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# Designing edible oil blends to achieve ideal fatty acid composition for human consumption

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## Abstract

**Aim:** To study the effect of blending on improvement of nutritional properties and oxidative stability of edible oils.

**Methodology:** Two hundred and thirty one blends were formulated by mixing oils of five different oilseed crops viz. Indian mustard (MUS), canola oilseed rape (CNL), sesamum (SES), sunflower (SUN) and groundnut (GNT) in different proportions. The fatty acid profile of oil blends were analyzed using Gas chromatography.

**Results:** Fatty acid analysis helped in selecting a total of 26 blends out of 231 blends on the basis of saturated fatty acid (SFA) content < 10%; ideal ω-6: ω-3 ratio (3.5-10:1) and proportion of oleic acid >50%. These oil combinations also possessed high smoke point (241.3-253.77°C) and oil stability index (OSI) (1.48-2.74) indicating their suitability for cooking at higher temperatures.

**Interpretation:** The results clearly show an increase in the OSI of both SUN and SES oil on blending with CNL oil, alternatively, CNL oil get benefitted with EFAs due to blending with SUN and SES oil. The blends of CNL with SUN and SES were more suitable compared to single oils and introducing them in the market holds the potential to reduce malnourishment and associated ill health.

**Key words:** Edible oils, Oxidative stability, Saturated fatty acids, Smoking point, Vegetable oils

Formulation of 231 oil blends using mustard (MUS), canola (CNL), sunflower (SUN), sesame (SES), groundnut (GNT) oils extracted from released varieties

⬇

Fatty acid profiling of oil blends using Gas chromatography

⬇

Criteria for selecting healthy edible oil blends
- Saturated fatty acid content <10%
- Essential fatty acid ratio (ω6: ω3): 3.5-10:1
- MUFA (oleic acid) content >50%

⬇

Out of 231 oil blends, twenty-six selected oil blends viz., CNL:SUN:SES (B1-B9), CNL:SUN (B10-B16) and CNL:SES (B17-B26) were found to possess high nutritional value and smoke point

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## Introduction

The quality and stability are the key elements of any good vegetable oil which help in predicting the market value and acceptability of oils. Fatty acid composition plays an important role in determining the quality of any oil. Oils differ widely in their fatty acid carbon chain length and number of double bonds, for example, saturated fatty acid (SFA) namely palmitic acid ($C_{16:0}$), stearic acid ($C_{18:0}$); monounsaturated fatty acid (MUFA) like oleic acid ($C_{18:1}$) and polyunsaturated fatty acid (PUFA) such as linoleic acid (ω-6; $C_{18:2}$) and linolenic acid (ω-3; $C_{18:3}$).

A different proportion of these fatty acids are required for maintaining good health. Many dietary recommendations advice to reduce the SFA intake and consume more PUFAs as high levels of SFA in oil elevate the level of LDL (low density lipoprotein) cholesterol in blood which may cause the risk of cardiovascular diseases, obesity and diabetes (Zhu *et al.,* 2019). In view of this, WHO has recommended 10% SFA as the acceptable limit in edible oils and, hence, oils with high SFA should be avoided (WHO, 2018). Rapeseed-mustard oils possess low level of saturated fats (<7%) in comparison to any other vegetable oil such as olive (15.03-20.48%), soyabean (13.5-18.3%), sesamum (14-36.43%), rice bran (15.4-24.77%), palm (12.3-49.45%), groundnut (10.7-19.2%) and sunflower oil (8.5-12.36%) (Awogbemi *et al.,* 2019; Orsavova *et al.,* 2015). Another important group of fatty acids are PUFAs also known as essential fatty acids (EFAs) as these cannot be synthesized by mammals and hence, need to obtain from the diet.

Diet with high intake of EFAs increase high density lipoprotein (HDL) cholesterol (healthy) and decreases LDL-cholesterol (non-healthy) levels. It is essential to strike a right balance between the two EFAs *viz.,* linoleic (ω-6) and linolenic acid (ω-3) which is considered important nutritionally and is recommended in the ratio of 5-10:1 or lower to prevent heart disease, cancer, inflammatory and autoimmune diseases (ICMR, 2010). The changing diet patterns have shown consumption of food rich in ω-6 with very less amount of ω-3 which leads to increase in ω-6: ω-3 ratio (14:1 to 20:1) resulting in diseases such as cancer, diabetes, artherosclerosis, obesity and high blood pressure (Simopoulos, 2016). A variety of oilseeds such as palm, soybean, sunflower, groundnut, coconut, olive and rapeseed are consumed worldwide for edible purposes, however, individually these oils do not yield balanced ω-6: ω-3 ratio. Apart from quality of an oil, resistance to oxidative deterioration after cooking and on storage is also an important consideration for selecting an ideal oil which does not get oxidized or rancid easily.

