OXIDATIVE AND THERMAL STABILITY OF LINSEED OIL BLEND AND ITS APPLICATION AS A FRYING OIL

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Abstract
Linseed oil is a rich source of Poly Unsaturated Fatty Acids, which is nutritionally very important for maintaining human health. But due to its poor thermal and oxidative stability linseed oil (LSO) is not used an edible oil. Therefore in the present study the efforts were being made to blend linseed oil with MUFA rich oil i.e. sunflower oil (SFO) and to explore the possibility of using it as a frying oil in Indian cookery. As per the standards given by Food Safety and Standards Act (2011) for blended oils, 4 blends of SFO:LS
O were formulated. The formulation was done by the physical mixing (mixing the two oils together and shaking vigorously and using vortex mixer at 150 rpm) of the two oils. SFO was used as a base oil and was mixed in the different ratios with LSO. 6 frying cycles for the selected oil blend were carried out to determine the impact of frying on the thermal stability of the selected oil blend. Each cycle was carried out for 3 minutes at 175^{0}C. Fatty acid composition of the control and blends was analysed using gas chromatography.
Physico-chemical properties like fatty acid composition, Free Fatty Acid (FFA) content, Peroxide Value, Specific Gravity, Radical Scavenging Activity, Total Polar Material, Colour and Refractive Index were analysed to determine the thermal stability of the oil blend after each frying cycle. The selected blend was further used in preparing the mathries, which was followed by the sensory evaluation.

Keywords
Oil blend, sunflower oil, linseed oil, PUFAs, omega-3, omega-6, healthy oils

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1. INTRODUCTION

Fats and oils constitute one of the three major food groups in the Indian diets. Many diseases, such as cardiovascular disease, obesity and other related disorders, are caused by an unbalanced diet particularly in regard to vegetable oils (Srinath and Katan 2004; Fleming et al. 2013). Most natural fats and oils offer limited application in their unaltered state, due to their particular fatty acid and triacylglycerol composition (Chiu, Gioielli and Grimaldi 2008). Based on their structures, each group has important roles in the improvement of the immune system, prevention of cancer and cardiovascular diseases (Tortosa-Caparro et al. 2017).
Poly Unsaturated Fatty Acids (PUFAs) are essential fatty acids and they can be divided into two groups; omega (ω) 3 and omega (ω) 6. Commonly consumed oils, such as sunflower, corn, grape seed and rice bran oils, have high levels of ω 6 fatty acids and, thus, lead to increases in the ratio of ω 6 compared to ω 3 fatty acids. The optimal ratio and balance of these fatty acids has an important effect on their functional properties (Simopoulos 2004). Most of them contain high oleic and/or linoleic acid along with palmitic acid as major Saturated Fatty Acids (SFA). The fatty acid profile of edible oils plays an important role in their nutritional value and stability. In general commonly consumed vegetable oils are rich in Mono Unsaturated Fatty Acids (MUFAs) and ω 6 PUFA but these oils are a poor source of ω 3 PUFA. On the other hand, linseed oil is rich in ω 3 fatty acids, which are easily oxidized, while sesame and olive oils are very stable to oxidation but contain low levels of ω 3 fatty acids. Thus there is no pure oil that has a balanced amount of essential fatty acids, good oxidative stability and optimum nutritional

characteristics (Hashempour-Baltork et al. 2018; Chugh and Dhawan 2014).
Keeping in mind from the context that consumption of ω 6 PUFA has a double edge sword its important to limit its consumption to the recommended levels and including sources of ω 3 PUFA for its health benefits (Dubnov and Berry 2004). Therefore, there is a need to balance the proportions of various fatty acids in the diet.
Blending vegetable oils with different properties is a simple procedure to create new products with the desired physical, nutritional and oxidative properties at an affordable price (Hashempour-Baltork et al. 2016; Aladedunye and Przybylski 2013). Two or more oils can be blended to obtain an oil blend with a desired fatty acid composition. Blending of oils not only dilutes the effect of undesirable constituents (example: erucic acid in mustard oil) but can also bring the advantage of micronutrients present in the individual oils used for making blended oils (Koohikamali and Alam 2019; Singh 2001). It also helps in improving the nutritional quality and physiochemical properties of the oils.
According to Food Safety and Standards Regulations (FSSR 2011) "Blended edible vegetable oil means an admixture of any two edible vegetable oils where the proportion by weight of any edible vegetable oil used in the admixture is not less than 20 per cent. The individual oils in the blend shall conform to the respective standards prescribed by these regulations. The blend shall be clear, free from rancidity, suspended or insoluble matter or any other foreign matter, separated water, added colouring matter, flavouring substances, mineral oil, or any other animal and non-edible oils, or fats, argemone oils, hydrocyanic acid, castor oil and tricresyl phosphate. (FSSR 2011).
Linseed oil, because of its high content of ω3 essential fatty acids and nutritional properties, has received more attention in food formulation. However, linseed oil is very unstable oil and cannot be used alone in food preparations. In this research, linseed oil was blended with sunflower oil to obtain a healthy oil blend with a balanced ω 6:ω 3 ratio. This oil could be used as a healthy alternative instead of traditional frying oils. It will also serve as a rich dietary source of alpha-linolenic acid (ALA) for the vegetarian population in India.
Therefore the present study was aimed at preparing and analyzing blends of sunflower oil and linseed oil for a balanced fatty acid profile and development of products using the best blend and evaluating them organoleptically.

