



Effects of Sesame Seed Oil (Black /White) as a Natural Antioxidant on the Oxidative and Frying Stability of Linseed Oil

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Authors' contributions

This work was carried out in collaboration among all authors. Authors KP and SNN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author UY managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: In today's scenario, the oil industry is striving for natural and newly synthesized bioactive compounds due to their distinct nutritional, safety and health benefits over chemically synthesized antioxidants. Sesame seeds are conventionally perceived as the wealthy source of bioactive lignans. Both water-soluble and oil-soluble lignans in sesame oil (SO) and sesame cake have been proclaimed to have therapeutic benefits on humans. On the contrary, linseed oil (LO) due to its high concentration of alpha-linolenic acid is prone to oxidation. To enhance the oxidative stability index (OSI) shelf life of LO, optimal formulations and admixtures of bioactive components with different mechanisms were studied.

Study Design: Different combinations of oil blends were prepared using SO and LO and the quality characteristics were compared with the pure oils.

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Methodology: Physical and biochemical analysis for the oil blends and pure oils were done. Along with that sensory and shelf life analysis of the fried products were also done using standard procedures.

Results: The oxidative stability of all the oil blends and pure oils were measured at 110°C, 120°C and 130°C. Out of all the ratios, 50:50 wt/wt of LO, WSO, BSO and their blends were exposed to deep fat frying. After frying blends were evaluated for physical and biochemical analysis. Fried potato chips were evaluated for its sensory attributes, moisture loss and fat absorption.

Conclusion: It is proposed that the OSI of LO was upgraded by blending. No significant changes were observed in the FTIR and SF/USF acid ratios of the blends and pure oils throughout the frying days implicit satisfying OSI. Sensory attributes, moisture loss and fat absorption exhibit no significant differences between potato chips fried in WSO, BSO and blends BSO: LO, WSO: LO over 5 days of frying.

Keywords: Natural antioxidants; oxidative stability index; frying stability; Linseed oil (LO); Sesame oil (SO); White / Black sesame oil (WSO & BSO).

ABBREVIATIONS

SO	:Sesame oil
LO	:Linseed oil
OSI	:Oxidative stability index
WSO & BSO	:White / Black sesame oil
SF/USF	:Saturated Fatty acids / Unsaturated fatty acids
FTIR	:Fourier Transform infrared spectroscopy
PUFA	:Polyunsaturated fatty acids
MUFA	:Mono unsaturated fatty acids
ALA	: α -linolenic acid
FS	:Frying stability
TPC	:Total polar compounds

1. INTRODUCTION

The food industry is fronting considerable challenges in lipid oxidation. This phenomenon pre-dominantly occurs in those edible oils which are composed of unsaturated or polyunsaturated fatty acids (PUFA) that are susceptible to rancidity [1]. Autoxidation is the most common process leading to oxidative deterioration during the storage of fats and oils. The rate of autoxidation in oils increases with the degree of unsaturation and decreases with the presence of lipid-soluble antioxidants. Antioxidants work on the various mechanisms such as inactivation of lipid-free radicals, regulating the transformation of hydroperoxides into free radicals, stimulate the activity of other antioxidants, chelating with heavy metals etc. Application of antioxidants can be utilized in restraining autoxidation, loss of tocopherols and destabilization of PUFA [2,3].

Sesame oil contains 45 – 49% mono unsaturated fatty acids (MUFA) and 37– 41% PUFA, the thermally stable lignans present in the oil contribute towards safeguarding it from

autoxidation. Further, SO exhibited higher oxidative stability index (OSI) than soybean, corn and other vegetable oils [4]. Zeb et al [5], revealed that there were nearly 16 bioactive compounds present in SO i.e. sesamol, Syringic acid, Quinic acid, Ellagic acid pentoside sesamin, sesamol, sesaminol, sesamol and other lignans etc. Hussain et al., [6] & Khan et al., [7]. Lignans are among the potent natural antioxidants that protect oils from oxidation, hence it can be used for blending oil to enhance their shelf life [8]. However, their high expenditure confines their utilization on a major scale. On the contrary, Linseed oil (LO) is an affluent source of PUFA and comprises majorly of α -linolenic acid (ALA). Consumption of N-3 fatty acid is necessary for many physiological reasons and has been associated with a lower incidence of many types of illnesses among which inflammatory and cardiovascular diseases are prominent [9]. Unfortunately, besides these functional and nutritional benefits, when LO is exposed to atmospheric oxygen the PUFA of the oil tend to get oxidized into hydroperoxides and production of further degraded products resulted in off-flavour [10].

According to Anwar et al [11], blending of vegetable oils has appeared as a cost-effective and reasonable way to customize the physiochemical characteristics, enhancement of OSI of vegetable oils and doubles up the bioactive constituents/ nutraceutical components during blending. Oil blending is permitted practice in many countries, in India blending is becoming a popular way to increase shelf- life of the vegetable oils during storage. According to Serjouie et al (2010), Farhoosh et al., [12] & Khan et al [7], SO blended with canola oil and coconut oil improves its frying stability (FS) and total polar compounds (TPC). Furthermore, Ali et al [13] and Vaidya and Choe [14], reported that the thermal oxidation properties of the edible oils can be best computed by monitoring the continuous changes in the oils during heating.

In the presented study, LO was blended with WSO/BSO at 20:80, 40:60, 50:50, 60:40 and 80:20 wt/wt ratio. We aimed mainly on the OSI and FS of linseed oil by rancimat test. The fatty acid composition, peroxide value, free fatty acid content, FT-IR, conjugated diene value were also determined in pure oils and all blends. Similarly, the frying stability was also determined along with the sensory evaluation of the fried products.

2. MATERIALS AND METHODS

2.1 Materials

Sesamum indicum L (black/white) seeds were obtained by M/S. Mangu Mal Rajender Kumar (Khari Baoli, Delhi, India) then expelled by M/S Shri Nath Enterprises (Tilak Bazaar, Delhi, India), LO were procured from Sayyam Foods (Nagpur, Maharashtra, India) then expelled by M/S Shri Nath Enterprises (Tilak Bazaar, Delhi, India) packed and stored in amber bottles at 4°C.