Although, MUFA (oleic acid; $C_{18:1}$) is non-essential for humans but its presence in oil imparts oxidative stability. Oil stability index (OSI) is the ratio of oleic acid to linoleic acid and is related to shelf life of oil. Higher the OSI value, longer the shelf life. Stability of oils with short shelf life can be enhanced by blending with the oils having longer shelf life being rich in oleic acid (Anwar *et al.,* 2007; Premavalla *et al.,* 1998).

Oils with high oxidative stability and high smoke point are considered good for frying (Kochhar, 2002). Minor constituents like chlorophylls, carotenoids, phenolics, squalene etc also affect the stability and quality of vegetable oils (Uncu and Ozen, 2019). Vegetable oil with low SFA; high oxidative stability; good flavor and free from trans fats are considered of good quality. Unfortunately, none of the oils possess ideal EFAs ratio and satisfactory oxidative stability requirement (Hashempour-Baltork *et al.,* 2017). Studies have proved that oil blending helps in producing vegetable oils with good storage life and optimum fatty acid composition (Sura *et al.,* 2020; Roiaini *et al.,* 2015); however, scanty information is available on selection of oil blends with ideal omega6: omega3 ratio and high smoke point. Keeping the advantage of blending into consideration, we aimed to pool all the significant properties of these oils in one blend with high oxidative stability and improved nutritional properties which could raise its applicability.

## Materials and Methods

**Oil extraction:** Oil was extracted from seed samples of released varieties *viz.,* canola oilseed rape (*Brassica napus*) cv. GSC 7 (CNL), sunflower (*Helianthus annuus*) cv. PSH 1962 (SUN), sesamum (*Sesame indicum*) cv. Punjab Til No. 2 (SES), Indian mustard (*Brassica juncea*) cv. Giriraj (MUS) and groundnut (*Arachis hypogaea*) cv. SG 99 (GNT) using mini oil extractor. Seed samples were procured and the study was performed at Oilseeds Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, India.

**Formulation of oil blends:** A total 231 oil blends were formulated by mixing two or three oils together in different proportions following the instructions by Prevention of Food Adulteration (PFA) act which states that the proportion by weight of any edible vegetable oil used in the blend should not be less than 20% (PFA, 1954). The criteria for selecting healthy edible oil blend was to obtain SFA <10%; ω-6: ω-3 ratio (3.5-10:1) and > 50% oleic acid content.

**Fatty acid profiling:** Fatty acid profiling was carried out by preparing esters from oil samples following the method of Appelqvist (1968) and further 1µl was injected at a split ratio of 80:1 onto the FAME column CP-Sil 88 with dimensions 25m x 0.25mm x 0.20mm fitted in the gas chromatography (GC) model 7820A series (Agilent technologies) attached to a flame ionization detector and using $N_2$ as a carrier gas. The separation was carried out at oven temperature programmed at 180-200°C (rate 4°C $min^{-1}$). Temperatures of detector and injector were maintained at 240 and 230°C, respectively. The flow rate of nitrogen, hydrogen and air were 60, 30 and 30ml $min^{-1}$, respectively. Retention time ($R_T$) of standard fatty acyl esters were used for identification of peaks. The relative concentration of each fatty acid was calculated using EZ Chrome elite software. Individual fatty acids were expressed as percentages of total fatty acids.

**Smoke point:** The smoke point of oil samples were estimated following the method of Das *et al.* (2013). A beaker was filled with an oil sample a few cm below the rim of the beaker to make the smoke easily visible. The temperature at which a thin continuous stream of bluish smoke appears was recorded with the help of an infrared thermometer.

**Statistical analyses:** Analysis of variance of the data obtained was done by using completely randomized design (CRD) for different treatments using computer program CPCS (2008).The data was subjected to analysis of variance at LSD ($p<0.05$) using SAS 9.3.

