Effect of Star Fruit (Averrhoa carambola L.) By-product on Oxidative Stability of Sesame (Sesamum indicum) Oil under Accelerated Oven Storage and during Frying
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1 Introduction
Oxidation is the major reaction leading to the loss of quality of most edible oils. Thus, oxidative stability of edible oils is the major property determining their shelf life and applications. Various mechanisms have been postulated for the oxidation of oils such as autoxidation, photosensitized oxidation and thermal oxidation during processing and storage. Lipid oxidation results in reductions in the nutritional quality of lipids and harms human health by creating free radicals and other toxic compounds. Thus, it is necessary to improve the stability of oils against oxidation to maintain the nutritional value and improve shelf life during processing and storage. The most feasible way to enhance the oxidative stability of oils is the addition of antioxidants (natural or synthetic). Synthetic antioxidants, such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) are widely used in edible oils because of their effectiveness in suppressing oxidation. However, in recent years, applications of these synthetic antioxidants have been discouraged because of strong evidences reported on animal studies revealing their possible toxicity and carcinogenicity. For instance, it has been reported that BHA and BHT could exert carcinogenic effects in rodents. This has resulted in mounting interest in the applications of antioxidants from natural sources such as plant by-products as alternatives for synthetic antioxidants to enhance the oxidative stability of oils.

Sesame (Sesamum indicum) oil is one of the extensively used edible oils found in Sri Lanka. It helps improve human health by maintaining high density lipoprotein (HDL) cholesterol and lowering low density lipoprotein (LDL) cholesterol. In addition, sesame oil contains antioxidant compounds such as lignans (sesamin, episesamin and sesaminol) and vitamin E, which are responsible for higher stability of sesame oil compared to most other vegetable edible oils with similar fatty acid composition. However, it is susceptible to oxidation because it contains more than 46% polyunsaturated fatty acids. Thus, in...
this study, sesame oil has been selected to evaluate the potential of improving its oxidative stability during processing and storage using a natural source of antioxidant.

Star fruit (Averrhoa carambola), a tropical fruit belonging to Oxalidaceae family, is widely cultivated in Sri Lanka. Star fruit is valued as a rich source of both primary and secondary polyphenol antioxidants such as ascorbic acid and (−)epicatechin and proanthocyanidins
10. Peel of the star fruit is discarded as waste during making star fruit juice or when consumed as fresh. Thus, star fruit peel was selected to study its effect on improving the oxidative stability of sesame oil. Even though several plant sources have been evaluated for their ability to improve the oxidative stability of oils, the studies on the use of start fruit by-product for this purpose are scanty. Thus, this study has evaluated the effect of adding extracts from star fruit by-products as a cheaper and natural source of antioxidant to improve the oxidative stability of sesame oil and to explore the possibility to replace the synthetic antioxidants.

2 Materials and Methods
2.1 Materials and reagents
Star fruits were obtained from home gardens located in Kandana, Sri Lanka and sesame oil was purchased from an oil mill located in Jaffna, Sri Lanka. It was ensured that oil was free of any synthetic antioxidant and stored at −20°C until further use. Potato was purchased from a local market. All chemicals were purchased from Sigma Aldrich (St Louis, USA). All chemicals used in this study were of analytical grade.

2.1.1 Preparation of extract and analysis
Mature star fruits were cleaned and peel was separated and cut into small (0.5 × 0.5 × 0.5 cm³) pieces. Then juice was extracted using a domestic blender and residue was collected after removing the juice completely using a muslin cloth. Collected peel and residue of star fruit were used for antioxidant analysis. Peel and residue were dried for 24 h at 40°C in an oven and ground into fine powder using a domestic grinder. Powdered sample was extracted using acetone (sample: solvent ratio = 1:20) for 4, 6 and 24 h in a shaker at 200 rpm at ambient temperature (30 ± 1°C). The filtrate was collected and the residue was re-extracted two more times as explained above. Solvent was evaporated from combined filtrate using a rotary evaporator to get dry extract. Dry extract was used to analyze total phenolic content, antioxidant capacity and DPPH radical scavenging activity as explained below.