2. MATERIALS AND METHODS

Selection and Procurement of oils
The objective of the study was to blend two different oils to balance the ω 6:ω 3 ratio, where, Linseed oil (LSO; richest source of ALA) and Sunflower oil (SFO; good source of linoleic acid) were used for the research work. Sunflower oil contains about 60% linoleic acid; 8-15% saturated fatty acids, mainly palmitic and stearic acid (Orsavova et al. 2015). Sunflower oil is characterized by naturally having a tocopherol profile mainly consisting alpha-tocopherol. It also has a light taste and is the most commonly used cooking and frying oil (Mishra and Sharma. 2014).
Linseed oil contains approx. 55 % ALA, which is a good vegetarian source of ω -3 fatty acid. The main reasons for its limited industrial utilization can be attributed to its high reactivity towards oxygen, which results in high autoxidation rate and a distinct property to polymerization and yellowing. The oxidative drying property has given the oil its historical usage in coating and linoleum industry (Hamilton 1986).
All the ingredients were procured in a single lot from the local markets of Delhi and stored in air tight containers for future research work.
Blending of oils
As per the standards given by Food Safety and Standards Act (2011) for blended oils, 4 blends of SFO:LSO were formulated. The formulation was done by the physical mixing (mixing the two oils together and shaking vigorously and using vortex mixer at 150 rpm) of the two oils.

SFO was used as a base oil and was mixed in the different ratios with LSO (Table 1).

Table 1: Blending proportions of sunflower oil and linseed oil

BLEND	SUNFLOWER OIL (%)	LINSEED OIL (%)
CONTROL	100	0
BLEND 1	50	50
BLEND 2	60	40
BLEND 3	70	30
BLEND 4	80	20

Fatty acid composition of individual oils and their blends

Fatty acid composition of the control and blends was analysed using gas chromatography.

Gas chromatography is more convenient and precise method for qualitative and quantitative analysis of fatty acid methyl esters. The samples were saponified using methanolin potassium hydroxide (0.5 M) fatty acid methyl esters were prepared using boron trifluoride in methanol (Morrison and Smith 1964). The fatty acid methyl esters were extracted with n-heptane, mixed with anhydrous sodium sulphate and analysed by gas chromatography. The fatty acids in the form of methyl esters were analysed by gas chromatography (Perkin Elmer, Clarus 500) using capillary column. The injector temperature was 180^{0}C and Flame Ionisation Detector (FID) was used. One micro L of the sample was injected and Helium was used as a carrier gas at a flow rate of 1mL/min. Individual fatty acids were identified by comparing with the retention time of standards.

Thermal stability testing of selected oil blend using frying cycle method

6 frying cycles for the selected oil blend were carried out to determine the impact of frying on the thermal stability of the selected oil blend. Each cycle was carried out for 3 minutes at 175^{0}C. 1 minute gap was taken between each frying cycle.

Physico-chemical Analysis of the blended oil after the frying cycles

Physico-chemical properties like fatty acid composition (Morison and Smith 1964), Free Fatty Acid (FFA) content (AOAC 2000), Peroxide Value (PV; AOAC 2000), Specific Gravity (SG; AOAC 2000), Radical Scavenging Activity (RSA; Ramadan et al 2003), Total Polar Material (TPM; Fletcher 1968), Colour (AOAC 2000) and Refractive Index (RI; AOAC 2000) were analysed to determine the thermal stability of the oil blend after each frying cycle.