## Results and Discussion

Fatty acid composition (as % total fatty acid) of five oils including canola oilseed rape (GSC 7) (CNL), sunflower (PSH 1962) (SUN), sesame (PbTil no.2) (SES), mustard (Giriraj) (MUS) and groundnut (SG 99) (GNT) is presented in Table 1. A total of 231 blends formulated by mixing these oils in different proportions and their fatty acid profiles are shown in Supplementary Table 1. The criteria for selecting healthy edible oil blends was to obtain less than 10% SFA; 3.5-10:1 ω-6: ω-3 ratio and > 50% oleic acid in the oils. The fatty acid profile of selected vegetable oil blends (B1-26) is presented in Table 2. Fatty acid profile of tested oils comprised of mixture of SFA {palmitic acid ($C_{16:0}$), stearic acid ($C_{18:0}$), arachidic acid ($C_{20:0}$), behenic acid ($C_{22:0}$)}, unsaturated fatty acids (UFA) which are classified as MUFA (oleic acid; $C_{18:1}$) and PUFA {linoleic acid ($C_{18:2}$, ω-6) and linolenic acid ($C_{18:3}$, ω-3)}. In addition to this, another class of very long chain fatty acid (VLCFA) with C>20 such as eicosenoic acid ($C_{20:1}$), erucic acid ($C_{22:1}$), and behenic acid ($C_{22:0}$) were also found in some oils.

The SFA was highest in SES (14.63%) followed by GNT (12.32%), SUN (9.19%), CNL (5.51%) and MUS (3.09%) oil. Saturated fats are responsible for raising the blood cholesterol level and increase the risk of heart disease. WHO has recommended that total intake of SFA should not exceed 10% of the total fatty acids concentration (WHO, 2018). Among the five oils studied, only CNL, SUN, MUS agree to this recommendation. Arachidic acid ($C_{20:0}$) and behenic acid ($C_{22:0}$) was present only in GNT oil. The SFA content in all 231 vegetable oil blends ranged from 4.04 (50MUS:50CNL) to 16 % (75GNT:25SES) (Supplementary Table 1; Fig.1a). A total of 94 blends mixed in different proportions namely, MUS:SUN:SES (6.80-9.74%); MUS:CNL (4.04%); MUS:SUN (4.18-8.30%); MUS:SES (5.90-9.69%); CNL:SES (7.73-9.98%); CNL:SUN (6.38-8.70%); CNL:SUN:SES (8.09-9.93%); CNL:GNT (7.93-9.97%) and CNL:GNT:SUN (8.09-9.95%) were selected based on their SFA content less than 10%. Two PUFAs, namely, linoleic acid ($C_{18:2}$; ω-6) and linolenic acid ($C_{18:3}$; ω-3) are not synthesized in mammals, hence, they are classified as EFA and need substitution from food sources. High nutritional value contributed by EFA, place these edible oils in the list of important pillars of food industry. Linoleic acid ($C_{18:2}$) was highest in SUN (48.71%) followed by SES (43.32%), GNT (23.38%), CNL (16.13%) and MUS oil (15.46%) whereas linolenic acid ($C_{18:3}$) was predominant in mustard (18.16%) followed by CNL (8.58%), GNT oil (1.39%) and completely absent in SES and SUN oil.

The values for EFAs obtained in these five oils were supported by various studies which reported variation for linoleic acid ($C_{18:2}$) from 21.58-52% in SUN, 40.9-47.9% in SES, 18.2-43% in GNT, 15-30% in CNL and 14.38-39.36% in MUS oil. Linolenic acid ($C_{18:3}$) content varied from 5.84-17.79% in MUS, 2.63-10% in CNL, 0-1.5% in GNT, 0-0.3% in SUN and 0-0.4% in SES oil (Agidew *et al.,* 2021; Konuskan *et al.,* 2019; Sharma *et al.,* 2019; Sen *et al.,* 2018; Matthaus *et al.,* 2016; Orsavova *et al.,* 2015). Apparently, high UFA in oils can pose a problem to health because of their susceptibility towards oxidation, which can change the taste, aroma, color and deteriorate the oil quality by making it unfit for consumption. A proper balance has to be maintained between these two PUFAs for maintaining cardiovascular health. The ω-6: ω-3 ratio of vegetable oils indicates nutritional quality index (NQI) of oil and was recorded highest in SUN oil (48.70) followed by SES (43.32), GNT (16.88), CNL (1.88) and MUS oil (0.85). As per the WHO recommendations, ω-6: ω-3 ratio must be 5-10:1 in the diet. Simopoulos (2009) also reported that a ratio of 2-3:1 suppressed inflammation in patients with rheumatoid arthritis and a ratio of 5:1 has beneficial effect on patient with asthma and if the ratio approaches to 10:1 then it may lead to adverse effects on health.