2.2 Methods
2.2.1 Determination of antioxidant activity
2.2.1.1 Determination of total phenolic content
Total phenolic content of the extracts was determined by Folin–Ciocalteau reagent method
12 using gallic acid as standard. In brief, plant extract or gallic acid standard was mixed with Folin–Ciocalteau reagent and kept at ambient temperature (30 ± 1°C) for 5 min, and then sodium bicarbonate (7.5%) was added. Then, excess acetone was added and vortexed. After keeping for 30 min at ambient conditions, absorbance of the solution was measured at 765 nm using UV-Visible spectrophotometer (Thermo Fisher Scientific). Results were calculated and expressed as mg gallic acid equivalent (GAE) per g of dry matter (DM).

2.2.1.2 Determination of antioxidant capacity by phosphomolybdenum assay
The antioxidant capacity of extracts was determined by phosphomolybdenum assay
13 using ascorbic acid as standard. Plant extract or ascorbic acid standard was added to 4 mL of the reagent solution. Then it was incubated at 95°C for 90 min in a boiling water bath. After 90 min, absorbance of the solution was read at 695 nm using UV-Visible Spectrophotometer (Thermo Fisher Scientific). The phosphomolybdenum reduction potential of the studied extracts were calculated expressed as mg ascorbic acid (AA) per g of DM.

2.2.1.3 Determination of DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity
The radical scavenging activity of the extracts was evaluated using DPPH
14. The reduction in the absorption of the DPPH solution due to the addition of an antioxidant was measured at 517 nm using ascorbic acid as standard. Briefly, to prepare the DPPH solution, 6 mg of DPPH was dissolved in 100 mL of acetone. Different volumes of extract or ascorbic acid standard were made up to 350 μL with acetone. Then 10.65 mL of excess acetone and 5 mL DPPH solution were added. A mixture was allowed to stand in dark at ambient temperature for 30 min. and then, the absorbance was read at 517 nm using UV-Visible spectrophotometer (Thermo Fisher Scientific). Mixture of acetone and DPPH was taken as control. The% radical scavenging activity of the peel extracts was calculated using the following formula,

\[
\%RSA = \frac{Abs \ control - Abs \ sample}{Abs \ control} \times 100
\]

Where, RSA is radical scavenging activity; Abs control is the absorbance of DPPH radical + acetone; Abs sample is the absorbance of DPPH radical + extract or ascorbic acid standard.

2.2.2 Determination of oxidative stability of oil
2.2.2.1 Determination of peroxide value
Peroxide value of the samples was determined by spectrophotometric method
15. To prepare Fe(II) stock solution, equal volumes (50 mL) of a solution of BaCl₂·2H₂O (0.8%, w/v) and a solution of FeSO₄·7H₂O (1%, w/v) were mixed and 2 mL of concentrated HCl was added to this mixture. The solution was filtered and stored (stock solution). A working solution of Fe(III) (10 µg/mL) was prepared from a standard stock solution by diluting using chloroform/acetic
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2.2.2.5 Determination of thiobarbituric acid reactive substances (TBARS)
The oil sample (0.05-0.10 g) was dissolved in 5 mL of 1-butanol and added with 5 mL of thiobarbituric acid (TBA) in 1-butanol solution [0.2% (w/v)] and mixed. The resulting solution was boiled for 2 h in a water bath maintained at 95°C and cooled immediately and absorbance was measured at 532 nm using a UV-Visible spectrophotometer (Thermo Fisher Scientific) against a reagent blank. A calibration curve was prepared using 1,3,3,3-tetraethoxypropane standard solution. The results were expressed as mg malondialdehyde equivalent/g of oil using following equation:

$$\text{TBARS (mg malondialdehyde equivalent/g of oil)} = \frac{A \times 72.3}{C \times W}$$

Where, A is the absorbance of oil at 532 nm; 72.3 is the molecular weight of malondialdehyde; C is the constant (slope) established from calibration curve and W is the sample weight (g).

2.2.3 Determination of quality of frying oil
2.2.3.1 Determination of iodine value

Iodine value of the oil samples was determined by Wijs (cyclohexane-acetic acid mixture) method. Briefly, oil sample (0.3-3.0 g) was dissolved completely in 15 mL of cyclohexane-acetic acid solvent (1:1 v/v). Wijs solution (25 mL) was added and mixed thoroughly and allowed to stand in dark for 1 h. Then, flask was removed from dark, 20 mL of 15% KI solution was added and mixed thoroughly. Then 150 mL of distilled water was added to the solution. The solution was titrated with 0.1 M standard Na2S2O3 solution.

