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# Effect of Culinary Oil on Changes in Lipid Quality and Physical Properties of Fried Indian Mackerel (*Rastrelliger kanagurta*) Steaks

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## Abstract

Separate vegetable oils are preferred for frying fish in different parts of India. The oil can influence composition of lipid, quality and physical properties of fried fish. Five culinary oils such as sunflower, coconut, groundnut, palm and mustard oil were selected for frying Indian mackerel (*Rastrelliger kanagurta*) and changes in fatty acid composition, lipid oxidation indices, texture profile and colour were evaluated. A significant ($p<0.05$) influence of culinary oil type on fatty acid composition of fried mackerel was observed. Content of EPA and DHA were significantly decreased in all the deep fried samples. ω3/ω6 ratio was higher in the fish deep fried in coconut oil compared to other oils. The fish - derived EPA and DHA were detected in culinary oils after frying. Principal component analysis of fatty acids of culinary oils and deep fried samples clearly revealed the influence of oil on fatty acid profiles of fried fish. Hardness was highest sample fried in coconut oil. Variation in colour was also observed with respect to type of oil used.

**Keywords:** Indian mackerel, deep frying, fatty acid profile, physical properties, principal component analysis

## Introduction

Fish lipids have assumed great nutritional significance, because of their high polyunsaturated fatty acid (PUFA) levels mainly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Improving the dietary ratio by decreasing ω6 fatty acids and increasing ω3 fatty acids is essential for brain function, prevention of cardiovascular diseases, arthritis and cancer. ω3 and ω6 fatty acids compete for the same metabolic enzymes in human body and the ratio of ω3/ω6 will significantly influence the ratio of ensuing eicosanoids, which can alter metabolic functions (Kolanowski & Laufenberg, 2006) and it is essential to maintain a favourable ω3/ω6 ratio in the diet.

Indian mackerel (*Rastrelliger kanagurta*), one of the most popular marine fatty fish having high PUFA content was selected for this study. In India, mackerel is fried in different culinary oils. The various chemical and physical reactions taking place during cooking can improve or impair the nutritional value of food (Sanchez-muniz et al., 1992; Matilla et al., 1999). There can be loss of fish lipids into the oil (Yanar et al., 2007). It is relevant to investigate the influence of culinary oil on fatty acid profile and lipid oxidation of fish after deep frying.

Major changes occuring during heat processing of food is due to oxidation. Lipid oxidation is much faster in cooked meat than in fresh meat (Kingston et al., 1998). High temperature during cooking accelerate the oxidative processes and high temperature culinary treatments can increase susceptibility of EPA and DHA to oxidative changes (SantAna & Mancini-Filho, 2000).

Frying alters the physical and chemical properties of food, resulting in product with different texture and colour. Deep fried foods are now popular for their distinct flavour and texture, as evidenced by multi-billion dollar market products. In this background a study was carried out to evaluate the influence of culinary oils like sunflower oil, coconut oil, groundnut oil, palm oil and mustard oil on the

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composition and quality of lipids and physical properties in fried fish.

## Materials and Methods

Indian mackerel, *R. kanagurta* with a mean weight and length of 144.59±32.8 g and 22.7±1.54 cm respectively was collected from a local fish market in Mumbai, India. The samples were iced in 1:1 ratio and transported to the laboratory and were cut into steaks of 2.8 cm length. Sunflower oil, coconut oil, groundnut oil, palm oil and mustard oil were procured from a local retail shop and chemicals of analytical grade were procured from Sigma Aldrich, India and Merck, India. Deep frying was carried out in oil at a temperature of 180°C and the duration of frying was 5 min (Farkas et al., 1996). The oil temperature was monitored using a temperature probe (Fisher Scientific, India). After frying the samples were cooled to room temperature and analysed further.

For the evaluation of fatty acid profile, lipid was extracted from the raw and cooked samples as per Folch et al. (1957). Fatty acid methyl esters (FAME) were prepared from the extracted lipids by refluxing with methanolic NaOH followed by $BF_3$ methanol (AOAC, 1995). Analysis of fatty acid profile was done using a quadrupole gas chromatography Mass Spectrometer (Shimadzu; QP 2010; Kyoto, Japan) equipped with a carbowax capillary column (Chromlab S.A) having ID 30 m × 0.25 mm and film thickness of 0.25 µm. Helium was used as a carrier gas. Injector and detector temperature were set at 250°C. The column temperature was programmed initially at 50°C for 2 min and then increased at the rate of 10°C $min^{-1}$ to a final temperature of 230°C. Separation was carried out at 23.1 KPa and peaks were compared with mass spectral database (Dhanpal et al., 2010). Total content of saturated fatty acids (SFA), mono unsaturated fatty acids (MUFA), poly unsaturated fatty acids (PUFA), ω3 and ω6 fatty acids, Σω3/Σω6 value and ΣPUFA/ΣSFA were calculated using the results of fatty acids.