Development, standardization and sensory evaluation of products developed with the selected oil blend

The selected blend was further used in preparing the fried products. Mathries were prepared and fried using the selected blend for the purpose of sensory evaluation. This commonly eaten fried snack was selected because it was assumed that if the blended oil is acceptable in fried foods than it would be acceptable in curries and paranthas as well. The basic recipe of mathries as described in Khanna et al (2005) was used for the development process.

Overall acceptability of the product was rated on Hedonic Rating Scale (5 point scale; 5 – Excellent, 4 – Very Good, 3 – Good, 2 – Satifactory and 1 - Unsatisfactory). This rating scale method measures the level of the liking of foods or any other product. The organoleptic evaluation of fried products was done by the 40 panelists of the Institute of Home Economics, University of Delhi and the products were analyzed for various characteristics viz. appearance, colour, texture, taste, aftertaste and overall acceptability. Each attribute was allotted 20 marks.

Statistical Analysis

The data obtained through the various tools and techniques were tabulated in the excel master sheets. Prior to analysis, all the data were further screened and errors (if any) were corrected. It was then subjected to quantitative and qualitative analysis.

Sensory data was subjected to chi-square test and physico chemical parameters were subjected to ANOVA and Dunnett’s test. SPSS (version 16) was used for the statistical analysis.

3. RESULTS AND DISCUSSIONS

Fatty acid composition of the control (SFO) and its blends (SFO:LSO)

Table 2 depicts the fatty acid composition and ratios of ω -6:ω -3 of the control and the four blends. As discussed in the table below, a variation in the ω 6:ω 3 ratio of the blended oils was observed. There was statistically significant increase ($p = <0.05$) in linolenic acid content as linseed oil proportion increased in the blended oil formulations. Thus, the blend of sunflower oil and linseed oil in the ratio of 80:20 was selected as the oil of choice, having ω -6:ω -3 fatty acid ratio in the recommended limits (WHO 2008). This oil blend was further subjected to thermal stability analysis for assessing its shelf life through various frying cycles and also was used as a frying oil in developing products to assess its acceptability among consumers.

Effect of frying cycles on ω -6: ω -3 ratio and P/S ratio of SFO and SFO:LSO oil blend formulation (80:20)

The blended oil formulation (SFO: LSO; 80: 20) and sunflower oil (control), were fried for 6 times i.e. 6 frying cycles where each cycle was carried out for 3 minutes at 175 ^{0}C and 1 minute gap was taken between each frying cycle. As depicted in Table 4 and 5 significant difference was seen in the percentage of fatty acids (Palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid), Total SFA, total MUFA, total PUFA, total P/S ratio and total ω 6:ω 3 during 6 frying cycles. the amounts of palmitic and stearic acid of sunflower oil (control) and blended oil formulation (SFO : LSO; 80: 20) increased with increase in the number of frying cycles when compared with the fresh sunflower oil and fresh blended oil formulation (SFO: LSO; 80: 20). Therefore the total SFA content also increased in both the oils (Table 4 and 5). The amounts of linoleic acid and linolenic acid decreased with the increase in the frying cycles. This resulted in a decline in total PUFAs (Table 4 and 5).

The effect on the % of total PUFAs also affected the ω 6:ω 3 ratio of control (Sunflower) blended oil formulation (SFO : LSO ; 80 : 20). Results also indicated that the rate of reduction in C18: 3 is faster than C 18:2 in both the oils. This could be due to the relative reaction rate of C18:3 with oxygen is much faster than that of C18:2 and C18:1. If the trend of effect of frying cycles is observed in control (sunflower oil) than it can be concluded that there was a continuous increase in the amounts of palmitic and stearic acid, thus the total SFA also increased during 6 frying cycles. There was a continuous increase in the oleic acid and a continuous decrease in the linoleic and linolenic acid (Table 5). A study conducted by Alireza et al. (2010) reported that there was a decrease in both the linolenic acid (C18:3) and linoleic acid (C18:2) contents and the palmitic acid (C16:0) increased with a prolonged frying time.

In the blended oil formulation (SFO : LSO ; 80 : 20), during cycle 2 there was a marginal increase in the amounts of linoleic and linolenic acid. This may be due to the amount of these fatty acids being extracted from the food material that was being fried. Similar results were reported by Smith et al (1986). Results also indicated that that there was an overall increase in the amount of palmitic acid and stearic acid. This could be related to the breaking of double and triple bonds in the Unsaturated Fatty Acids (i.e., mono-, di-, and polyunsaturated fatty acids), which could then be transformed into fatty acids with the same number of carbons or a shorter chain. During cycles 1-4 there was a constant increase in the amounts of the palmitic and stearic acid followed by a decline in cycles 5 and 6. This could be due to the fact that the bond breakage of unsaturated fatty acids was maximum during the respective cycles (Alireza et al. 2010). This further affected the total P/S ratio (Table 5).