Oils such as SUN, SES and GNT with low or no ω-3 leads to increase in ω-6: ω-3 ratio. Prolonged ingestion of such oils, without supplementing with ω-3 from other sources, gradually leads to chronic diseases such as cancer, inflammatory and autoimmune diseases. Ninety-four oil blends with SFA content <10% were further screened for their ideal ω-6: ω-3 ratio (3.5-10:1) as the ratio contributes to the nutritional aspects of oil. Out of 94 blends, 44 blends *viz.,* MUS: SES (3.69-4.02), MUS: SUN (3.72-9.90), MUS: GNT (3.43-9.41), CNL: SES (3.70-9.70), CNL: SUN (3.61-9.27), CNL:SUN: SES (5.74-9.37), MUS: SUN: SES (4.12-9.96) were shortlisted (Fig. 1b) and were further evaluated for their oleic acid content as oleic acid imparts oxidative stability and longer shelf life to oil (Braddock *et al.,* 1995). Its presence also lowers the cholesterol level contributing to prevention of cardiovascular disease; reduce blood pressure and serum lipoprotein levels (Noh and Yoon, 2012). The decreasing trend followed by the five vegetable oils for oleic acid ($C_{18:1}$) content was CNL (68.42%) > GNT (60.52 %) > SUN (42.11%) > SES (42.06%) > MUS (10.52%) which are in accordance with other research findings where oleic acid content ranged from 51 to 70% in CNL, 50-71.1% in GNT, 27-82.87% in SUN, 39-42% in SES and 9.56-18.69% in MUS oil (Zahran and Tawfeauk, 2019; Sharif *et al.,* 2017; Orsavova *et al.,* 2015).

The Oil stability index (OSI) is the ratio of oleic acid to linoleic acid (O/L) and it is an established method for predicting relative oil shelf life. Davis *et al.* (2016) reported that peanut with high O/L ratio (upto 9% or higher) results in increased shelf life (upto 10 times) and improved flavor compared to normal O/L ratio (~1.5:1). High oleic acid also lowers the bad cholesterol (LDL) level in the body (Kris-Etherton *et al.,* 1999). Additionally, high

**Table 1:** Fatty acid composition and smoke point of five different vegetable oils extracted from released varieties

| Oils | Fatty acid composition (%) | | | | | | | | NQI ($\omega$-6: $\omega$-3) | OSI ($C_{18:1}$/$C_{18:2}$) | Smoke point (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | SFA | MUFA | PUFA | | VLCFA | | | | | | |
| | Palmitic $C_{16:0}$ + Stearic $C_{18:0}$ | Oleic $C_{18:1}$ | Linoleic $C_{18:2}$ | Linolenic $C_{18:3}$ | Eicosenoic $C_{20:1}$ | Erucic $C_{22:1}$ | Arachidic $C_{20:0}$ | Behenic $C_{22:0}$ | | | |
| Canola (GSC 7) | 5.51±0.02 | 68.42±0.02 | 16.13±0.04 | 8.58±0.01 | ND | 1.37±0.01 | ND | ND | 1.88±0.00 | 4.24±0.02 | 254.93±0.64 |
| Sunflower (PSH 1962) | 9.19±0.51 | 42.11±0.43 | 48.71±0.04 | ND | ND | ND | ND | ND | 48.70±0.04 | 0.86±0.02 | 245.50±0.44 |
| Sesame (Pb Til no.2) | 14.63±0.76 | 42.06±0.09 | 43.32±0.07 | ND | ND | ND | ND | ND | 43.32±0.07 | 0.97±0.00 | 226.67±0.64 |
| Mustard (Giriraj) | 3.09±0.08 | 10.52±0.02 | 15.46±0.07 | 18.16±0.04 | 0.43±0.07 | 52.35±0.03 | ND | ND | 0.85±0.01 | 0.68±0.01 | 239.40±0.46 |
| Groundnut (SG 99) | 12.32±0.01 | 60.52±0.01 | 23.38±0.03 | 1.39±0.01 | ND | ND | 1.30±0.04 | 0.92±0.01 | 16.88±0.08 | 2.60±0.01 | 228.47±0.59 |

SFA: Saturated fatty acid; MUFA: Mono-unsaturated fatty acid; PUFA: Polyunsaturated fatty acid; VLCFA: Very long chain fatty acid; NQI: Nutritional quality index; OSI: Oil stability index; ND: not detected