Oxidative stability of extracted fish lipid was estimated based on peroxide value and thio barbituric acid value (TBA value). Estimation of peroxide value was done by method of Shantha & Decker (1994), a modification of IDF (1991). TBA values were measured by method described by Tarladgis et al., (1960).

Texture profile analysis (TPA) was performed using a TA-XT2i texture analyser (Stable Microsystems, Surrey, England) equipped with a 50 kg load cell and 5 mm diameter cylindrical stainless steel probe (Bourne, 1978). The pre-test speed, test speed and post-test speed were set at 5, 3 and 10 mm $s^{-1}$ respectively. Penetration distance of probe was set at 5 mm and the time duration was adjusted to 5 s. The texture analysis parameters – hardness, adhesiveness, cohesiveness, springiness, resilience, stringiness, gumminess and chewiness were calculated based on force time curve using software 'texture expert exceed' (Sarika et al., 2015). The surface colours of raw and fried samples were measured by Labscan – XE- spectrophotometer (Hunter Associates Laboratory Inc., Reston, VA, USA) using method described by Hunter & Harold (1987) and measurements were made with illuminant D65, 10°C standard observer and 13 mm viewing size.

Statistical analysis on the effect of deep frying in different culinary oils on fatty acid composition, lipid oxidation, texture and colour were carried out by one way analysis of variance using SPSS 16.0 (SPSS Inc., Chicago). Post hoc analysis was carried out using Duncan's test. Differences were considered to be significant when $p<0.05$. Principal component analysis was carried out using software Unscrambler 9.5 (CAMO, Oslo, Norway) on the data matrix of the fatty acid composition of different culinary oils used in the study and also the fatty acid profiles of deep fried fishes in different culinary oils.

## Results and Discussion

Fatty acid composition of raw fish and steaks fried in five selected culinary oils is given in Table 1. Fatty acid profiles of the oils before and after frying were determined and presented in Table 2.

Most abundant fatty acid determined in the raw Indian mackerel was C16:0 (Palmitic acid; 21.27%) followed by C22:6ω3 (Docosahexaenoic acid; 15.23%), C20:5ω3 (Eicosapentaenoic acid; 10.58%), C18:1ω9 (Oleic acid; 9.63%), C 18:0 (Stearic acid, 8.63%), C14:0 (Myristic acid; 8.06%) and C 16:1ω9 (Palmitoleic acid; 8.04%) (Table 1). The fatty acid profile of sunflower oil showed a higher percentage of C18:2ω6 (Linoleic acid; 50.56%) (Table 2). Content of oleic acid and linoleic acid were found significantly ($p<0.05$) high at 26.07%, 24.29% respectively in the steaks fried in sunflower oil in comparison

Table 1. Fatty acid profile (%) of total lipids of raw and fried fish steaks of Indian mackerel in different culinary oils