Considering the merits and demerits of single oil as a cooking medium, blended oil may be more suitable for culinary and frying purposes. Oil blends have nutritional merits and have more stability during heating and frying. Therefore, from the present study it may be concluded that blending of linseed oil at 20 % level into sunflower oil is a viable option to formulate an oil blend with a balanced ω 6:ω 3 ratio. Therefore, in the present study the SFO:LSO (80:20) was used as frying oil in the preparation of Indian snack, i.e. mathries.

Table 2: Fatty acid composition of the formulated oil blends

Fatty Acids	SFO	SFO:LSO (80:20)	SFO:LSO (70:30)	SFO:LSO (60:40)	SFO:SLO (50:50)
Palmitic Acid (%)	5.45	6.2	6.57	8.79	7.32
Stearic Acid (%)	4.45	4.54	4.58	4.63	4.67
Oleic Acid (%)	51.6	46.18	43.47	40.76	38.05
Linoleic Acid (%)	37.4	32	29.33	26.6	23.95
Linolenic Acid (%)	0.41	11	16.3	21.74	27.1
∑ SFA (%)	9.9	10.74	11.15	13.42	11.9
∑ MUFA (%)	51.6	46.18	43.47	40.76	38.05
∑ PUFA (%)	37.81	43	45.63	48.34	51.05
∑ P/S	3.8/1	4.0/1	4.09/1	3.6/1	4.2/1
∑ ω -6: ω -3	91.2/1	3/1	1.7/1	1.2/1	0.8/1

SFO – Sunflower oil, LSO – Linseed oil, ∑ - TOTAL, SFA - Saturated Fatty Acids, MUFA - Monounsaturated Fatty Acids, PUFA - Polyunsaturated Fatty Acids, ω – omega

Table 3 Chemical behavior of SFO and SFO:LSO during 6 frying cycles

Parameter	Sample	Fresh	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
FFA	SFO	0.0260±0.0010*	0.0270±0.0010*	0.0600±0.0010*	0.0700±0.0010*	0.1100±0.0010*	0.1400±0.0010*	0.1700±0.0010*
	SFO:LSO	0.030±0.006*	0.040±0.010*	0.120±0.010*	0.150±0.010*	0.230±0.010*	0.270±0.010*	0.300±0.100*
PV	SFO	0.040 ± 0.010*	1.100 ±0.100*	1.500±0.100*	1.767±0.058*	2.200±0.100*	82.500±0.100*	3.000±0.100*
	SFO:LSO	0.006±0.005*	1.267±0.05*	2.800±0.0100*	3.200±0.100*	3.5±0.002*	3.733±0.058*	3.800±0.100*
RSA	SFO	64.90±0.100	59.60±0.590*	55.53±0.2120*	50.40±0.100	47.10±0.100*	45.10±0.100*	43.70±0.200*
	SFO:LSO	54.40±0.100*	36.50±0.100*	26.60±0.150*	7.40±0.100*	6.70±0.100*	6.50±0.100*	5.47±0.210*
TPM	SFO	0.023±0.006*	0.140±0.010*	0.217±0.006*	0.280±0.010*	0.337±0.015*	0.400±0.100*	0.470±0.010*
	SFO:LSO	0.110±0.010*	0.260±0.010*	0.300±0.010*	0.500±0.010*	0.670±0.010*	0.753±0.006*	0.880±0.010*
CVI (Yellow Units)	SFO	0.53±0.06	0.67±0.06	0.70±0.10	0.70±0.10*	0.80±0.10*	0.87±0.006	0.87±0.100
	SFO:LSO	5.20±0.100	5.20±0.100	5.27±0.06	5.3±0.100	5.3±0.100	5.4±0.100*	5.60±0.100*
CVI (Red Units)	SFO	1.77±0.06*	1.80±0.100*	1.80±0.100*	1.9±0.100*	1.9±0.100*	2.10±0.100*	2.17±0.150*
	SFO:LSO	0.2±0.100*	0.6±0.100*	0.7±0.100*	0.8±0.100*	1.0±0.100*	1.1±0.100*	1.6±0.100*
RI	SFO	1.4610±0.00006*	1.4614±0.00010*	1.4615±0.00010*	1.4615± 0.0.00006*	1.4617±0.00006*	1.4617±0.0001 0*	1.4618±0.00010*
	SFO:LSO	1.4725±0.00001*	1.4755±0.00001*	1.4756±0.00006*	1.4756± 0.00006*	1.4756±0.00006*	1.4757±0.0001 0*	1.4757±0.00010*
SG	SFO	0.9000±0.436	0.9500 ±0.010	0.9700±0.010	0.980 ±0.010	1.033 ±0.058	1.100 ±0.100*	1.030 ± 0.010
	SFO:LSO	1.033 ±0.058	1.011 ±0.006	1.030 ±0.006	1.040±0.010	1.080±0.010*	1.100±0.011*	1.130±0.010*