**Table 2:** Fatty acid composition and smoke point of vegetable oil blends selected as per WHO recommendations

| Code | Oil blend | Ratio | Fatty acid composition (%) | | | | | | NQI ($\omega$-6: $\omega$-3) | OSI ($C_{18:1}$/ $C_{18:2}$) | Smoke point (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SFA | MUFA | PUFA | | Total PUFA | VLCFA | | | |
| | | | Palmitic + Stearic $C_{16:0}$ + $C_{18:0}$ | Oleic $C_{18:1}$ | Linoleic $C_{18:2}$ | Linolenic $C_{18:3}$ | | Erucic $C_{22:1}$ | | | |
| B1 | CNL:SUN:SES | 60:20:20 | 8.85±0.09 | 57.31±0.04 | 28.29±0.02 | 4.93±0.03 | 33.22 | 0.64±0.02 | 5.74±0.03 | 2.03±0.00 | 248.27 |
| B2 | CNL:SUN:SES | 50:25:25 | 8.99±0.03 | 56.82±0.02 | 29.43±0.02 | 4.38±0.02 | 33.81 | 0.39±0.03 | 6.72±0.03 | 1.93±0.00 | 246.03 |
| B3 | CNL:SUN:SES | 40:30:30 | 9.27±.06 | 52.78±0.05 | 33.53±0.07 | 4.12±0.04 | 37.65 | 0.32±0.01 | 8.15±0.05 | 1.58±0.01 | 244.57 |
| B4 | CNL:SUN:SES | 30:30:40 | 9.22±0.31 | 52.49±0.08 | 34.37±0.09 | 3.67±0.11 | 38.04 | 0.26±0.02 | 9.37±0.26 | 1.53±0.00 | 241.33 |
| B5 | CNL:SUN:SES | 35:30:35 | 8.84±0.15 | 51.78±0.07 | 35.10±0.03 | 3.99±0.03 | 39.09 | 0.30±0.02 | 8.80±0.06 | 1.48±0.00 | 242.50 |
| B6 | CNL:SUN:SES | 40:20:40 | 9.46±0.14 | 54.06±0.03 | 32.64±0.04 | 3.53±0.06 | 36.17 | 0.33±0.01 | 9.25±0.14 | 1.66±0.00 | 243.20 |
| B7 | CNL:SUN:SES | 55:20:25 | 8.95±0.09 | 56.13±0.02 | 30.88±0.04 | 3.47±0.09 | 34.35 | 0.58±0.01 | 8.90±0.24 | 1.82±0.01 | 247.20 |
| B8 | CNL:SUN:SES | 50:30:20 | 8.83±0.05 | 56.39±0.07 | 30.72±0.05 | 3.61±0.03 | 34.33 | 0.46±0.02 | 8.51±0.08 | 1.84±0.01 | 245.30 |
| B9 | CNL:SUN:SES | 45:25:30 | 9.09±0.06 | 55.04±0.00 | 30.93±0.06 | 4.58±0.04 | 35.51 | 0.38±0.01 | 6.75±0.07 | 1.78±0.01 | 244.63 |
| B10 | CNL:SUN | 50:50 | 8.02±0.15 | 54.75±0.05 | 33.19±0.04 | 3.58±0.02 | 36.77 | 0.47±0.01 | 9.27±0.04 | 1.66±0.00 | 250.87 |
| B11 | CNL:SUN | 60:40 | 7.27±0.07 | 58.09±0.00 | 29.50±0.01 | 4.51±0.02 | 34.01 | 0.64±0.01 | 6.54±0.03 | 1.97±0.00 | 251.50 |
| B12 | CNL:SUN | 70:30 | 7.40±0.07 | 59.86±0.08 | 26.82±0.04 | 5.27±0.03 | 32.09 | 0.67±0.01 | 5.09±0.02 | 2.23±0.01 | 252.73 |
| B13 | CNL:SUN | 80:20 | 6.38±0.10 | 63.32±0.04 | 23.15±0.04 | 6.41±0.04 | 29.56 | 0.76±0.01 | 3.61±0.02 | 2.74±0.01 | 253.77 |