| Fatty acids | Raw fish | Fried fish | | | | |
|---|---|---|---|---|---|---|
| | | Sunflower oil | Coconut oil | Groundnut oil | Palm oil | Mustard oil |
| Saturated fatty acids | | | | | | |
| 8:0 | - | - | 3.73±0.06 | - | 0.04±0.00 | 0.06±0.00 |
| 10:0 | - | - | 3.32±0.06 | - | 0.04±0.01 | 0.04±0.01 |
| 12:0 | 0.52±0.00 | 0.24±0.00 | 19.25±0.01 | 0.09±0.00 | 0.65±0.00 | 0.06±0.00 |
| 13:0 | 0.06±0.00 | 0.02±0.00 | 0.07±0.01 | 0.02±0.01 | 0.01±0.00 | 0.01±0.00 |
| 14:0 | 8.06±0.01 | 4.74±0.02 | 13.54±0.03 | 2.17±0.01 | 3.94±0.01 | 1.52±0.00 |
| 15:0 | 1.43±0.00 | 0.70±0.03 | 0.67±0.02 | 0.29±0.01 | 0.35±0.00 | 0.21±0.01 |
| 16:0 | 21.27±0.03 | 15.19±0.01 | 15.37±0.09 | 14.32±0.01 | 32.18±0.03 | 6.15±0.01 |
| 17:0 | 1.80±0.00 | 0.36±0.01 | 0.82±0.04 | 0.48±0.01 | 0.61±0.01 | 0.27±0.01 |
| 18:0 | 8.63±0.02 | - | 7.17±0.03 | - | - | 3.52±0.02 |
| 19:0 | 0.02±0.00 | - | 0.35±0.04 | 0.13±0.03 | 0.06±0.01 | 0.13±0.02 |
| 20:0 | 0.53±0.01 | 0.62±0.01 | 0.37±0.01 | 2.79±0.04 | 0.97±0.01 | 1.49±0.01 |
| 22:0 | 0.51±0.03 | - | - | - | - | 1.15±0.01 |
| 24:0 | - | - | - | - | - | 1.63±0.00 |
| ΣSFA | 42.83±0.04C | 21.87±0.04B | 64.66±0.06f | 20.40.02c | 38.85±0.02 | 16.40.04[a] |
| Mono and polyunsaturated fatty acids | | | | | | |
| 16:1 ω9 | 8.04±0.00 | 4.52±0.01 | 4.44±0.01 | 2.69±0.01 | 2.47±0.02 | 1.72±0.02 |
| 16:1 ω9 | 0.22±0.01 | 0.10±0.01 | 0.10±0.01 | 0.05±0.00 | 0.11±0.01 | 0.03±0.01 |
| 18:1 ω9 | 9.63±0.02 | 26.07±0.02 | 7.99±0.01 | 40.75±0.01 | 35.90±0.02 | 9.62±0.04 |
| 20:1 ω9 | 1.19±0.01 | 0.47±0.04 | 0.29±0.03 | 2.11±0.02 | 0.48±0.01 | 7.52±0.01 |
| 22:1 ω9 | - | - | 0.14±0.04 | 0.25±0.04 | - | 36.11±0.02 |
| 24:1 ω9 | - | - | - | - | - | 3.84±0.01 |
| ΣMUFA | 19.08±0.03B | 31.16±0.06C | 12.96±0.05A | 45.85±0.02E | 38.96±0.04D | 58.84±0.04f |
| | | | | | | |
| 18:2 ω6 | 1.99±0.00 | 24.29±0.02 | 1.95±0.03 | 15.23±0.02 | 10.02±0.01 | 9.68±0.01 |
| 18:3 ω3 | 2.12±0.00 | 1.10±0.01 | 1.12±0.01 | 0.33±0.02 | 0.47±0.01 | 8.41±0.01 |
| 20:2 ω7 | 0.18±0.00 | 0.13±0.03 | 0.11±0.02 | 0.13±0.02 | 0.11±0.00 | 1.10±0.01 |
| 20:3 ω3 | - | - | - | 0.04±0.01 | 0.04±0.01 | 0.24±0.01 |
| 20:3 ω7 | 0.40±0.01 | 0.21±0.01 | | - | 0.11±0.01 | - |
| 20:4 ω6 | 3.34±0.01 | 1.99±0.01 | 1.83±0.03 | 1.29±0.04 | 1.45±0.01 | - |
| 20:4 ω3 | 0.76±0.01 | 0.38±0.01 | 0.37±0.06 | 0.12±0.01 | 0.22±0.01 | 0.07±0.01 |
| 20:5 ω3 | 10.58±0.02 | 6.68±0.01 | 5.33±0.05 | 4.15±0.05 | 3.02±0.01 | 1.57±0.01 |
| 22:4 ω3 | 0.87±0.01 | 0.56±0.01 | 0.66±0.04 | - | 0.41±0.01 | |
| 22:5 ω3 | 2.61±0.04 | 1.83±0.03 | 1.52±0.06 | 0.43±0.01 | 1.11±0.01 | 0.27±0.01 |
| 22:6 ω3 | 15.23±0.01 | 9.78±0.02 | 9.51±0.04 | 5.00±0.01 | 5.24±0.01 | 2.66±0.01 |
| ΣPUFA | 38.08±0.05[e] | 46.95±0.07[f] | 22.43±0.04[b] | 26.72±0.10[d] | 22.20±0.06[a] | 24.08±0.02[c] |
| Σω3 | 32.17±0.05[f] | 20.33±0.06[e] | 18.51±0.05[d] | 10.07±0.04[a] | 10.51±0.07[b] | 13.22±0.01[c] |
| Σω6 | 5.33±0.01[b] | 26.28±0.02[f] | 3.78±0.03[a] | 16.52±0.02[e] | 11.47±0.02[e] | 9.76±0.02[c] |
| Σω3/Σω6 | 6.04±0.02[f] | 0.77±0.00[b] | 4.90±0.06[e] | 0.61±0.00[a] | 0.92±0.01[c] | 1.35±0.00[d] |
| ΣPUFA/"SFA | 0.89±0.00 [c] | 2.15±0.01 [f] | 0.35±0.00 [a] | 1.31±0.00 [d] | 0.57±0.00 [b] | 1.47±0.02[e] |
| EPA+DHA | 25.81±0.00 [f] | 16.46±0.00 [e] | 14.84±0.08 [d] | 9.15±0.05 [c] | 8.26±0.02 [b] | 4.23±0.00[a] |