Potato chips (unsalted and dried) were procured from M/S. Mangu Mal Rajender Kumar (Khari Baoli, Delhi, India) packed in air tight containers and stored in cool dry place.

2.2 Chemicals

All chemicals and solvents used in this study were of analytical reagent grade and supplied by Merck India and Sigma Aldrich.

2.3 Blending of Vegetable Oils

The vegetable oil blends were formulated by blending LO with BSO and WSO in proportions

of 20:80, 40:60, 50:50, 60:40 and 80:20 (wt/wt). The oils blends were thoroughly homogenized on a magnetic stirrer at 50°C at 100 rpm for 60 min to form blends. The oil blends were tested for OSI and the best blend was utilized for thermal stability test [11].

2.4 Oxidative Stability of Blended Oils at a Different Temperature Range

An automated Metrohm Rancimat apparatus, model 743, capable of operating over a temperature range of 50–200°C, was used to determine induction periods (IP) of the pure and blended oils (Metrohm, 2003). Testing was carried out at a various temperature range $110 \pm 0.1^\circ\text{C}$, $120 \pm 0.1^\circ\text{C}$ and $130 \pm 0.1^\circ\text{C}$. Each of the eight reaction vessels were carefully weighed (3 ± 0.2 g) and analyzed simultaneously. IPs of the sample were recorded automatically and corresponded to the breaking point in the plotted curves [11].

2.5 Fatty Acid Composition of Pure and fried Oils

The fatty acid methyl esters (FAME) were analyzed using the method described by Madankar et al [15] with slight modifications. FAME was prepared using a lipid sample in a screw-capped glass tube (16.5×105 mm) was hydrolyzed with 1 mL of 1 M KOH in 70% ethanol at 90°C for 1 h. The reaction mixture was acidified with 0.2 mL of 6 M HCl, and then 1 mL of water was added. Free fatty acids (FFA) released were extracted with 1 mL of hexane. After evaporation of the hexane in a vacuum, the FFA were methylated with 1 mL of 10% Boron trifluoride (BF_3) in methanol at 37°C for 20 min. Water was added to the solution, and then FAME was extracted with 1 mL of hexane. Nucon 5765 gas chromatograph equipped with a flame ionization detector (Nucon Engineers, Delhi, India), was used with fused silica capillary column BPX 70, $60 \text{ m} \times 0.25 \text{ mm} \times 0.25 \mu\text{m}$ (SGE, India). The column temperature was programmed to increase from 180°C to 240°C at 4°C/min. The detector and injector temperature were set at 240°C and 230°C respectively. The carrier gas used was nitrogen (40 psi) at a flow rate of 45.0 mL/min and air and hydrogen were used at flow rates 30 mL/min and 300 mL/min respectively. The sample injection volume was 0.2 μL with a split flow of 60 mL/min. FAMES were identified by comparing their relative and absolute retention times to those of authentic standard (Sigma Aldrich, USA).

2.6 Frying Experiment

Frying experiments were conducted in BSO: LO (50:50), WSO: LO (50:50), LO, BSO and WSO. Each of the frying oil (1 kg) was put into a 2.5 Lt deep fryer (Oster CKSTDFM40 Electric Deep Fryer). The temperature was raised to 180°C and maintained for the first 30 min before frying. A batch of 50 g dried potato chips of the same thickness, height and weight were fried for 3 min. For five consecutive days, samples were fried in all oil blends and pure oils. Oil samples and potato chips were collected in amber bottles and zip lock pouch respectively at every interval and stored at 4°C and air tight container respectively. Potato chips collected from the first to fifth cycles were kept at ambient temperature for sensory evaluation [16].

2.7 Analysis of Chemical Properties of Pure and Blended Oil

Free fatty acid (FFA) and peroxide value (PV) were analyzed by the AOCS official methods Ca 5a-40, Cd 8-53 (1997) respectively. Conjugated dienes value (CDV) was determined by using a double beam spectrophotometer, (UV-VIS Spectrophotometer, UV-2700 by Shimadzu) according to Farhoosh and Moosavi [17], with slight modifications. The colour of the oil was measured using Lovibond Tintometer (Model F, Tintometer Ltd., Salisbury, U.K.) in 1inch cell in the transmittance mode and expressed as red (R), Yellow (Y) and blue (B) values according to PORIM method [18]. All experiments were carried out in triplicates and average values were presented. A Perkin-Elmer Spectrum RXI FT-IR spectrophotometer equipped with a deuterated triglycine sulphate (DTGS) detector was used to collect FT-IR spectra with our resolution of 2 cm^{-1} at 128 scans. The data interval provided by the instrument for a resolution of 4 cm^{-1} is 1 cm^{-1} . A small quantity (~50 μL) of the sample was deposited with the use of a Pasteur pipette between two well-polished KBr disks, creating a thin film. Duplicate spectra were collected for the same sample. All spectra were recorded from 4000 to 400 cm^{-1} and processed with the computer software program Spectrum for Windows (Perkin-Elmer). FAME for the analysis of the fatty acid composition of the samples was prepared using the above protocol.

2.8 Determination of Moisture and Oil Content of Fried Potato

The moisture content of the dried potato chips was determined by drying the sample in moisture

analyzer (Sun labtek equipment Pvt. Ltd.). The oil content was estimated by drying the sample at 105°C for 24 h followed by soxhlet extraction with petroleum ether [19]. Oil content was expressed on a dry weight basis as a percentage of total oil content. All experiments were carried out in triplicates and average values were presented.

2.9 Sensory Evaluation of Fried Potato Chips

The organoleptic quality of dried potato chips on the first day to the fifth day of frying was used for sensory attributes. Nine -point hedonic scale was used to evaluate sensory attributes like taste, odour, crispiness, and colour of the fried potato chips by giving a score ranging from 1 to 9 (1 = Dislike extremely, 3 = Dislike moderately, 5 = neither like or dislike, 7 = Like moderately and 9 = Like extremely). All these attributes were evaluated by 40 untrained panellists who are regular consumers of potato chips. Each sample was coded with a three-digit random number. The significance of each attribute was described to the panellists to avoid misconception [20].