2.2.3.2 Determination of polar compounds by column chromatography

Amount of polar compounds in the oils used for frying was determined by column chromatography. Briefly, the column (10 mm internal diameter and 150 mm length) was prepared using slurry of silica gel (pore size 100Å, 70-230 mesh) in elution solvent containing light petroleum and diethyl ether. Oil samples dissolved in the elution solvent were injected onto the column and triacylglycerol fraction was eluted with the elution solvent containing diethyl ether and elute was collected separately. Solvent from elute containing polar fraction was evaporated and polar compounds were weighed. The ratio of polar compounds was calculated as% on weight basis.

2.2.3.3 Determination of fatty acid profile of the oils

Fatty acid profile of the oil samples was determined using gas-liquid chromatography (GLC). Fatty acid methyl esters (FAMEs) were prepared using sodium methyelate and one microliter of FAME was injected into GLC (14-B, Shimadzu, Japan) equipped with fused silica capillary column (100 m length, 0.25 mm internal diameter and 0.2 μm film thickness) and flame ionization detector. Helium was used as carrier gas (20 mL/min). Authentic FAMEs mixture (SUPELCO 37 Component FAME Mix) was used to identify the fatty acids.

2.3 Experiments
2.3.1 Accelerated oven storage test

Oven storage test was conducted according to AOCS Official method Cg 5-97 (AOCS, 2009) with slight modifica-
...The star fruit peel extract was incorporated into sesame oil at the concentrations; 200, 500, 800 and 1000 ppm. Oil samples were added with the extract at the required amount and stirred in a magnetic stirrer for 30 min. to ensure the complete solubilization. BHT at 200 ppm was used as a positive control. Sesame oil devoid of any added antioxidants was used as the negative control. Five millilitre of samples were placed in glass vials (2 cm internal diameter x 4.5 cm height). Four sets of each sample were prepared in triplicates. Then the vials were capped loosely and stored in an oven maintained at 60 ±5°C for up to 14 days. One set of each sample was taken on 1st, 3rd, 7th and 14th day of storage and analyzed for the level of oxidation by determining free fatty acid content, p–anisidine value, peroxide value, TOTOX value and CD and CT values.

2.3.2 Frying experiment

Fresh potatoes were peeled off and cut into uniformly sized slices (0.5 cm x 0.5 cm x 0.8 cm). Soon after slicing, the slices were soaked in distilled water for 1 min, drained off and excess water on the surface of the pieces was wiped with tissue papers.

The star fruit extract was added to the oil at the concentration selected based on the results of the accelerated oven storage study and stirred using a magnetic stirrer for 20 min. BHT was used at 200 ppm as positive control and oil without added antioxidant was used as the negative control. The ratio of oil and raw potato was 3:1 (weight basis). Potato slices were introduced into the oil after the temperature of oil is brought to 170 ± 5°C and fried for 10 min at the same temperature. The same oil samples were reused two more times (one frying cycle per day) maintaining same ratio of oil and potato during frying as the first frying cycle. After frying, the oil was cooled to room temperature and oil samples were flushed with nitrogen, sealed in airtight vials and stored at -20°C until analysis for the level of oxidation by determining free fatty acid content, p–anisidine value, peroxide value, TOTOX value, CD and CT values, iodine value and thiobarbituric acid reactive substances (TBARS). Samples were also analyzed for polar compounds and fatty acid composition as explained.

2.4 Statistical analysis

All experiments were carried out in triplicates. All data are presented as the mean ± standard deviation of the mean using Microsoft excel 2013. Analysis of variance (ANOVA) was calculated using the two factor Completely Randomized Design using Statistical Analysis System (SAS), version 9.1.3. The treatment means at p <0.05 were compared using Duncan’s Multiple Range Test. Pearson Correlation analysis was performed using IBM SPSS statistics.

3 Results and Discussion

3.1 Antioxidant properties of peel and residue extracts

The total phenolic content, total antioxidant activity and DPPH radical scavenging activity (as IC50 value) of aceton extracts of peel and residue obtained at different time periods are shown in Table 1. The peel extract contained a higher antioxidant capacity than residue extract. Studies have reported that star fruits contain antioxidant compounds in the form of proanthocyanins, vitamin C and gallic acid(20). In most plants, antioxidants compounds are located in the peel. For example, pomegranate, plum, nectarines, apple and mango are reported to contain high amount of antioxidants in the peel(24, 20). Since peel extract exhibited higher antioxidant potential than residue extract, peel extract was selected to study its effectiveness in suppressing oxidation of sesame oil during accelerated oven storage and frying.