*Values are mean ± standard error, values within a row with different superscript letters are significantly different (P<0.05)

Table 2. Fatty acid profile (%) of total lipids of different culinary oils before and after frying of fish steaks

| Fatty acids | Sunflower oil | | Coconut oil | | Groundnut oil | | Palm oil | | Mustard oil | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After | Before | After | Before | After |
| 8:0 | 0.77±0 | 0.12±0.00 | 7.82±0.03 | 7.2±0.03 | - | - | - | - | - | - |
| 10:0 | - | 0.008±0.0 | 0.008±0.02 | 6.12±0.04 | - | - | - | - | - | - |
| 11:0 | 1.52±0.03 | - | - | 35.16±0.02 | - | - | 0.05±0.01 | - | - | - |
| 12:0 | 6.53±0.11 | 1.17±0.02 | 1.17±0.02 | 21.38±0.01 | - | 0.02±0.01 | 0.47±0.01 | 0.58±0.04 | 0.03±0.003 | - |
| 14:0 | 1.72±0.03 | 0.9±0.01 | 21.26±0.01 | 0.07±0.01 | 0.07±0.01 | 0.16±0.012 | 2.27±0.03 | 2.77±0.04 | 0.12±0.01 | 0.24±0.01 |
| 15:0 | - | 0.06±0.00 | - | 12.35±0.01 | - | 0.04±0.01 | 0.1±0.02 | 0.17±0.02 | 0.02±0.00 | 0.04 0.01± |
| 16:0 | 8.56±0.15 | 11.25±0.0.04 | 11.36±0.1 | 0.11±0.01 | 13.64±0.01 | 15.15±0.01 | 40.05 0.03± | 40.62±0.02 | 3.35±0.02 | 3.69±0.02 |
| 17:0 | - | 0.13±0.01 | 0.04±0.02 | 5.77±0.02 | 0.13±0.01 | 0.16±0.01 | 0.21±0.01 | 0.23±0.02 | 0.04±0.01 | 0.06±0.01 |
| 18:0 | 5.36±0.55 | 8.03±0.01 | 5.18±0.06 | 0.18±0.02 | 6.36±0.00 | 6.73± 0.02 | 7.75±0.02 | 7.25±0.08 | 1.79±0.00 | 1.94±0.01 |
| 20:0 | - | 0.59±0.01 | - | 2.96±0.02 | 2.96±0.02 | 2.95±0.02 | 0.69±0.01 | 0.91±0.03 | 1.31±0.07 | 1.47±0.03 |
| 22:0 | - | 0.47±0.00 | - | 5.20±0.02 | 5.2±0.02 | 5.17±0.01 | 0.19±0.01 | - | 1.84±0.02 | 1.97±0.01 |
| 24:0 | - | 24.45±0.09 | 0.07±0.01 | 2.34±0.03 | 2.34±0.03 | - | - | 0.17±0.02 | 1.01±0.03 | 1.04±0.02 |
| ΣSFA | 24.46±0.88 | 24.45±0.09 | 88.45 ±0.18 | 30.7±0.09 | 30.7±0.09 | 30.38±0.09 | 51.78±0.14 | 52.7 ±0.25 | 9.51±0.15 | 10.45±0.14 |
| Mono and polyunsaturated fatty acids | | | | | | | | | | |
| 16:1 ω7 | - | 0.44±0.00 | 0.04±0.02 | 0.37±0.02 | 0.22±0.02 | 0.36±0.01 | 0.46±0.02 | 0.60±0.01 | 0.27±0.01 | 0.41±0.01 |
| 18:1 ω9 | 24.99±0.34 | 28.44±0.02 | 8.68±0.06 | 8.44±0.02 | 45.09±0.04 | 45.37±0.02 | 34.88±0.04 | 33.89±0.06 | 11.12±0.01 | 8.74±0.04 |
| 20:1 ω9 | - | - | 0.09±0.00 | 0.13±0.01 | 2.22±0.01 | 2.12±0.02 | 0.33±0.02 | 0.42±0.02 | 8.4±0.01 | 8.74±0.04 |