2.10 Statistical Analysis

All the data are reported as means ($n = 3$) \pm SD ($n = 3$). For all investigated parameters, two - way analysis of variance (ANOVA) was performed, using the SPSS statistical software (version 16.0).

3. RESULTS AND DISCUSSION

3.1 Oxidative Stability of Blended Oils at a Different Temperature Range

OSI determines the formation of primary or secondary oxidation products and it is directly proportional to the percentage of antioxidants present in oils [21]. The results of OSI, in terms of induction periods (IP's) of the pure BSO, WSO and LO and their blends at different ratios and temperature ranges are given in Table 1. The OSI of LO decrease from 3.20 to 1.47 h after increasing the temperature from 110°C to 130°C. With the blending of BSO and WSO at 80% wt/wt in LO at 110°C the IP increase from 4.23 to 9.80% and 3.43 to 5.57%, corresponding to increase in the OSI by 131% and 62%, respectively. The results of OSI also revealed an overall decrease in IP of the pure and blended oils over 110°C to 130°C, in a temperature-dependent manner further it was noticed that increase in temperature is directly proportional to

decrease in IP. The results of the change in IP, concerning temperature change of all pure and blended oils, followed a linear regression, with values of R^2 in the range of 0.90 – 1.00. With the increase in the blending ratio of the BSO and WSO, the protection-factor the LO increased from 1 to 3.06 and 1.74 at 110°C. The protective factor increased even at a higher temperature, making LO more stable (Table 1). Shahidi [22] & Mokbli et al [23], reported that the higher content of PUFA results in lower OSI. The OSI of soyabean oil (SSO) significantly increased upon blending with humilis seed oil (HSO) from 2.4 to 4.4 h (at 120°C), from 5.2 to 9.6 h (at 110°C), and 11 to 21 h (at 100°C). Siger et al [24], indicated that the OSI of blended rapeseed oil (RO) with 15% addition of either rice bran (RBO) or black cumin oils (BCO) increased by nearly 1.05 folds. According to Koh et al [20], Palm-based Medium and long-chain triacylglycerol's (MLCT) oil with 1000 ppm oleoresin increased IP in the palm-based MLCT.

3.2 Fatty Acid Composition of Pure and Blended Oils at the Initial Stage

Fatty acid composition of substrate oils and oil blends is presented in Table 2. Due to the blending of BSO and WSO, major changes were noted in the contents of C18:1, C18:2 and C18:3 of the substrate oils. The blending of BSO and WSO at a proportion of 80% wt/wt resulted in significant ($P = .05$) increases from 21% to 41.3% and 20.4% to 41.9%, in the oleic acid, linoleic acid were significantly ($P = .05$) increased from 9.37% to 62.8% and 11.2% to 50.2% and significantly ($P = .05$) decreased linolenic acid 44.5% to 5.6% and 47.0% to 13.2% respectively. The polyene index was measured which estimate the extent of poly-unsaturation of oil, an indicator for the tendency of oil to undergo autoxidation. The polyene index (PUFA/SFA) ratio was the highest for the LO followed by the BSO and WSO.

As conferred above the SFA: MUFA: PUFA (SMP) ratio of BSO: LO (80:20 wt/wt) was 12.9%: 37.88%: 59.3% and BSO: LO (20:80 wt/wt) was 7.28%: 15.53%: 64.49%, whereas the SMP ratio of WSO: LO (80:20 wt/wt) was 12.3%: 35.74%: 54.91% and WSO: LO (20:80 wt/wt) was 7.33%: 13.68%: 58.9% respectively. According to Hayes [25], oil should have SFA: MUFA: PUFA ratio as below 33%: above 33%:

about 33%, the results revealed that SMP ratio of blends with BSO and WSO (80:20 wt/wt) were near to the recommendations [26,27].

Out of all the ratios, 50:50 wt/wt of BSO: LO, WSO: LO and pure oils (LO, WSO, BSO) were exposed to deep fat frying. After frying blends were evaluated for physical and biochemical analysis. Fried potato chips were evaluated for its sensory attributes, moisture loss and fat absorption.

3.3 Chemical Properties of Pure and Blended Oil

3.3.1 Free fatty acid content (FFA)

Free fatty acids in fats and oils are formed primarily due to hydrolytic rancidity and is the utmost pressing criterion in accepting the oil quality in the industry, it leads to the initiation of off- flavour in oils and fried products [6]. FFA content was found to increase with the increase in frying cycles. A significant change in FFA ($P = .05$) content throughout the frying cycles in all substrate as well as blended oils systems was observed. No smoke haze was observed throughout 5 days of frying in all oil systems. The FFA % in BSO, WSO and LO were 0.13, 0.61 and 1.25%, which increased to 1.04, 2.15 and 4.45%, corresponding to an increase of 0.91, 1.54 and 3. % respectively (Fig. 1). The results indicated that when LO was blended with BSO and WSO at a ratio of 50:50 wt/wt, the FFA content increased from 0.94 to 2.85% and 1.05 to 3.43% respectively, corresponding to an increase of 1.91 and 2.38 respectively. Results indicated that blending of LO with BSO lowers the FFA contents followed by WSO, hence results showed that LO when blended with BSO at a 50:50 wt/wt % level, can make it stable for frying. Hussain et al [6], also claimed that antioxidant activity of sesame seed extract also helps in reducing FFA content of sunflower oil. The moisture in products enhances the hydrolysis of triacylglycerols to form mono and diacylglycerol, glycerol and free fatty acids. The rate of this hydrolysis is faster in oils containing polyunsaturated fatty acids. The FFA content increase due to cleavage and oxidation of double and triple bonds to form carbonyl compounds, which gets oxidized to low molecular weight fatty acid during frying [16].