Increasing duration of extraction resulted in higher antioxidant capacity than less time duration. Highest antioxidant properties were exhibited by the extract obtained after 24 h of extraction. The radical scavenging ability of a compound is directly proportional to the DPPH reduction. Thus, the amount of antioxidants present in the extract determines the DPPH reduction. Higher DPPH reduction means that the compound is associated with greater scavenging activity(26). The higher DPPH radical scavenging activity of a compound, the lower is the IC50 value. In the present study, star fruit peel exhibited lesser IC50 values than residue in all time durations of extraction, that is,

| Extraction time (h) | Total phenolic content (mg GAE/g DM) Peel | Total phenolic content (mg GAE/g DM) Residue | Total antioxidant activity (mg AAE/g DM) Peel | Total antioxidant activity (mg AAE/g DM) Residue | IC50 values (mg/mL) Peel | IC50 values (mg/mL) Residue |
|---------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-------------------------|-------------------------|
| 4                   | 19.09 ± 1.40a | 2.21 ± 0.65a | 26.10 ± 4.21ab | 5.91 ± 0.83ab | 3.94 ± 0.11a | 42.59 ± 0.15b |
| 6                   | 15.09 ± 4.83b | 1.28 ± 0.08c | 22.13 ± 1.86c | 5.14 ± 0.18b | 3.53 ± 0.54c | 34.89 ± 0.21b |
| 24                  | 26.96 ± 2.28c | 2.47 ± 0.06a | 32.44 ± 5.22c | 7.35 ± 1.01a | 2.85 ± 0.25b | 24.93 ± 0.17c |

The values are expressed as means ± standard deviation for triplicate (n=3) analyses. Means in each column followed by different superscripts are significantly different (p < 0.05).
higher DPPH radical scavenging activity of the peel extract than residue extract. It has been reported that the antioxidant activity of plant materials usually correlate with their total phenolic contents\textsuperscript{27}. In the present study, strong positive correlations were observed between total phenolic content and DPPH radical scavenging activity ($R^2 = 0.96$) and total phenolic content and total antioxidant activity ($R^2 = 0.99$).

### 3.2 Effect of addition of star fruit peel extract on oxidative stability of sesame oil during accelerated oven storage

The peroxide values of the samples under accelerated storage are shown in Fig. 1. The peroxide values of all samples showed a significant increase up to 14 days of storage. However, addition of extract significantly decreased the peroxide value. Significantly less values were recorded for the samples added with the extract. Moreover, among the samples added with the extract, the sample added with extract at 1000 ppm showed significantly less peroxide values than other samples. Hydroperoxide is the primary products formed during oxidation of lipids, thus, it is used as an indicator of initial stage of lipid autoxidation. This primary product further decompose into secondary products with off odour and taste, leading to decrease in the quality of the oil\textsuperscript{31}. The results of the present study demonstrate that the star fruit peel extract can significantly reduce the peroxide value of the sesame oil and the effect is increasing with increasing concentration.

The $p$-anisidine value measures the secondary oxidation products produced from primary oxidation product into to aldehydes, carbonyls, and other compounds leading to the rancid flavor of the oil\textsuperscript{28}. The $p$-anisidine values of the samples under accelerated storage are shown in Fig. 2. The $p$-anisidine values of controls and test samples increased significantly up to 14 days of storage. However, sample added with extract at 1000 ppm was reported to have lowest value, this was followed by sample with 800, 500 and 200 ppm of extract on each day. Thus, it is obvious that, as the concentration of extract is increased, the $p$-anisidine values is decreased. This reveals that the star fruit peel extract was more effective in reducing the oxidation of oils at higher concentrations. The $p$-anisidine values of the controls were significantly higher than that of all the supplemented samples.

The TOTOX value is a measure of progressive oxidative deterioration of lipids as it measures both primary and secondary oxidation products\textsuperscript{29}. The TOTOX values of the samples are shown in Table 2. TOTOX values of all samples increased significantly up to 14 days of storage. Compared to negative control, positive control and test samples had significantly lower TOTOX values. The sample added with extract at 1000 ppm showed significantly less TOTOX values than other samples.