| 22:1 ω9 | - | - | - | - | 0.11±0.01 | 0.12±0.01 | - | - | 42.33±0.05 | 42.5±0.01 |
| 24:1 ω9 | - | - | - | - | - | - | - | - | 3.01±0.01 | 2.95±0.03 |
| ÓMUFA | 24.99±0.34 | 28.88±0.02 | 8.81±0.07 | 8.94±0.05 | 47.64±0.02 | 47.97±0.03 | 35.67±0.07 | 34.91±0.08 | 65.03±0.07 | 65.4±0.06 |
| 18:2 ω6 | 50.56±0.15 | 46.14±0.03 | 2.62±0.01 | 2.28±0.02 | 21.25±0.02 | 20.99±0.01 | 12.16±0.04 | 11.76±0.03 | 12.77±0.02 | 12.32±0.02 |
| 18:3 ω3 | - | 0.33±0.00 | - | 0.79±0.8 | 0.12±0.01 | 0.13±0.01 | 0.33±0.02 | 0.36±0.03 | 11.1±0.01 | 10.13±0.02 |
| 20:2 ω7 | - | - | - | - | - | - | - | - | 1.14±0.01 | 1.19±0.007 |
| 20:3 ω3 | - | - | - | - | - | - | - | - | 0.25±0.01 | 0.23±0.03 |
| 20:4 ω6 | - | 0.04±0.00 | - | - | - | 0.03±0.00 | - | - | - | - |
| 20:5 ω3 | - | - | - | 0.18±0.01 | - | - | - | - | - | - |
| 22:6 ω3 | - | 0.13±0.01 | - | 0.13±0.01 | - | 0.14±0.01 | - | 0.16±0.00 | - | - |
| ΣPUFA | 50.56±0.15 | 46.67±0.1 | 2.62±0.01 | 3.38±0.03 | 21.37±0.03 | 21.3±0.03 | 12.49±0.06 | 12.28±0.5 | 25.31±0.01 | 23.9±0.04 |
| Σ ω3 | - | 0.46±0.01 | - | 2.59±0.05 | 0.12±0.012 | 0.27±0.02 | 0.33±0.02 | 0.52±0.03 | 11.35±0.01 | 10.36±0.03 |
| Σ ω6 | 50.56±0.15 | 46.21±0.2 | 2.62±0.01 | 2.28±0.02 | 21.25±0.015 | 21.13±0.11 | 12.16±0.04 | 11.76±0.03 | 12.82±0.02 | 12.35±0.02 |
| Σ ω3/ Σ ω6 | 0.00 | 0.01±0.0 | 0.00 | 1.14±0.01 | 0.01±0.001 | 0.01±0.001 | 0.03±0.001 | 0.04±0.002 | 0.89±0.001 | 0.84±0.00 |
| ΣPUFA/ΣSFA | 2.07±0.018 | 1.91±0.01 | 0.03±0 | 0.04±0 | 0.59±0.002 | 0.69±0.001 | 0.24±0.001 | 0.23±0.01 | 2.64±0.03 | 2.27±0.04 |
| EPA+DHA | - | 0.13 | - | 0.31 | - | 0.14 | - | 0.16 | - | - |

*Values are mean ± standard error

to 9.63% and 1.99% respectively in raw sample. The decrease of major fatty acids like C14:0, C16:1ω9, C18:3ω3, C20:5ω3 and C22:6ω3 (Table 2) could be due to uptake of C18:2ω6 rich sunflower oil and the leaching of fish lipid into frying medium. Franscico et al. (1992) reported losses of DHA and EPA in fried sardine fillets and also found a significantly lower loss in sunflower oil and olive oil compared to that fried in lard. Castrillon et al. (1997) reported a noteworthy increase in proportion of oleic acid in the olive oil fried sample.