Table 1. Induction period and preliminary assessment of BSO, WSO, LO, BSO: LO and WSO: LO during different temperature

Oil samples	Induction period ^a (h) for different temperatures (°C)			Protection factor (PF)*			R ² value	Decrease in IP from initial ^b	% Increase in IP ^c	F value
	110°C	120°C	130°C	110°C	120°C	130°C				
BSO	13.67±0.07	8.47±0.04	5.63±0.06	4.27±0.02	4.31±0.02	3.84±0.02	0.97	8.04	-	34.81
WSO	8.30±0.01	5.15±0.04	2.30±0.02	2.59±0.02	2.09±0.03	1.79±0.03	0.99	6.00	-	141.79*
LO	3.20±0.03	1.97±0.04	1.47±0.04	1.00±0.03	1.00±0.03	1.00±0.01	0.94	1.73	-	16.84*
BSO:LO 20:80	4.23±0.03	2.03±0.04	1.87±0.04	1.32±0.01	1.03±0.05	1.27±0.02	0.90	2.36	66.79	4.01*
BSO:LO 40:60	5.47±0.05	3.83±0.04	2.87±0.03	1.71±0.01	1.44±0.06	1.95±0.05	0.97	2.60	151.61	43.85*
BSO:LO 50:50	6.10±0.04	4.37±0.04	3.27±0.03	1.91±0.02	2.22±0.04	2.23±0.04	0.98	2.83	111.07	60.53*
BSO:LO 60:40	7.90±0.04	5.73±0.02	4.63±0.04	2.47±0.06	2.92±0.02	3.15±0.04	0.96	3.27	138.32	28.01*
BSO:LO 80:20	9.80±0.03	7.47±0.04	5.17±0.03	3.06±0.02	3.80±0.01	3.52±0.04	1.00	4.63	107.03	0.07
WSO:LO 20:80	3.43±0.02	1.58±0.03	0.31±0.02	1.07±0.02	0.64±0.01	0.19±0.04	0.98	3.12	11.18	90.46*
WSO:LO 40:60	4.17±0.05	1.76±0.02	0.49±0.03	1.30±0.01	0.71±0.06	0.31±0.01	0.96	3.68	157.75	31.26*
WSO:LO 50:50	4.80±0.03	3.83±0.04	0.71±0.03	1.50±0.01	1.04±0.04	0.45±0.02	0.99	4.09	144.41	298.53
WSO:LO 60:40	5.13±0.03	2.85±0.04	0.91±0.03	1.60±0.03	1.15±0.08	0.58±0.02	0.99	4.22	127.46	462.15
WSO:LO 80:20	5.57±0.03	3.14±0.02	1.34±0.04	1.74±0.02	1.27±0.03	0.86±0.06	0.99	4.23	146.34	135.24*

Bold values are for the pure substrate oils

BSO = Black Sesame oil, WSO = White Sesame oil, LO = Linseed oil

^a Values are means ± SD of three separate determinations.

^b Decrease in IP from initial with respect to storage period

^c % Increase in IP with respect to blending of BSO and WSO

* $PF = IP_{Ant}/I_{Po}$, where IP_{Ant} is the induction period (the time needed to reach the break point in the plotted curve from Rancimat analysis) of LO in the presence of the BSO and WSO, and I_{Po} is the induction period of LO alone.

Table 2. Fatty acid composition of BSO, WSO, LO, BSO: LO and WSO: LO at initial stage

Oil Samples	BSO	WSO	LO	BSO:LO 20:80	BSO:LO 40:60	BSO:LO 50:50	BSO:LO 60:40	BSO:LO 80:20	WSO:LO 20:80	WSO:LO 40:60	WSO:LO 50:50	WSO:LO 60:40	WSO:LO 80:20
C 16:0	10.0±0.06	9.9±0.04	8.6±0.02	5.87±0.03	6.62±0.05	7.36±0.02	7.67±0.03	7.90±0.01	5.75±0.02	6.55±0.02	7.07±0.03	7.56±0.02	7.88±0.03
C 18:0	4.8±0.02	5.4±0.02	1.11±0.02	1.41±0.03	2.47±0.03	3.56±0.04	4.55±0.04	5.00±0.02	1.58±0.03	2.33±0.02	3.02±0.04	3.87±0.04	4.42±0.02
C 18:1	41.8±0.02	39.4±0.03	10.91±0.04	15.53±0.03	20.80±0.03	28.62±0.05	34.11±0.04	37.88±0.04	13.68±0.03	19.12±0.02	26.30±0.02	32.57±0.03	35.74±0.04
C 18:2	41.0±0.06	38.0±0.06	31.84±0.03	21.88±0.03	24.53±0.03	28.60±0.04	32.55±0.02	35.61±0.02	18.89±0.03	21.51±0.03	23.18±0.02	27.09±0.03	33.74±0.03
C 18:3	1.6±0.05	2.8±0.03	46.23±0.02	42.61±0.02	39.31±0.03	34.02±0.04	29.18±0.02	24.19±0.05	40.01±0.05	37.24±0.02	34.35±0.02	29.90±0.01	21.17±0.01
SFA	14.8±0.08	15.3±0.06	9.71±0.04	7.28±0.06	9.09±0.08	10.92±0.06	12.22±0.07	12.9±0.03	7.33±0.05	8.88±0.04	10.09±0.07	11.43±0.06	12.3±0.05
MUFA	41.8±0.02	39.4±0.03	10.91±0.04	15.53±0.03	20.80±0.03	28.62±0.05	34.11±0.04	37.88±0.04	13.68±0.03	19.12±0.02	26.30±0.02	32.57±0.03	35.74±0.04
PUFA	42.6±0.11	40.8±0.09	78.14±0.05	64.49±0.05	63.84±0.06	62.62±0.08	61.73±0.04	59.3±0.07	58.9±0.08	58.75±0.05	57.53±0.04	56.99±0.04	54.91±0.04
PUFA/SFA	2.87	2.66	8.04	8.85	7.02	5.73	5.05	4.59	8.03	6.61	5.7	4.98	4.46