CD and CT values of the samples under accelerated storage are shown in Fig. 3. Formation of high amounts of CDs could be attributed to the presence of high amount of polyunsaturated fatty acids. CTs can be formed from CD hydroperoxides by dehydration\textsuperscript{30}. The CT values of controls and sesame oil with extract at 200 ppm and 500 ppm concentrations were increased significantly up to 7\textsuperscript{th} day, after that, it did not show any significant increase. In case of samples added with 800 ppm and 1000 ppm of extracts, CT values were not significantly increased after 1\textsuperscript{st} day. Highest values were observed for negative control, followed by positive control and test samples. This clearly indicates
that the star fruit peel extract can significantly reduce conjugable oxidation and the conjugable oxidation is decreasing with increasing concentration of star fruit peel extract.

Results showed that CD values of the samples under accelerated storage increased significantly up to 14 days of storage (Fig. 3(b)) with highest CD values for negative control. However, as the sample concentration increases, CD values were decreased significantly.

It is obvious that the protective effects of star fruit peel extract was higher than BHT. Among the concentrations examined, 1000 ppm of extract showed a superior suppressive effect against oxidation. Similar observations were reported by other researchers. Few examples include Rambutan (Nephelium lappaceum) extract at 300 ppm\(^{31}\), garlic extract at 1000 ppm\(^{22}\) and pomegranate peel extract\(^{32,33}\) were reported to be more effective in preventing oil oxidation than synthetic antioxidants such as BHT and BHA, which have been shown to possess carcinogenic activity in rodents\(^{5-7}\). Antioxidants from natural plant extracts have been reported to possess greater antioxidant activity and thermal stability in edible oils than synthetic antioxidants\(^4,34\). Thus, considering potential adverse health effects of synthetic antioxidants and low stability during thermal processing, the necessity to substitute synthetic antioxidants with natural antioxidants is highly understood. According to this study star fruit peel extract is a potential and cheaper source of natural antioxidants with greater antioxidant activity and thermal stability than extensively used synthetic antioxidants.

### 3.3 Effect of star fruit peel extract on stability of sesame oil during deep-fat frying

Deep-fat frying causes various chemical changes such as hydrolysis, oxidation, and polymerization of the oil. During deep-fat frying, oxidation occurs at a higher rate compared to hydrolysis and leads to the production of hydroperoxides as primary oxidation products and then secondary oxidation products such as low molecular volatile compounds.

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**Table 2** TOTOX values of samples under accelerated oven storage.

| Days   | 0        | 1        | 3        | 7        | 14       |
|--------|----------|----------|----------|----------|----------|
| Negative control | 1.15 ± 0.20\(^{bc}\) | 2.94 ± 0.18\(^{ad}\) | 4.38 ± 0.12\(^{bc}\) | 7.42 ± 0.82\(^{ab}\) | 11.86 ± 0.56\(^{aa}\) |
| Positive control  | 1.15 ± 0.20\(^{bc}\) | 2.45 ± 0.13\(^{ad}\) | 3.41 ± 0.06\(^{bc}\) | 5.69 ± 0.07\(^{ab}\) | 8.25 ± 0.05\(^{ba}\) |
| SO + 200 ppm SFE  | 1.15 ± 0.20\(^{ad}\) | 2.44 ± 0.51\(^{bc}\) | 2.91 ± 0.08\(^{bc}\) | 5.46 ± 0.31\(^{ab}\) | 7.01 ± 1.43\(^{ab}\) |
| SO + 500 ppm SFE  | 1.15 ± 0.20\(^{ad}\) | 2.17 ± 0.10\(^{bc}\) | 2.66 ± 0.14\(^{bc}\) | 4.98 ± 0.27\(^{ab}\) | 7.00 ± 0.22\(^{ab}\) |
| SO + 800 ppm SFE  | 1.15 ± 0.20\(^{ad}\) | 1.70 ± 0.41\(^{bc}\) | 2.56 ± 0.41\(^{bc}\) | 4.76 ± 0.31\(^{ab}\) | 6.56 ± 0.80\(^{ab}\) |
| SO + 1000 ppm SFE | 1.15 ± 0.20\(^{ad}\) | 1.34 ± 0.04\(^{bc}\) | 1.84 ± 0.25\(^{bc}\) | 3.69 ± 0.10\(^{bc}\) | 6.25 ± 0.17\(^{bc}\) |