All the analysis were done in triplets mean (+/-SD); SFO- Sunflower oil, LSO- Linseed oil, FFA – Free Fatty Acid, PV – Peroxide Value, RSA – Radical Scavenging Activity, TPM – Total Polar Material, CVI- Colour Value Index, RI – Refractive Index, SG – Specific Gravity; Means with superscripts are significantly different as tested by Dunnett; *Significant at $p < 0.05$

Table 4: Fatty acid composition of sunflower oil during 6 frying cycles

Fatty acid	SFO	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
Palmitic acid (%)	5.45 ± 0.00*	5.50 ± 0.00*	5.55 ± 0.00*	5.65 ± 0.00*	5.72 ± 0.00*	5.95 ± 0.00*	6.20 ± 0.00*
Steric acid (%)	4.45 ± 0.00*	5.55 ± 0.00*	5.65 ± 0.00*	5.70 ± 0.00*	5.85 ± 0.00*	5.95 ± 0.00*	6.70 ± 0.00*
Oleic acid (%)	51.6 ± 0.00*	52.6 ± 0.00*	54.7 ± 0.00*	55.9 ± 0.00*	57.1 ± 0.00*	59.3 ± 0.00*	60.5 ± 0.00*
Linoleic acid (%)	37.4 ± 0.00*	13.56 ± 0.00*	13.12 ± 0.00*	13.09 ± 0.00*	13.03 ± 0.00*	12.6 ± 0.00*	12.2 ± 0.00*
Linolenic acid (%)	0.41 ± 0.00*	0.39 ± 0.00*	0.36 ± 0.00*	0.35 ± 0.00*	0.34 ± 0.00*	0.33 ± 0.00*	0.29 ± 0.00*
∑ SFA (%)	9.9 ± 0.00*	11.05 ± 0.00*	11.21 ± 0.00*	11.35 ± 0.00*	11.57 ± 0.00*	11.9 ± 0.00*	12.9 ± 0.00*
∑ MUFA (%)	51.6 ± 0.00*	52.6 ± 0.00*	54.7 ± 0.00*	55.9 ± 0.00*	57.1 ± 0.00*	59.3 ± 0.00*	60.5 ± 0.00*
∑ PUFA (%)	37.81 ± 0.00*	23.95 ± 0.00*	23.48 ± 0.00*	23.44 ± 0.00*	23.37 ± 0.00*	22.93 ± 0.00*	22.49 ± 0.00*
∑ P/S	3.8/1 ± 0.00*	2.1/1 ± 0.00*	2.09/1 ± 0.00*	2.06/1 ± 0.00*	2.01/1 ± 0.00*	1.9/1 ± 0.00*	1.7/1 ± 0.00*
∑ ω -6/ ω -3	91.2:1 ± 0.00*	34.7:1 ± 0.00*	36.4:1 ± 0.00*	39.7:1 ± 0.00*	38.3:1 ± 0.00*	38.1:1 ± 0.00*	42:1 ± 0.00*

All the analysis were done in triplets mean (+/-SD); SFO- Sunflower oil, ∑- Total, SFA - Saturated Fatty Acids, MUFA - Monounsaturated Fatty Acids, PUFA - Polyunsaturated Fatty Acids, ω – omega; Means with superscripts are significantly different as tested by Dunnett. *Significant at $p < 0.05$

Table 5: Fatty acid composition of the blend of sunflower oil: linseed oil (80:20) during 6 frying cycles