**Bold values are for the pure substrate oils.*

BSO = Black sesame oil; WSO = White sesame oil; LO = Linseed oil

Values are means ± SD of three separate determinations

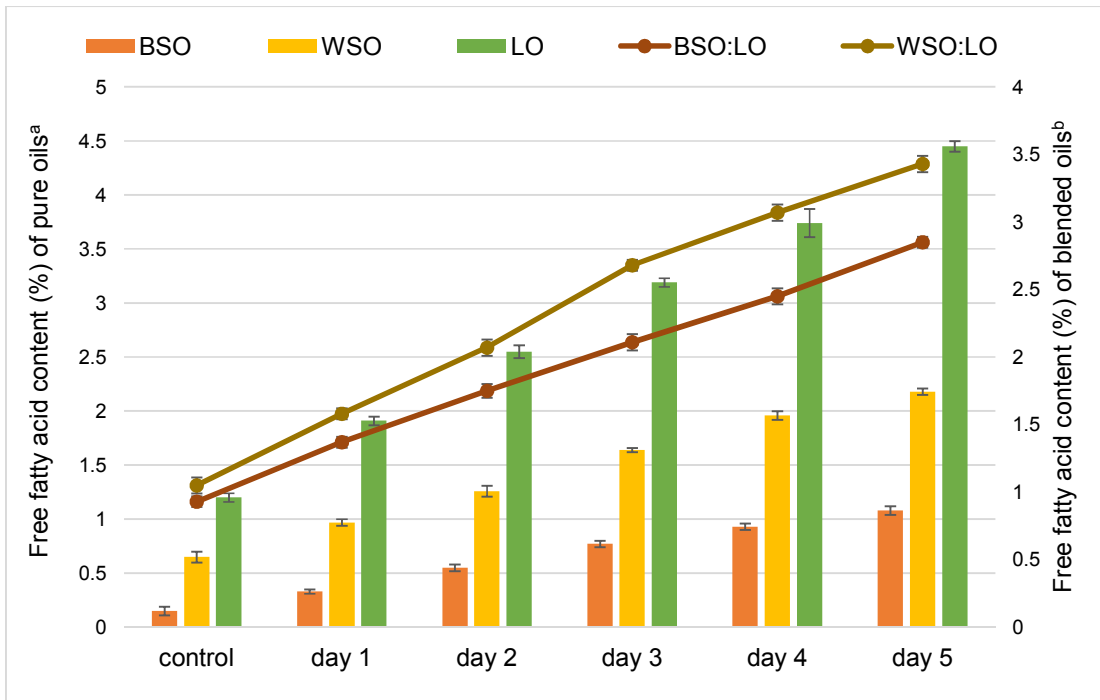


Fig. 1. Free fatty acid content of BSO, WSO, LO, BSO: LO and WSO: LO after five frying cycles
 BSO = Black sesame oil; WSO = White sesame oil; LO = Linseed oil, ^a Free fatty acid content (%) of pure oil, ^b Free fatty acid content (%) of blended oils



Fig. 2. Peroxide value of BSO, WSO, LO, BSO: LO and WSO: LO after five frying cycles
 BSO = Black sesame oil; WSO = White sesame oil; LO = Linseed oil, ^a Peroxide value (%) of pure oil, ^b Peroxide value (%) of blended oils

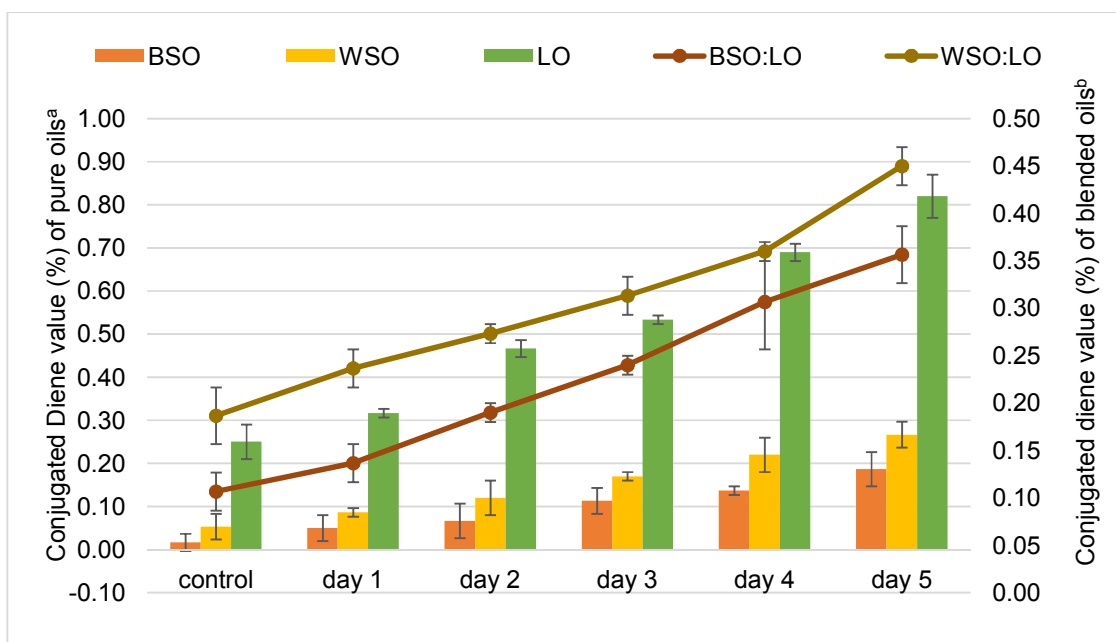


Fig. 3. Conjugated diene value of BSO, WSO, LO, BSO: LO and WSO: LO after five frying cycles

BSO = Black sesame oil; WSO = White sesame oil; LO = Linseed oil. ^a Conjugated diene value (%) of pure oil, ^b Conjugated diene value (%) of blended oils