Values are means ± standard deviation for triplicate (n=3) analyses. Means in each row followed by different superscripts (a-e) are significantly different (p < 0.05). Means in each column followed by different superscripts (A-E) are significantly different (p < 0.05). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.
The effect of addition of star fruit peel extract on the stability of sesame oil during frying was determined. The concentration of extract was selected as 1000 ppm based on the results of accelerated oven storage study. Oil added with 200 ppm of BHT was used as the positive control and oil devoid of any antioxidant was used as negative control. The changes in peroxide value during frying cycles are shown in Fig. 4. The peroxide value increased gradually with the increase in the number of frying cycles. Test sample showed a significant increase in peroxide value only between the initial and first cycle. After the third frying cycle, the negative control exhibited highest level of oxidation, while, oil samples containing extract showed the lowest level of oxidation. The hydroperoxides are unstable under deep frying conditions. These products readily decompose into mixtures of volatile aldehyde compounds.

Changes in $p$-anisidine values during frying are shown in Fig. 5. $p$-Anisidine values of the samples indicate that the level of secondary oxidation significantly increased during frying cycles.

**Fig. 3**  CT(a) and CD(b) values of samples under accelerated oven storage. Values are means $\pm$ standard deviation for triplicate ($n=3$) analyses. Means are significantly different ($p<0.05$). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.
the first frying cycle, however the level oxidation remained same between first and second frying cycles. Then during third cycle, p-anisidine values showed a significant increase in all samples indicating increase in the production of secondary oxidative products. During second and third frying cycles, negative control showed a significantly higher p-anisidine, followed by positive control and extract added sesame oil.

TOTOX values of samples used for frying are shown in Table 3. TOTOX values of all samples increased significantly during the first frying cycle from the initial value, however, the TOTOX values of all oils after second and third frying cycles showed no significant differences among them and TOTOX values of all samples increased significantly during the third frying cycle. At the end of the frying cycles, oils added with 1000 ppm of extract showed significantly lower TOTOX value than other samples.

CD and CT values of samples are shown in Fig. 6. Both CD and CT values of oil added with the extract showed a significant increase only between initial and first cycle. Both control samples showed a significant increment throughout the frying cycles. The oil added with the extract showed significantly less values of CD and CT than other samples, which indicates that the addition of extract significantly reduced the formation of CD and CT. Another study also have reported that addition of red ginseng extract to the flour dough at 1% and 3% have reduced the formations of CDs in palm oil during deep-fat frying at 160°C.

TBARS values of the oils are shown in Fig. 7. The oil added with the extract showed significantly less TBARS value than positive control during the second and third
**Table 3**  TOTOX values of samples during deep fat frying.

|                | Frying Cycles |
|----------------|---------------|
|                | 0             | 1             | 2             | 3             |
| Negative control | 1.15 ± 0.20<sup>Ac</sup> | 7.41 ± 0.39<sup>Ab</sup> | 8.18 ± 0.43<sup>Ab</sup> | 14.48 ± 0.24<sup>As</sup> |
| Positive control   | 1.15 ± 0.20<sup>Ac</sup> | 6.77 ± 0.09<sup>Ab</sup> | 7.55 ± 0.14<sup>Ab</sup> | 14.32 ± 1.21<sup>As</sup> |
| SO + SFE           | 1.15 ± 0.20<sup>Ac</sup> | 6.42 ± 0.71<sup>Ab</sup> | 6.82 ± 0.73<sup>Ab</sup> | 12.85 ± 1.75<sup>As</sup> |

Values are means ± standard deviation for triplicate (n=3) analyses. Means in each row followed by different superscripts (a-e) are significantly different (p < 0.05). Means in each column followed by different superscripts (A-E) are significantly different (p < 0.05). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.

**Fig. 6**  CD(a) and CT(b) values of samples during deep fat frying.

Values are means ± standard deviation for triplicate (n = 3) analyses. Means in each frying cycle followed by different superscripts (a-e) are significantly different (p < 0.05). Means in each treatment followed by different superscripts (A-E) are significantly different (p < 0.05). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.
frying cycles. Thus, it is obvious that the star fruit peel extract are more effective than BHT in reducing the oxidation of sesame oil during frying. Similar observation has been reported in another study. They have reported that TBARS in the frying oil is increased gradually with frying cycles.