| B14 | CNL:SUN | 55:45 | 7.53±0.13 | 57.87±0.02 | 29.86±0.09 | 4.29±0.06 | 34.15 | 0.59±0.02 | 6.96±0.08 | 1.95±0.01 | 251.00 |
| B15 | CNL:SUN | 65:35 | 6.68±0.04 | 59.17±0.01 | 28.86±0.01 | 4.63±0.00 | 33.49 | 0.67±0.02 | 6.24±0.01 | 2.06±0.00 | 252.20 |
| B16 | CNL:SUN | 75:25 | 6.53±0.06 | 61.82±0.02 | 25.66±0.08 | 5.30±0.04 | 30.96 | 0.71±0.01 | 4.84±0.05 | 2.42±0.01 | 253.00 |
| B17 | CNL:SES | 50:50 | 9.19±0.12 | 55.27±0.02 | 30.09±0.02 | 4.95±0.03 | 35.04 | 0.51±0.01 | 6.08±0.03 | 1.83±0.00 | 244.77 |
| B18 | CNL:SES | 60:40 | 8.48±0.11 | 58.33±0.07 | 26.68±0.05 | 5.87±0.01 | 32.55 | 0.65±0.01 | 4.54±0.02 | 2.19±0.01 | 246.17 |
| B19 | CNL:SES | 40:60 | 9.84±0.03 | 53.68±0.13 | 32.74±0.02 | 3.42±0.06 | 36.16 | 0.34±0.02 | 9.59±0.15 | 1.64±0.01 | 243.13 |
| B20 | CNL:SES | 70:30 | 7.73±0.07 | 60.88±0.12 | 24.19±0.08 | 6.53±0.04 | 30.72 | 0.68±0.01 | 3.70±0.03 | 2.52±0.02 | 248.77 |
| B21 | CNL:SES | 80:20 | 7.94±0.11 | 57.02±0.06 | 29.82±0.01 | 4.49±0.07 | 34.31 | 0.73±0.01 | 6.64±0.10 | 1.92±0.00 | 250.27 |
| B22 | CNL:SES | 55:45 | 9.07±0.08 | 57.16±0.05 | 28.09±0.01 | 5.13±0.05 | 33.22 | 0.57±0.02 | 5.48±0.06 | 2.04±0.00 | 245.03 |
| B23 | CNL:SES | 45:55 | 9.58±0.06 | 53.04±0.02 | 33.00±0.01 | 4.04±0.03 | 37.04 | 0.35±0.01 | 8.17±0.06 | 1.61±0.00 | 244.00 |
| B24 | CNL:SES | 65:35 | 8.59±0.11 | 58.43±0.02 | 26.94±0.04 | 5.39±0.08 | 32.33 | 0.67±0.01 | 5.00±0.06 | 2.17±0.01 | 247.17 |
| B25 | CNL:SES | 35:65 | 9.98±0.04 | 51.54±0.03 | 34.62±0.04 | 3.57±0.02 | 38.19 | 0.31±0.01 | 9.70±0.06 | 1.49±0.00 | 241.30 |
| B26 | CNL:SES | 75:25 | 7.85±0.11 | 61.07±0.05 | 24.12±0.04 | 6.27±0.02 | 30.39 | 0.70±0.01 | 3.85±0.01 | 2.54±0.01 | 249.87 |
| | **Mean±S.E** | | **8.60±0.10** | **56.70±0.06** | **29.49±0.08** | **4.53±0.07** | | **0.43±0.01** | **6.94±0.12** | **1.96±0.01** | **247.25±0.39** |
| | Range | | 7.27-9.98 (B11-B25) | 51.54-63.32 (B25- B13) | 23.15-35.10 (B13- B5) | 3.42-6.52 (B19- B20) | 29.56-39.09 (B13-B5) | 0.26-0.76 (B4- B13) | 3.61-9.70 (B13- B25) | 1.48-2.74 (B5- B13) | 241.30-253.77 (B25-B13) |
| | CD (p<0.05) | | 0.334 | 0.133 | 0.909 | 0.32 | | 0.738 | 0.952 | 0.76 | 0.65 |