3.3.2 Peroxide value

Peroxide value is the measure of peroxide and hydroperoxide formed during the initial stages of primary oxidation of oils/fats [28]. It acts as a benchmark for the commencement of the primary oxidation and rancidity of oils and fats. By increasing the storage time, a gradual increase in peroxide value of all the samples was observed (Fig. 2). At higher temperatures and deep-fat frying studies, it was noticed that PV decomposes to form secondary oxidation products [20]. Addition of BSO and WSO to LO resulted in an initial increase than a decline in their PV, resulting in improvement of the oxidative state of the blended oils. PV of BSO, WSO and LO at control day was 3.50, 7.55 and 37.21 respectively. The blending of BSO and WSO with LO at the level of 50:50 wt/wt % resulted in a reduction of PV from 61.11 to 40.25 (34.1% reduction) and from 61.11 to 47.11 (23%), respectively, as calculated after 5 days of frying for 30 min each. Results indicated that PV of all pure oils and blends increase during storage period followed this order: BSO < WSO < BSO: LO (50:50 wt/wt) < WSO: LO (50:50 wt/wt) < LO. A slower rate of increase in PV of BSO (4.04 from initial), WSO (8.77 from initial), BSO: LO (18.94 from initial) compared with those of WSO: LO (23.76 from initial) and LO (23.9 from

initial). Hussain et al [6], reported that sesame seed extract at various concentrations decreased the peroxide value of the oil which concluded the good antioxidant ability in stabilizing the sunflower oil. A decrease in PV was also noted by Anwar et al [11], that PV of moringa oil (MOO) (3.24 from initial) and MOO: SFO (sunflower oil) (5.98–11.1 from initial), MOO: SBO (soyabean oil) (4.76– 8.26 from initial) blends compared with those of SFO (12.1 from initial) and SBO (9.37 from initial) was reported with slower increments when MOO was blended in SFO and SBO.

3.3.3 Conjugated diene

The conjugated diene content of the frying oils is depicted in Fig. 3. The CDV of BSO, WSO and LO at control day was 0.02, 0.05 and 0.25 to 0.19, 0.27 and 0.82 respectively. The blending of BSO and WSO with LO at the level of 50:50 wt/wt % resulted in increment of CDV from 0.11 to 0.36 and from 0.19 to 0.45, respectively, as calculated after 5 days of frying for 30 min each. Results indicated that CDVs of all oil samples increased with increase in storage period followed the order: BSO < WSO < BSO: LO (50:50 wt/wt) < WSO: LO (50:50 wt/wt) < LO. During continuous frying, the oxidized compounds produced increase oxidation rate in oil. These oxidized compounds proliferate

degradation in oil, increase the viscosity of the oil, and develop undesirable colour in the food after being fried and increase the rate of oil absorption. These conjugated dienes polymers when comes in contact with air they form a sticky dark brown coloured residue on the sides on the frying vessels. LO contains a good amount of linolenic acid which is responsible for the increase in CDV, but this increment was controlled when blended with BSO and WSO [7].

3.3.4 Colour value

Colour of the oil was measured at the beginning of the frying followed by 5 days of frying results are shown in Fig. 4. All pure oils and oil blends experienced darkening of oils throughout the subsequent frying of the oils. The darkening of oil blended with BSO was higher because of the initial colour of the BSO due to the presence of the tannins in it, hence colour change was more in BSO oil samples. Whereas, acceptability of WSO blended with LO was more in terms of the colour appearance as it was far lesser than the BSO. Darkening of the colour is not only due to the presence hydroperoxides in oil but due to the presence of natural bioactive constituents in it as well, but their darkening doesn't affect the quality of the products. According to Koh et al [20], RBD palm olein, when blended with oleoresin, leads to

darkening of palm olein could which was not be solely linked to the oxidative deterioration of oil but because of the presence of trace phenolic compounds present in oleoresin of rice bran.

3.4 Fatty Acid Composition of BSO, WSO, LO and Its Blends before and after Frying

The overall fatty acid composition of the blends after frying showed no significant change (Table 3). But individual fatty acids showed inconsistent changes. During deep fat frying changes in unsaturated fat content is a normal phenomenon, however in the present set of oil blends BSO: LO and WSO: LO (50:50 wt/wt) no significant change was observed. Simultaneously no marked change was noticed in UFA/SFA ratio, attributed due to the lignans present in SO. Herein, it can be inferred that SO, when blended to LO, provides a greater potential and stability at higher temperature range. Similar results were also reported by Khan et al [7], the fatty acid composition shows that on blending with coconut oil and coconut olein the USFA was less than sesame oil and palm olein. Blends also had less SFA content than coconut oil, which contains about 91% SFA.