The content of total polar components in frying oils is an important criterion for assessing the quality of the oil. Total polar content are considered to be non-volatile compounds resulting from thermal, hydrolytic and oxidative alteration during deep frying. In several European countries, for commercial frying oils, the maximum permitted value for total polar compounds is set between 24-27%. The amounts of total polar compounds of the oils used for frying are shown in Table 5. In all samples, total polar content increased significantly throughout the frying cycles, while, there were no significant differences in the total polar compounds of negative and positive controls throughout the frying cycles. The sample added with extract showed significantly lower amount of total polar compounds than other samples. These results thus indicate that star fruit peel extract at 1000 ppm level could effec-

Fig. 7  TBARS values of samples during deep fat frying. Values are means ± standard deviation for triplicate (n=3) analyses. Means in each frying cycle followed by different superscripts (a-e) are significantly different (p<0.05). Means in each treatment followed by different superscripts (A-E) are significantly different (p<0.05). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.

Table 4  Iodine value of samples during deep fat frying.

| Frying Cycles | 0      | 1      | 2      | 3      |
|---------------|--------|--------|--------|--------|
| Negative control | 115.8 ± 0.3\textsuperscript{a} | 106.1 ± 1.8\textsuperscript{b,b} | 101.1 ± 1.9\textsuperscript{bc} | 95.4 ± 3.7\textsuperscript{a} |
| Positive control | 115.8 ± 0.3\textsuperscript{a} | 108.8 ± 1.6\textsuperscript{ab,b} | 102.5 ± 0.6\textsuperscript{bc} | 97.8 ± 3.1\textsuperscript{a} |
| SO + SFE      | 115.8 ± 0.3\textsuperscript{a} | 115.9 ± 0.6\textsuperscript{a} | 104.1 ± 1.6\textsuperscript{a} | 101.7 ± 1.8\textsuperscript{a} |

Values are means ± standard deviation for triplicate (n=3) analyses. Means in each row followed by different superscripts (a-e) are significantly different (p<0.05). Means in each column followed by different superscripts (A-E) are significantly different (p<0.05). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.

Table 5  Amount of polar compounds (%) of samples during deep fat frying.

| Frying Cycles | 0      | 1      | 2      | 3      |
|---------------|--------|--------|--------|--------|
| Negative control | 10.9 ± 1.4\textsuperscript{b} | 27.6 ± 0.8\textsuperscript{a} | 28.4 ± 0.1\textsuperscript{a} | 30.8 ± 0.4\textsuperscript{a} |
| Positive control | 10.9 ± 1.4\textsuperscript{b} | 27.4 ± 0.4\textsuperscript{b} | 28.2 ± 1.4\textsuperscript{a} | 28.6 ± 0.5\textsuperscript{a} |
| SO + SFE      | 10.9 ± 1.4\textsuperscript{b} | 17.7 ± 0.1\textsuperscript{b} | 22.8 ± 0.6\textsuperscript{b} | 28.5 ± 0.9\textsuperscript{a} |

Values are means ± standard deviation for triplicate (n=3) analyses. Means in each row followed by different superscripts (a-e) are significantly different (p<0.05). Means in each column followed by different superscripts (A-E) are significantly different (p<0.05). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.
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Iodine value is a measure of degree of unsaturation of fatty acids and is widely employed to characterize oils and fats. Thus, reductions in iodine value of an oil is indicating the decreasing number of double bonds in oil due to oxidation. Iodine values of oils after the frying cycles are shown in Table 4. The level of unsaturation gradually decreased with the frying cycle for all the samples. However, during every frying, sample added with extract showed a significantly higher iodine values than other samples indicating high level of unsaturation than the controls. This indicates that the level of oxidation was less in the sample containing the extract, thus, the extract has significantly reduced the level of oxidation.

