBC} (0.21)
8	55.94 ^{bcBCD} (0.16)	58.15 ^{aBCD} (0.32)	55.20 ^{cEF} (0.44)	56.21 ^{bCD} (0.60)	56.77 ^{bDEF} (0.06)
10	53.74 ^{bDE} (0.16)	56.68 ^{aDE} (0.59)	53.53 ^{bG} (0.30)	56.04 ^{aCD} (1.17)	55.67 ^{aG} (0.49)
12	52.41 ^{bE} (0.40)	55.05 ^{aEF} (0.23)	52.31 ^{bH} (0.88)	55.07 ^{aDE} (0.43)	55.49 ^{aG} (0.54)
12	53.59 ^{cDE} (0.18)	60.12 ^{aA} (0.28)	59.08 ^{aA} (0.91)	56.12 ^{bCD} (0.28)	57.18 ^{bCDF} (0.35)
14	52.36 ^{cE} (0.81)	57.68 ^{aDC} (0.06)	58.19 ^{aABC} (0.33)	55.99 ^{bCD} (1.10)	56.02 ^{bGF} (0.28)
16	48.45 ^{cF} (0.40)	53.99 ^{abF} (1.24)	53.57 ^{bG} (0.01)	55.14 ^{aDE} (0.18)	55.30 ^{aG} (0.31)
18	45.24 ^{dG} (0.83)	49.72 ^{cG} (0.89)	51.48 ^{bH} (0.62)	54.09 ^{aE} (0.17)	53.77 ^{aH} (0.13)

Data are expressed as mean (standard deviation)

Means within a column by the different superscript are significantly different ($P \leq 0.05$).

Means within a row by the different superscript are significantly different ($P \leq 0.05$).

[1]Control: The oil was filtered.

[2]Treatment I: No fresh oil replenishment and the oil was treated with mixed adsorbent and filtered.

[3]Treatment II: 10% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[4]Treatment III: 20% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[5]Treatment IV: 30% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

Table 6 Effects of mixed adsorbents and fresh oil replenishment on redness (a^*) of soybean oil during 3 days of frying

Time (h)	Control[1]	Treatment I[2]	Treatment II[3]	Treatment III[4]	Treatments IV[5]
0	9.11^{aG} (0.45)	8.50^{aI} (0.22)	8.64^{aK} (0.42)	8.66^{aI} (0.19)	8.70^{aF} (0.30)
2	10.30^{aF} (0.19)	10.04^{abH} (0.12)	9.85^{bJ} (0.26)	9.28^{cHI} (0.05)	9.07^{cEF} (0.08)
4	12.86^{aE} (0.27)	12.47^{aF} (0.45)	10.72^{bI} (0.25)	10.03^{cbFGH} (0.11)	9.65^{cCD} (0.31)
6	13.11^{aDE} (0.22)	13.04^{aEF} (0.15)	12.26^{bFG} (0.52)	10.80^{cDEF} (0.08)	9.97^{dBCD} (0.11)
6	13.54^{aDE} (0.59)	11.74^{bG} (0.15)	11.11^{bHI} (0.54)	9.29^{cHI} (0.11)	8.54^{cF} (0.30)
8	13.99^{aD} (0.06)	12.92^{bEF} (0.53)	11.68^{cGH} (0.22)	9.80^{dGH} (0.01)	9.55^{dDE} (0.12)
10	15.06^{aC} (1.10)	13.92^{abCD} (0.08)	13.09^{bDE} (0.17)	10.57^{cEFG} (0.15)	10.17^{cBC} (0.08)
12	15.65^{aC} (0.40)	14.52^{bBC} (0.21)	14.11^{bBC} (0.37)	12.02^{cABC} (0.05)	11.71^{cA} (0.21)
12	15.86^{aC} (0.81)	12.79^{bF} (0.08)	12.64^{bEF} (0.45)	11.19^{cCDE} (0.34)	9.66^{dCD} (0.30)
14	16.96^{aB} (0.05)	13.52^{bDE} (0.14)	13.43^{bCD} (0.35)	11.63^{cBCD} (0.30)	10.33^{dB} (0.43)
16	17.55^{aB} (0.15)	14.66^{bB} (0.18)	14.35^{bAB} (0.11)	12.31^{cAB} (0.59)	11.58^{cA} (0.23)
18	19.03^{aA} (0.26)	15.91^{bA} (0.65)	14.87^{bA} (0.16)	12.99^{cA} (0..34)	12.03^{cA} (0.17)

Data are expressed as mean (standard deviation)

Means within a column by the different superscript are significantly different ($P \leq 0.05$).