Fatty acid	SFO:LSO (80:20)	Cycle 1	Cycle 2	Cycle3	Cycle 4	Cycle 5	Cycle 6
Palmitic acid	6.2 ± 0.00*	8.41 ± 0.00*	7.22 ± 0.00*	8.83 ± 0.00*	9.09 ± 0.00*	8.62 ± 0.00*	7.89 ± 0.00*
Stearic acid (%)	4.54 ± 0.00*	9.33 ± 0.00*	8.43 ± 0.00*	8.09 ± 0.00*	8.10 ± 0.00*	7.03 ± 0.00*	5.44 ± 0.00*
Oleic acid (%)	46.18 ± 0.00*	56.67 ± 0.00*	56.08 ± 0.00*	58.53 ± 0.00*	59.95 ± 0.00*	42.31 ± 0.00*	45.33 ± 0.00*
Linoleic acid (%)	32 ± 0.00*	8.29 ± 0.00*	8.19 ± 0.00*	7.8 ± 0.00*	7.2 ± 0.00*	6.89 ± 0.00*	6.50 ± 0.00*
Linolenic acid (%)	11 ± 0.00*	10.46 ± 0.00*	10.76 ± 0.00*	9.43 ± 0.00*	8.93 ± 0.00*	6.46 ± 0.00*	6.29 ± 0.00*
∑ SFA (%)	10.74 ± 0.00*	17.74 ± 0.00*	15.65 ± 0.00*	16.92 ± 0.00*	17.19 ± 0.00*	15.65 ± 0.00*	13.33 ± 0.00*
∑ MUFA (%)	46.18± 0.00*	56.67 ± 0.00*	56.08 ± 0.00*	58.53 ± 0.00*	59.95 ± 0.00*	42.31 ± 0.00*	45.33 ± 0.00*
∑ PUFA (%)	43 ± 0.00*	18.75 ± 0.00*	18.95 ± 0.00*	17.23 ± 0.00*	16.13 ± 0.00*	13.35 ± 0.00*	12.79 ± 0.00*
∑ P/S	4.0 ± 0.00*	0.4/1 ± 0.00*	1.18/1 ± 0.00*	1.0/1 ± 0.00*	0.9/1 ± 0.00*	0.8/1 ± 0.00*	0.9/1 ± 0.00*
∑ ω -6/ ω -3	3:1 ± 0.00*	0.79:1 ± 0.00*	0.76:1 ± 0.00 0.00*	0.82:1 ± 0.00 *	0.80:1± 0.00*	1.0:1 ± 0.00*	1.0:1 ± 0.00*

All the analysis were done in triplets mean (+/-SD); SFO- Sunflower oil, LSO- Linseed oil, ∑- Total, SFA - Saturated Fatty Acids, MUFA - Monounsaturated Fatty Acids, PUFA - Polyunsaturated Fatty Acids, ω – omega; Means with superscripts are significantly different as tested by Dunnett. *Significant at $p < 0.05$

Effect of frying cycles on physico-chemical properties of SFO and SFO:LSO oil blend formulation (80:20)

Colour Value Index

Pure fats and fatty acids are colourless and devoid of spectral properties in the visible range. Pure refined sunflower oil is very light in colour as compared to the formulated oil blend. Blending of the two oils (namely, sunflower and linseed) resulted in an increase in the colour value index when compared with the sunflower oil i.e. the base oil. Linseed oil is highly reactive towards oxygen, which results in auto oxidation, polymerization and yellowing (Knorr 1995).

SFO and the SFO:LSO blend were analysed for the Color Value index . The color value index (in terms of yellow and red color) of individual oils, SFO was 0.6 and 1.8 and LSO was 5.2 and 0.3.

The color value index of SFO increased from 0.6 - 0.8 (yellow units) and from 5.2 – 5.6 (red units). There was also an increase in the Color value index of SFO:LSO (80:20) blend from 1.8 – 2 (yellow units) and 0.5 – 1.7 (red units) through 6 frying cycles .The change in the color value index, (in terms of yellow and red color) also increased from through 6 frying cycles with an increase of 5.7% (yellow color) and 152.3% (red color). The trend for the change in the colour values of control (SFO) and blended oil formulation (SFO : LSO ; 80 : 20) is presented in figures 11 and 12.

Refractive Index

SFO and SFO:LSO blend formulated were analysed for the refractive index. The refractive index of SFO and SFO:LSO oil was 1.4611 and 1.4725 respectively.

During 6 frying cycles, the refractive index of SFO increased from 1.4611 – 1.4618 and of SFO:LSO (80:20) blend from 1.4755 – 1.4757. The trend in the change of the refractive index during 6 frying cycles of Control (SFO) and blended oil formulation (SFO : LSO ; 80 : 20) is discussed in Table 3.