Values are mean ± S.D. significant at 5%; CNL: canola oil; SUN: Sunflower oil; SES: Sesame oil; SFA: Saturated fatty acid; MUFA: Mono-unsaturated fatty acid; PUFA: Polyunsaturated fatty acid; VLCFA: Very long chain fatty acid; NQI: Nutritional quality index; OSI: Oil stability index

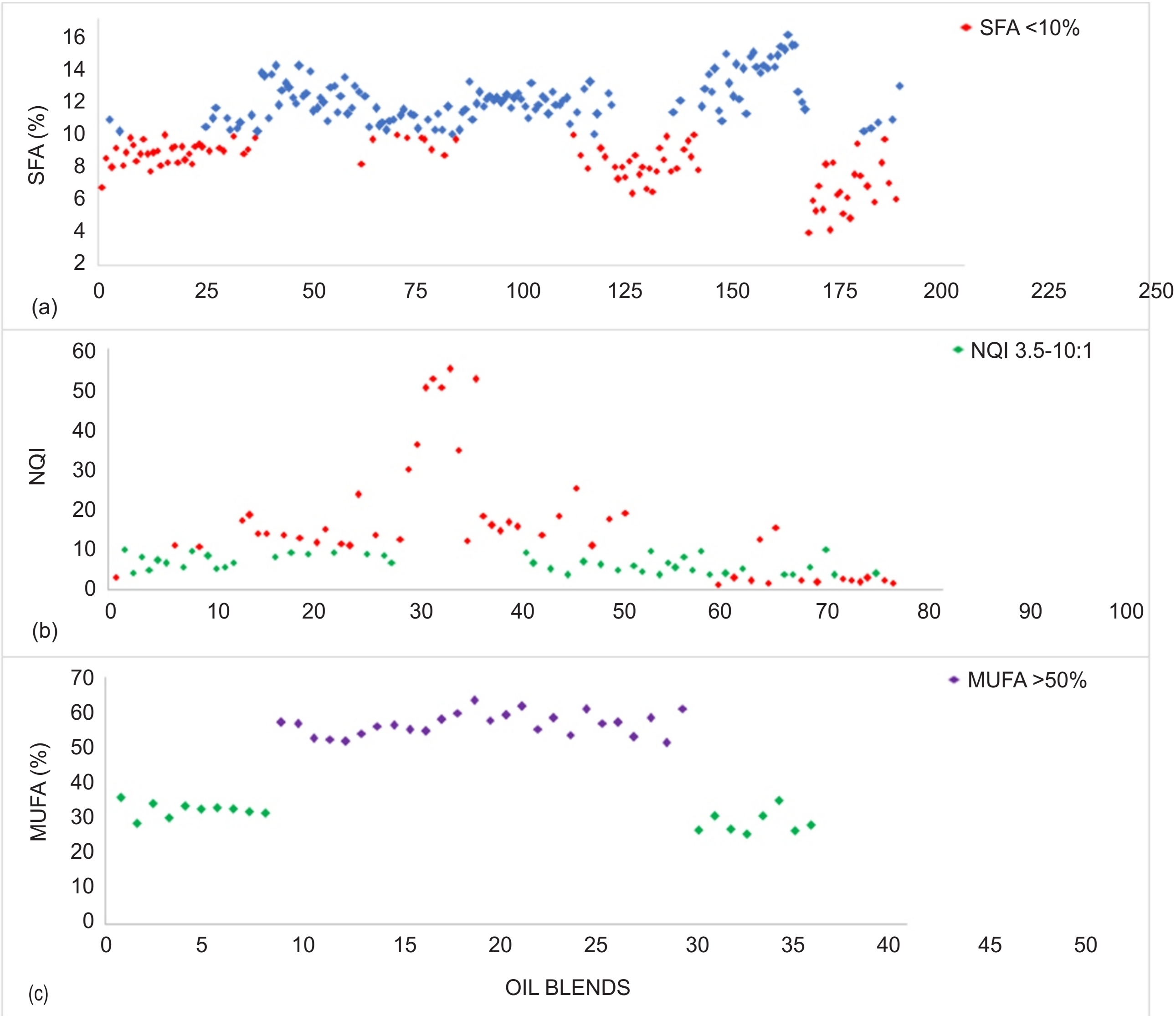


**Fig.1:** Variation in SFA, NQI and MUFA content of 231 vegetable oil blends prepared by mixing CNL, SUN, SES, MUS and GNT oil in different proportions (a) indicate 94 selected blends out of 231 with SFA content <10%; (b) indicate 44 selected blends out of 94 with ideal NQI and (c) indicate 26 selected blends out of 44 with >50% MUFA content.

oleic acid in oil leads to high smoking point, faster cooking and less oil absorption (Miller *et al.,* 1987). The OSI was highest in CNL (4.24) followed by GNT (2.60), SES (0.97), SUN (0.86) and MUS oil (0.68). Other MUFA's with very long carbon chain such as eicosenoic acid ($C_{20:1}$) (0.43%) and erucic acid ($C_{22:1}$) (52.35%) were detected in MUS oil, however, higher intake of erucic acid is not suitable for human consumption since it results in serious pathological changes in animals (FSANZ, 2003). Hence, development of canola oil with erucic acid less than 2% has been a big achievement for the food industry. Out of 44 blends, twenty-six blends namely, CNL:SUN:SES (51.78-57.31%), CNL:SUN (54.75-63.32%) and CNL:SES (51.54-61.07%) were selected based on their oleic acid content >50% (Table 2; Fig.1c) and were further analyzed for their smoking points (Table 2). MUFA content was higher in blends of CNL with SUN as compared to other blends. The temperature at which oil begins to disintegrate into free fatty acids and glycerol, with liberation of bluish smoke is known as its smoke point. Acrolein, a component of smoke is released on further break down of glycerol molecule. The smoke point also signals the start of both flavor and nutritional degradation. High smoke point makes the oil suitable for deep frying. Oils having low smoke point are preferred for dressings and not for high temperature cooking. According to the Working Group of Regional Food Chemistry Experts and the German Federal Public Health Department (1991), the smoke point of cooking oil must be at least 170 °C. The smoke point of an oil increases with decrease in free fatty acid content. Heating any oil produces free fatty acid and as heating time increases, more free fatty acids are produced, thereby decreasing smoke point.