Major fatty acids found in the sesame oil were oleic acid and linoleic acid (around 40 and 43%, respectively) (Table 6). For all samples, the amount of saturated and monounsaturated fatty acids content did not change significantly. Polyunsaturated fatty acid content decreased significantly for the controls whereas that of test samples did not change significantly (Table 7). The changes in the fatty acid composition of negative control is higher than positive control and test samples. Polyunsaturated fatty acids undergo oxidation and polymerization during thermal processes. In the present study, fatty acid profiles of the samples showed that the changes in fatty acid composition of sesame oil containing extract is less compared to other samples. At the end of thermal oxidation process, the star fruit peel extract added sesame oil had a higher amount of polyunsaturated fatty acids compared to other treatments.

| Table 6 | Fatty acid composition of sesame oil. |
|---------|-------------------------------------|
| Fatty acid | Percentage |
| Myristic acid (C14:0) | 0.05 ± 0.01 |
| Palmitic acid (C16:0) | 10.30 ± 0.40 |
| Stearic acid (C18:0) | 5.34 ± 0.12 |
| Oleic acid (C18:1) | 39.68 ± 0.78 |
| Linoleic acid (C18:2) | 42.96 ± 0.80 |
| Linolenic acid (C18:3) | 0.32 ± 0.01 |
| Eicosanoic acid (C20:0) | 0.18 ± 0.01 |
| Eicosanoic acid (C20:1) | 0.18 ± 0.01 |
| Docosanoic acid (C22:0) | 0.13 ± 0.01 |
| Tetracosanoic acid (C24:0) | 0.11 ± 0.01 |

Values are means of triplicate analyses (n=3).

| Table 7 | Fatty acid groups (saturated, monounsaturated and polyunsaturated fatty acids) in oil samples after frying. |
|---------|--------------------------------------------------|
| Treatment | Frying Cycles | 1 | 2 | 3 |
| Saturated fatty acids | | | | |
| Negative control | 16.62 ± 0.68<sup>Ab</sup> | 16.7 ± 0.67<sup>Ab</sup> | 16.67 ± 0.25<sup>Ab</sup> |
| Positive control | 16.20 ± 0.12<sup>Ab</sup> | 16.57 ± 0.45<sup>Ab</sup> | 16.45 ± 0.97<sup>Ab</sup> |
| SO + SFE | 16.59 ± 0.05<sup>Ab</sup> | 16.52 ± 0.97<sup>Ab</sup> | 16.52 ± 0.48<sup>Ab</sup> |
| Monounsaturated fatty acids | | | | |
| Negative control | 39.99 ± 1.56<sup>Ab</sup> | 40.12 ± 2.08<sup>Ab</sup> | 40.19 ± 2.15<sup>Ab</sup> |
| Positive control | 40.00 ± 0.75<sup>Ab</sup> | 39.86 ± 0.35<sup>Ab</sup> | 39.94 ± 0.86<sup>Ab</sup> |
| SO + SFE | 39.64 ± 0.76<sup>Ab</sup> | 39.75 ± 1.12<sup>Ab</sup> | 39.86 ± 1.67<sup>Ab</sup> |
| Polyunsaturated fatty acids | | | | |
| Negative control | 43.39 ± 0.80<sup>Ab</sup> | 43.18 ± 0.65<sup>Ab</sup> | 43.14 ± 0.68<sup>Ab</sup> |
| Positive control | 43.80 ± 0.10<sup>Ab</sup> | 43.57 ± 0.01<sup>Ab</sup> | 43.61 ± 0.31<sup>Ab</sup> |
| SO + SFE | 43.77 ± 1.05<sup>Ab</sup> | 43.73 ± 0.89<sup>Ab</sup> | 43.62 ± 0.29<sup>Ab</sup> |

Values are means ± standard deviation for triplicate analyses of one (n=1) sample. Means in each row followed by different superscripts (a-e) are significantly different (p < 0.05). Means in each column followed by different superscripts (A-E) are significantly different (p < 0.05). Abbreviations: SO = Sesame oil, SFE = Star fruit peel extract.
Thus, it can be concluded that star fruit peel extract has protected the polyunsaturated fatty acids from oxidative deterioration and its effectiveness is higher than BHT.

4 Conclusion

This study demonstrates that star fruit peel contains high concentration of antioxidants. The extract of star fruit peel was more effective than synthetic antioxidant (BHT at 200 ppm) in improving the oxidative stability of sesame oil during accelerated oven storage up to 14 days and the effectiveness of extract increased with increasing concentration up to the maximum level used in this study (1000 ppm). Moreover, star fruit peel extract at 1000 ppm exhibited better protection than BHT at 200 ppm against oxidation of sesame oil during frying of potato. Thus, the star fruit peel could be used as a potential source of antioxidant at low cost to improve the oxidative stability of edible oils and can be used as a green alternative to synthetic antioxidants.

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