Specific Gravity

Specific gravity of oil is defined as the ratio of the weight in air of a given volume of the oil at 30^0 C to the weight of an equal volume of water at 30^0C. The specific gravity of the SFO was 0.900 units and of SFO:LSO (80:20) blend was 1.00 units. During 6 frying cycles, the Specific Gravity of SFO increased from 0.94 – 1.03 units and of SFO:LSO (80:20) blend from 1.02 -1.12 units (Table 3). The rise in the specific gravity observed may be attributed to the formation of polymeric fractions of high molecular weight (Gupta 2005).

Free fatty acid content

FFA is considered to be an indicator of oil quality in food industry as it leads to development of off-flavour in oils and fried products. SFO and SFO:LSO oil blend were analysed for free fatty acid content. As the number of frying cycles increased, the free fatty acid content and acid value also increased. The FFA content of sunflower oil increased from 0.028% – 0.017% (% oleic acid) during 6 frying cycles. The trend in the increase in the FFA content (%) during 6 frying cycles of Control (SFO) and blended oil formulation (SFO: LSO; 80: 20) is represented in table 3.

According to the FSSR standard (2011), the FFA should be 0.5%. Therefore, the blended oil formulated using SFO:LSO (80:20) was considered safe for consumption even up to 6 frying cycles.

Peroxide value

Peroxides are the foremost initial reaction products of lipid oxidation, which are responsible for primary oxidation. Oil initially forms hydro-peroxide compounds, which are a good indicator of lipid oxidation under normal conditions. However, at higher temperatures, it breaks and forms secondary oxidation products during cooling.

In the present study, during 6 frying cycles, PV of SFO increased from 0.05 – 3.0 meq O_2/kg and of SFO:LSO (80:20) blend from 1.3 - 3.9 meqO_2/kg.

The rise in peroxide was in the limits as per the standards given by FSSR (2011), fresh oils usually have PV well below 10 meq O_2/kg. A rancid taste often begins to be noticeable when PV is > 20 meqO_2/kg. In the present study, the blended oil showed a comparatively higher degree of degradation from first to the sixth cycle, though the rise in the peroxide was within limits. The trend in the increase of the PV during 6 frying cycles of Control (SFO) and blended oil formulation (SFO:LSO; 80: 20) during 6 frying cycles is discussed in Table 3.

Radical Scavenging Activity (RSA)

Sunflower oil contains natural antioxidants. With a content of tocopherols of 50-150mg/100 g sunflower oil belongs to the vitamin-E-rich oils. Alpha-tocopherol, which shows the highest biological activity comprises more than 90% of the total tocopherols in sunflower oil, making this oil an interesting source of this vitamin (AOCS 1996). The tocopherols present in the oil blend were able to quench the free radicals to some extent during the frying experiments. The RSA of SFO and SFO:LSO blend was 65.0% and 54.5% respectively. Changes in the RSA of the Control (Sunflower oil) and blended formulation oil (SFO: LSO ; 80 : 20) during 6 frying cycles are discussed in Table 3. During 6 frying cycles, the ability of SFO and SFO:LSO blend to quench DPPH radicals changed from 59.6% to 43.7% and 36.6% to 5.7% respectively. A significant difference was seen in the RSA (%) of the control and blended oil formulation (SFO: LSO; 80: 20) during 6 frying cycles.

No standards for RSA are given by FSSR 2011.

Total Polar Material

Total polar material (TPM) is one of the most valid and objective criteria for the evaluation of deterioration of oils and fats during deep-fat frying.

During 6 frying cycles, the TPM of SFO increased from 0.14% to 0.47% and of SFO:LSO (80:20) blend from 0.26% to 0.88%.The trend in the change of the TPM during 6 frying cycles of Control (SFO) and blended oil formulation (SFO : LSO ; 80 : 20) is discussed in Table 3. No standards for Total Polar Material are given by FSSR 2011.

During frying, as peroxides/hydroperoxides break down, short chain fatty acids, aldehydes, ketones, alcohols and non-votalite end products are formed in the frying oil. These cause some molecules in oils to become polar (Xu et al. 1999). This rise could be due the production of peroxides/hydroperoxides break down, short chain fatty acids, aldehydes, ketones, alcohols and non-votalite end products in the frying oil. These cause some molecules in oils to become polar (Xu et al. 1999). The polar material is an indicator for the extent of deterioration of oils used for frying. The total polar material consists of polymeric, cyclic nonvolatile substances (resulting from oxidation and hydrolysis) including soluble constituents leached from the fried products. Therefore the blended oil formulation was considered safe for consumption as the level of polar material has been fixed to 25-27% as the threshold point for discarding the frying oil (Mellema 2003; Sanibal and Mancini-Filho 2004). As the viscosity of the oil increases with frying, the polar materials also increased with the consecutive frying (Stier 2001).