Means within a row by the different superscript are significantly different ($P \leq 0.05$).

[1]Control: The oil was filtered.

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[3]Treatment II: 10% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[4]Treatment III: 20% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[5]Treatment IV: 30% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

Table 7 Effects of mixed adsorbents and fresh oil replenishment on yellowness (b^*) of soybean oil during 3 days of frying

Time (h)	Control[1]	Treatment I[2]	Treatment II[3]	Treatment III[4]	Treatments IV[5]
0	36.60 ^{aG} (0.37)	36.18 ^{aH} (0.05)	36.39 ^{aH} (0.40)	36.35 ^{aG} (0.19)	36.62 ^{aH} (0.30)
2	37.18 ^{abG} (0.16)	37.63 ^{aG} (0.30)	37.10 ^{abG} (0.16)	36.97 ^{abFG} (0.35)	36.75 ^{bGH} (0.52)
4	38.71 ^{aF} (0.23)	38.57 ^{aFG} (0.15)	37.48 ^{bG} (0.09)	38.03 ^{abEF} (0.54)	37.74 ^{bFGH} (0.28)
6	40.02 ^{aF} (0.08)	40.19 ^{aE} (0.03)	38.94 ^{bF} (0.25)	38.91 ^{bDE} (0.76)	38.70 ^{bEF} (0.08)
6	39.39 ^{aEF} (0.11)	39.00 ^{abF} (0.30)	37.60 ^{cG} (0.08)	38.07 ^{abcEF} (1.06)	37.81 ^{bcFG} (0.45)
8	41.50 ^{aD} (0.06)	40.50 ^{bE} (0.55)	38.65 ^{dF} (0.19)	39.48 ^{cD} (0.20)	38.97 ^{dcDE} (0.27)
10	43.23 ^{aC} (0.45)	41.88 ^{bD} (0.71)	39.91 ^{cE} (0.33)	40.95 ^{bcBC} (0.26)	39.92 ^{cCD} (0.69)
12	44.16 ^{aC} (0.53)	44.20 ^{aCB} (0.62)	41.60 ^{bD} (0.39)	41.99 ^{bB} (0.36)	41.09 ^{bAB} (0.20)
12	43.99 ^{aC} (0.94)	42.45 ^{aD} (0.30)	40.17 ^{bE} (0.09)	39.07 ^{bDE} (0.59)	39.26 ^{bDE} (0.71)
14	45.47 ^{aB} (0.50)	43.60 ^{bC} (0.61)	42.78 ^{bC} (0.14)	39.82 ^{cCD} (0.08)	40.02 ^{cBCD} (1.15)
16	47.01 ^{aA} (1.13)	44.79 ^{bB} (0.15)	43.77 ^{bB} (0.29)	41.92 ^{cB} (0.37)	40.79 ^{cBC} (0.46)
18	47.75 ^{aA} (0.51)	46.31 ^{abA} (0.63)	44.97 ^{cbA} (0.21)	43.86 ^{cA} (1.24)	42.00 ^{dA} (0.18)

Data are expressed as mean (standard deviation)

Means within a column by the different superscript are significantly different ($P \leq 0.05$).

Means within a row by the different superscript are significantly different ($P \leq 0.05$).

[1]Control: The oil was filtered.

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[3]Treatment II: 10% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[4]Treatment III: 20% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

[5]Treatment IV: 30% (v/v) of fresh oil replenishment every 2 h and the oil was treated with filter paper and mixed adsorbent.

4. CONCLUSIONS

Treating used soybean oil by adding mixed adsorbents and replenishing the oil can significantly improve its physico-chemical nature. The higher the replenishment level applied, the better the oil quality was observed. After 18 h of frying, a combination of replenishment level at 20 and 30% (v/v) and mixed adsorbents (treatments III and IV) was greater than other treatments, particularly in improving the quality parameters of the frying oil. Therefore, this technology can be recommended to use in fried poultry processing in order to obtain the good quality of finished products and frying medium.

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