The highest smoke point was observed in CNL oil (254.93°C) followed by SUN oil (245.50°C), MUS oil (239.40°C), GNT oil (228.47°C) and SES oil (226.67°C) (Table 1). Various studies revealed that the smoke point of oils ranged from 209-254.67°C in sunflower; 241-254°C in mustard; 170-227°C in sesame; 207-268°C in groundnut; 220-255.67°C in canola oil (De Alzaa *et al.,* 2018; Jain *et al.,* 2014). The highest smoke point of canola is due to the presence of high amount of oleic acid (Miller *et al.,* 1987). A variation in smoke point of selected vegetable oil blends is presented in Table 2. The highest smoke point was found in B13 (80CNL:20SUN) (253.77°C) whereas lowest was in B25 (35CNL:65SES) (241.30°C). Twenty-six oil blends selected were found ideally fit for consumption as they followed all the recommendations by WHO. In nine blends of CNL with both SUN and SES (CNL:SUN:SES), SFA, ω-6: ω-3 ratio, MUFA and PUFA ranged from 8.83 to 9.46%, 5.74 to 9.37, 51.78 to 57.31% and 33.22 to 39.09%, respectively.

In C:SU and C:SE blends, SFA content ranged from 6.38 to 8.02% and 7.73 to 9.98%; ω-6: ω-3 ratio from 3.61 to 9.27 and 3.70 to 9.70; MUFA ranged from 54.75 to 63.32% and 51.54 to 61.07%, PUFA varied from 29.56 to 36.77% and 30.72 to 38.19%, respectively (Table 2). Apart from antioxidative profile of any oil its PUFA content is also an important factor influencing its oxidative stability. An inverse relationship exist between OSI and PUFA content of any oil, thus the oxidative stability of high PUFA oil can be raised by blending with high MUFA oil (Chu and Kung,1998). This implies that raising the MUFA level reduces the PUFA content of oil which could increase the oxidative stability of oil blend, therefore, the same has been tried by incorporation of CNL oil to other PUFA rich SUN and SES oils. The ratio of ω-6: ω-3 ranged from 4-10:1, 4:1 and 4-10:1 in countries like USA, Japan and Canada, respectively. In this study blends with slightly less ω-6: ω-3 ratio than 4:1 was selected. As Simopoulos (2009) has reported that a ratio of 2-3:1 also helped in suppressing the rheumatoid arthritis inflammation. Table 2 also illustrates the OSI of selected vegetable oil blends which varied from 1.48 (35CNL:30SUN:35SES) to 2.03 (60CNL: 20SUN:20SES) in CNL:SUN:SES oil blends, 1.66 (50CNL:50SUN) to 2.74 (80CNL:20SUN) in CNL:SUN oil blends and 1.49 (35CNL:65SES) to 2.54 (75CNL:25SES) in CNL:SES oil blends. The results clearly showed an increase in the OSI of both SUN and SES oil on blending with CNL oil and the blends with high proportion of CNL oil showed high OSI.

Erucic acid ($C_{22:1}$) was less than 2% in canola oil, therefore, all the twenty-six canola oil blends has got erucic acid below 1% which is desirable as long consumption of erucic acid may leads to various health side-effects such as lipidosis in the heart muscle of animals (Bremer and Norum, 1982). Among the oil samples, SFA content of individual oils was found in the order SES (14.63%) > GNT (12.32%) > SUN (9.19%) > CNL (5.51%) > MUS (3.09%), whereas for MUFA the trend was CNL (68.42%) > GNT (60.52 %) > SUN (42.11%) > SES (42.06%) > MUS (10.52%) and for PUFA content the order was SUN (48.71%) > SES (43.32%) > MUS (33.32%) > GNT (24.77%) > CNL (24.71%). Blending of these oils resulted in even distribution of SFA, MUFA and PUFA and thus balanced the fatty acid composition in prepared blends. These oil blends were also found to have higher smoking points (241.30-253.77°C) which also make them more suitable for cooking at higher temperature. Taking into accounts both merits and demerits, blended oils appear to be more suitable than single oil for consumption.

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## Add-on Information

**Authors' contribution: A. Jassal:** Execution of lab experiments and data collection; **S. Sharma:** Conceptualization and designing of the research work. Analysis, data interpretation and preparation of the manuscript; **V. Sardana:** Data interpretation: Helped in data interpretation, review and editing of the manuscript.

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