Sensory evaluation of mathries prepared with SFO:LSO (80:20) blended oil

Mathries were prepared by incorporating the blended oil in the dough development and frying the mathries in the blended oil formulation. A comparison of sensory attributes namely appearance, colour, taste, texture, odour, aftertaste and overall acceptability are discussed in Table 6.

Organoleptic evaluation (Table 6) of the mathries revealed that, there was no significant difference (p = < 0.05) in all the sensory parameters i.e. appearance, colour, texture, taste, aftertaste and overall acceptability of mathries fried in control (SFO) and experimental oil blend (SFO : LSO ; 80 : 20). Mean scores of the control (SFO) as well as the experimental sample (SFO : LSO ; 80 : 20) were found to have no significant difference. Both of the samples had similar acceptability.

A difference, though insignificant was seen in aftertaste and color. This could be due to the development of lipid peroxidation products such as malondialdehyde (MDA). Studies have reported that the high ALA content of the flaxseed oil could produce lipid peroxidation products such as MDA, which could be undesirable in baked products (prepared using flaxseed oil) or in ground raw flaxseed (Cunnane et al. 1993).

Table 6: Sensory evaluation of the Mathries fried in SFO and SFO:LSO

Characteristics	Rating	Subjects (N=40)	Subjects (N=40)	Chi Square Critical	P Value
		Control (SFO)	Experimental (SFO : LSO; 80 : 20)		
Appearance (20)	12	1	0	12.59	0.67
	15	1	2		
	16	4	4		
	17	7	9		
	18	12	15		
	19	9	8		
	20	6	2		
Texture (20)	12	1	0	14.06	0.21
	14	1	1		
	15	2	2		
	16	1	3		
	17	5	13		
	18	18	13		
	19	10	8		
	20	3	0		
Colour (20)	10	1	0	15.50	0.41
	14	0	1		
	15	1	2		
	16	4	2		
	17	4	9		
	18	15	16		
	19	11	8		
	19.5	0	1		
	20	4	1		
Aftertaste (20)	12	1	0	14.06	0.15
	14	0	1		
	15	2	2		
	16	1	3		
	17	5	13		
	18	18	13		
	19	10	8		
	20	3	0		
Taste (20)	12	1	0	14.06	0.16
	14	0	1		
	15	2	2		
	16	1	3		
	17	5	13		
	18	18	13		
	19	10	8		
	20	3	0		
Odour (20)	12	1	0	12.59	0.34
	15	1	2		
	16	1	3		
	17	3	6		
	18	17	18		
	19	14	11		
	20	3	0		
Overall Acceptability (5)	3	3	1	9.48	0.29
	3.5	4	9		
	4	25	24		
	4.5	6	6		
	5	2	0		

*p significant at < 0.05; SFO – Sunflower Oil, LSO – Linseed Oil

Image 1: Mathries prepared with the Sunflower oil (CODE 1) and blended oil (SFO: LSO; 80:20) formulation (CODE 2)

4. CONCLUSIONS

By blending different types of oils, the consumer can be offered a better quality product with respect to flavor and nutritive value. In the last century, there has been a more emphasis on edible oils based on regional production due to traditional taste and flavor preferences in the different regions. Some unconventional oils such as soyabean and palmolein came into production since the last 20 years, which were being accepted by the general public only in their refined form. Blending would also reduce the pressure for regional preferences of specific individual oil, thereby indirectly helping in stabilizing the edible oil price in a country (Chopra et al. 2004).

Considering the merits and demerits of single oil as a cooking medium, blended oil may be more suitable for culinary and frying purposes. By blending, different oils the fatty acid ratios gets balanced which is nutritionally beneficial and blended oils shows better thermal and oxidative stability (Siddique et al. 2015; Siddeeg and Xia 2015; Chugh and Dhawan 2014; Mishra and Sharma 2014). Therefore, from the present study it may be concluded that blending of linseed oil at 20 % level into sunflower oil is a viable option to formulate an oil blend with a balanced omega 6: omega 3 ratio.

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