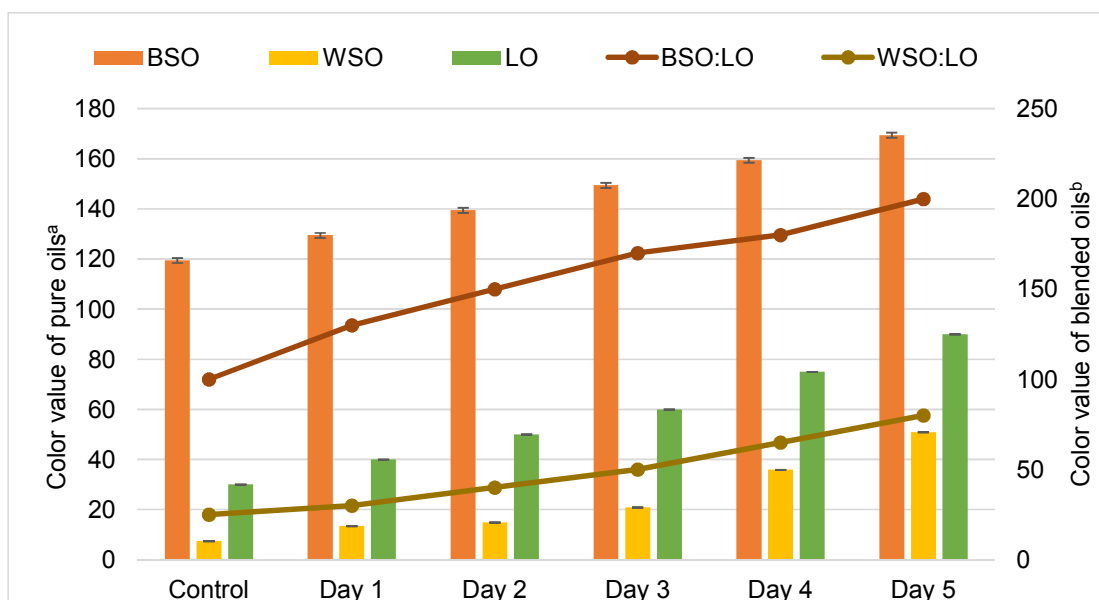


Fig. 4. Color value of BSO, WSO, LO, BSO: LO and WSO: LO after five frying cycles
 BSO = Black sesame oil; WSO = White sesame oil; LO = Linseed oil, ^a Conjugated diene value (%) of pure oil, ^b Conjugated diene value (%) of blended oils

Table 3. Fatty acid composition of BSO, WSO, LO, BSO: LO and WSO: LO before frying and after frying

Fatty acid	BSO		WSO		LO		BSO:LO		WSO:LO	
	BF	AF	BF	AF	BF	AF	BF	AF	BF	AF
C 16:0	9.99	11.54	9.94	10.43	8.6	9.47	12.01	13.21	10.26	11.4
C 18:0	1.13	1.18	1.12	1.16	1.11	1.23	1.84	1.12	1.61	2.08
C 18:1	4.79	6.42	5.42	7.05	3.91	5.11	4.83	6.34	5.64	7.76
C 18:2	41.82	43.54	40.36	42.61	31.84	38.12	33.15	36.07	35.61	39.73
C 18:3	40.99	37.23	38.03	36.42	23.41	25.21	29.62	24.71	29.26	26.03
C 20:4	1.59	1.14	2.78	1.52	24.67	21.51	16.38	14.33	16.87	15.01
SF	11.12	12.72	11.06	11.59	9.71	10.7	13.85	17.33	11.87	13.48
MUFA	4.79	6.42	5.42	7.05	3.91	5.11	4.83	6.34	5.64	6.76
PUFA	84.4	81.91	81.17	80.55	79.92	84.84	79.15	75.11	81.74	80.77
S:M:P	1:0.43:7.60	1:0.65:8.64	1:0.48:7.22	1:0.82:9.72	1:0.40:9.16	1:0.66:11.01	1:0.30:5.04	1:0.41:5.03	1:0.47:6.98	1:0.54:6.51

Table 4. Functional groups of BSO, WSO, LO, BSO: LO and WSO: LO before frying and after frying

Functional groups	Control oils and oil blends					Fried oils and oil blends				
	BSO	WSO	LO	BSO:LO (50:50)	WSO:LO (50:50)	BSO	WSO	LO	BSO:LO (50:50)	WSO:LO (50:50)
Hydro peroxides	722	722	720	721	721	722	722	720	721	722
Alcohol esters	1098	1098	1098	1096	1096	1098	1098	1098	1092	1092
Esters	1160	1160	1160	1160	1160	1160	1160	1160	1160	1160
Carboxylic acid esters	1237	1237	1237	1232	1236	1237	1237	1237	1231	1235
Methyl	1377	1377	1375	1372	1374	1377	1376	1376	1374	1372
Methylene	1458	1458	1458	1460	1461	1458	1458	1461	1462	1462
Conjugated dienes	1651	1649	1651	1652	1651	1649	1650	1653	1648	1653
Ketones (saturated/unsaturated)	1743	1743	1743	1744	1744	1743	1743	1743	1743	1743
Methylene	2853	2853	2853	2854	2854	2853	2853	2853	2853	2854
Double bond	2922	2922	2923	2923	2924	2922	2922	2923	2923	2924
Carboxylic acid	3009	3008	3010	3011	3013	3008	3008	3010	3010	3012

*BSO = Black sesame oil; WSO = White sesame oil; LO = Linseed oil

3.5 Functional Group Characterization of Oil before and after Frying

The infrared spectroscopy is a technique used to identify chemical compounds based on the way infrared radiation is absorbed by the compound. During frying, oils generate hydroperoxides (primary oxidation products), conjugated dienes (intermediate oxidation products), aldehydes/ ketones/ saturated or unsaturated alcohol (secondary oxidation products). Therefore, it was observed that the absorption peaks are the same for all the oil samples before and after five days of frying (Table 4). C-H stretching absorption occurs at a wavelength of 2922 cm^{-1} . Two alkane peaks observed at methylene and methyl groups appear at 1458 and 1377 cm^{-1} respectively [29,30,31].

3.6 Effect of Frying Cycles on the Moisture Content and Oil Uptake

Moisture loss from the fried product during frying is expected. The initial moisture content of the raw material to be fried usually affects the oil uptake by the fried product and in most cases is directly proportional. The initial moisture content of the dried potato chips which were used for frying was 18.33%. All the batches of fried products fried in different oils i.e. BSO, WSO, LO, BSO: LO and WSO: LO showed moisture loss during frying. The product fried in BSO: LO, BSO, WSO, LO and WSO: LO showed moisture loss from initial 18.33% to 11.17, 12.27, 13.87, 13.94 and 13.67% respectively, at the end of fifth

frying cycle (Fig. 5). No significant ($P = .05$) difference was noticed in the moisture content of dried potato chips subjected to periodic frying cycles. Correspondingly moisture loss, oil absorption by the product during frying is also. The initial oil content of dried potato chips which were used for frying was 5.05%. All the potato chips fried in the oils i.e. BSO, WSO, LO, BSO: LO and WSO: LO showed oil uptake during frying. Fried products in BSO: LO, BSO, WSO, LO and WSO: LO showed the uptake from initial 5.05% to final 27.15, 24.45, 21.69, 23.67, 25.03% respectively, at the end of the fifth frying cycle. Viscosity is the main reason behind the excessive oil absorption by the food, as high viscosity increases the association of food and oil leading to slow oil seepage from the food. This leads to excessive oil absorption by the food when it is removed from the frying medium. The viscosity of the oil and blended oils was lesser, hence the absorption of oil in potato chips was subsequently lesser. According to Ravi et al [32], studied the effect of blending of 20 parts of sesame oil in 80 parts of mustard oil, groundnut oil and sunflower oil on deep fat frying. It was found that the addition of sesame oil brings changes in their physical and sensory characteristics. Koh et al [20], observed that potato chips fried in RBD palm olein, Palm-based MLCT oil with 200 ppm TBHQ and palm-based MLCT oil with 1000 ppm oleoresin sage extracts showed significant differences ($P = .05$) among the three oil systems for the first 3 days of frying and then remained indifferent ($P > .05$) among all systems at fourth and fifth days of frying.



Fig. 5. Effect of frying cycles on moisture and oil uptake during frying of potato chips
BSO = Black sesame oil; WSO = White sesame oil; LO = Linseed oil

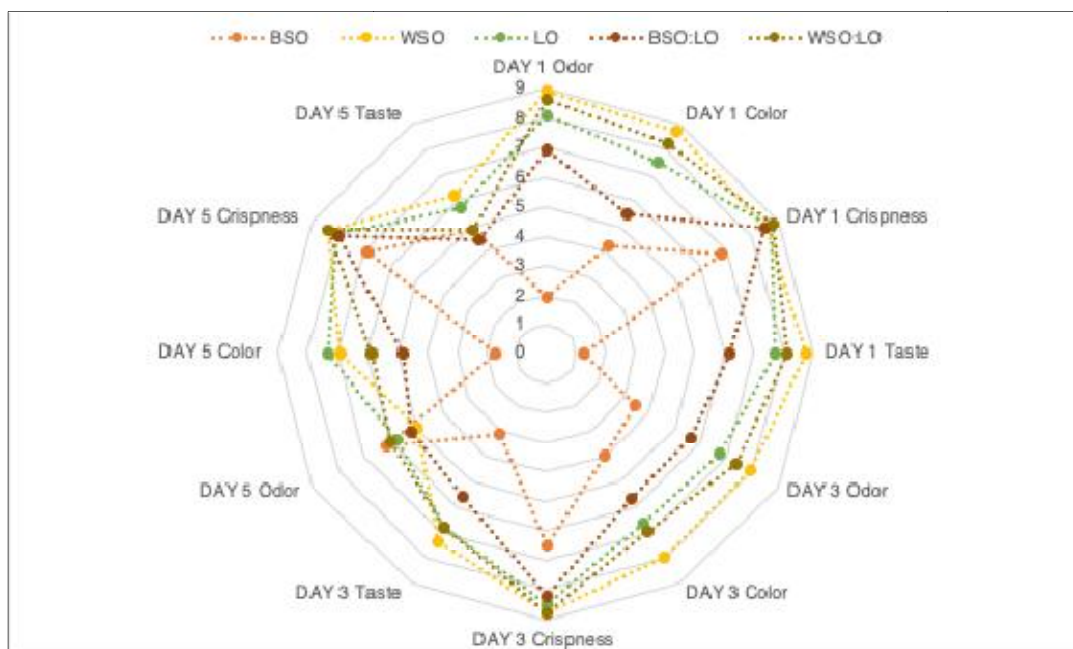


Fig. 6. Quantitative response of potato chips taste, crispness, color and taste after frying cycle

3.7 Sensorial Attributes of Potato Chips

The sensory attributes (odour, taste, crispiness and colour) of dried potato chips fried in BSO, WSO, LO, BSO: LO and WSO: LO are presented in Fig. 6. Samples were golden brown in colour with high crispness and intense fresh oil aroma, which was highest in samples fried in WSO, WSO: LO and LO. A bitter taste and off- odour was noticeable in chips fried in BSO and BSO: LO. A marked change in the colour and taste was noticed in the potato chips fried in BSO and BSO: LO which subsequently decreased with progressive frying because of the reduction of tannins present in BSO. A significant ($p < 0.05$) decrease in the taste of the potato chips was observed, but the taste of the potato chips fried in BSO and BSO: LO improved after progressive frying. A similar trend was seen in the odour of the potato chips fried in pure oils and blended oils. Products fried in BSO: LO and BSO improve in their quantitative response. Debnath et al [16], observed no significant differences in terms of appearance, colour, taste, crispiness and overall acceptability for poori fried using RBO for 6 cycles.

4. CONCLUSION

The shelf life LO was poor due to the high presence of alpha-linolenic acid, which is improved by blending with highly stable sesame

oil which is rich in bioactive constituents. Taking into consideration the cost and nutritive potential of both the oils; out of different ratios analyzed 50:50 wt/wt % blending ratio were evaluated for further thermal stability. After blending the OSI of LO which was 3.20 h initially increased to 9.80 and 5.57 respectively when blended with BSO and WSO at 80:20 wt/wt % ratio. The fatty acid composition of BSO: LO and WSO: LO showed SMP ratio of the blends near to the WHO recommendations. Both blends (BSO: LO and WSO: LO) at 50:50 wt/wt % ratio revealed a marked decrease in FFA content which is 2.85 and 3.43% respectively in comparison to 4.45% of LO after 5 days of frying. BSO and WSO blend showed an increase in PV i.e. 40.19 and 47.23% respectively which is far better than pure LO (61.24%) after 5 days of frying. No significant change in CDV, FTIR and colour was noticed in blends in comparison to the pure LO. The moisture and fat content of the blends showed no significant results in the blends which make them acceptable for high-temperature frying. Sensory attributes of the products fried throughout the study showed above average results which indicates that the blends can be used as an alternative for frying products. The inclusive inference of the above study is that blending of BSO and WSO with LO at 50:50 can be used as an advantageous and cost-effective technique in improving the shelf life and extending the stability of LO.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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