In case of coconut oil, C12:0 (Lauric acid; 36.06%) was determined as highest followed by C14:0 (21.26%), C16:0 (11.36%) and C18:1ω9 (8.68%). Short chain saturated fatty acids such as C8:0 (Caprylic acid; 7.82%) and C10:0 (Capric acid; 6.48%) were found in a significantly higher level in coconut oil (Table 2). Lauric acid content in coconut oil-fried sample increased to 19.25% from 0.52% in raw fish. Content of C8:0 and C10:0 were also observed in fried sample. Presence of EPA and DHA were noticed in coconut oil used for frying as well as in fried sample.

Oleic acid (45.09%) was detected to be highest followed by linoleic acid (21.25%) in case of groundnut oil while palm oil contained a higher percentage of C16:0 (Palamitic acid; 40.05%) followed by C18:1 μ9 (34.88%) prior to frying. Higher content of oleic acid (40.75%) and palmitic acid (35.9%) were detected in steaks deep fried in sunflower oil and palm oil respectively (Table 1). Presence of DHA was noticed in groundnut oil and palm oil after deep frying (Table 2).

In case of mustard oil, a MUFA named erucic acid (C22:1 ω9) was detected in high percentage of 42.33% (Table 2). This resulted in a higher content of erucic acid in mustard oil fried sample (36.11%) (Table 1). The decrease in the EPA and DHA content in all the fried samples in the present study is in agreement with the result of Gladyshel et al. (2007) and Weber et al. (2008).

Quality of fish lipids is determined by their ω3/ω6 ratio (Zdzislaw & Anna, 2003). ω3/ω6 ratio of coconut oil-deep fried sample (4.90) was found to be significantly higher compared to all other deep fried samples in different oils (Table 1). Mustard oil deep fried sample also showed a better ω3/ω6 ratio (1.35) while the higher content of ω6 fatty acids in the sunflower oil (50.56%) caused the ω3/ω6 ratio of the deep fried sample in sunflower oil to be the lowest (0.77). The ω3/ω6 ratio was found to be decreased in breaded and non-breaded fillets when fried in both sunflower oil and palm oil (Yazden et al., 2009). Silver catfish fillets fried in canola oil showed an interesting increase in ω3/ω6 ratio (Weber et al., 2008).

ΣSFA was found to be highest in coconut oil (88.5%) followed by palm oil (51.78%). The lowest ΣSFA (9.57%) and highest ΣMUFA (65.03%) was found in case of mustard oil (Table 2). Ratios of ω3/ ω6 and ΣPUFA/ΣSFA were observed to be 0.89 and 2.64 respectively in case of mustard oil due to the higher content of ω3 (11.35%). The highest ratio of ΣPUFA/ ΣSFA in case of sunflower oil deep fried sample (2.15) is mainly attributed to the high content of ΣPUFA in the oil (46.95%), particularly linolenic acid. The lowest ΣPUFA/ΣSFA ratio (0.35) in the coconut oil fried sample can be due to high ΣSFA and low ΣPUFA content in coconut oil (Table 1).

In view of the large data comprising several fatty acid variables, multivariate analysis was employed which reduces the dimensionality of multivariate data while preserving most of the variance within it. In the present study, the differences among the selected culinary oils with respect to fatty acid composition were ascertained by Principal component analysis (PCA). A graphical representation of the projection of variables and samples onto the first two principal components (PCI and PC2) were given in Fig. 1 in the form of bi-plot. All the selected oils appeared in distinct locations indicating the variation in fatty acid profiles. The PCA offered a better understanding of the fatty acid composition of these oils. The plot revealed information about patterns in the samples and it was found useful to interpret differences and similarities among the oils. The plot PC1 and PC2 was used in this study since these two components summarized more variation in the data (78%) than any other pair of components. Fig. 2 clearly showed that the variables such as SFA (14:0, 16:0, 18:0) MUFA (16:1 ω7, 18:1 ω9, 20:1 ω9 and 22:1 ω9) and linoleic acid were responsible in bringing out differences among the samples. PC1 discriminated coconut oil (CO) based on SFAs particularly short chain fatty acids (8:0, 10:0, 12:0 and 14:0).

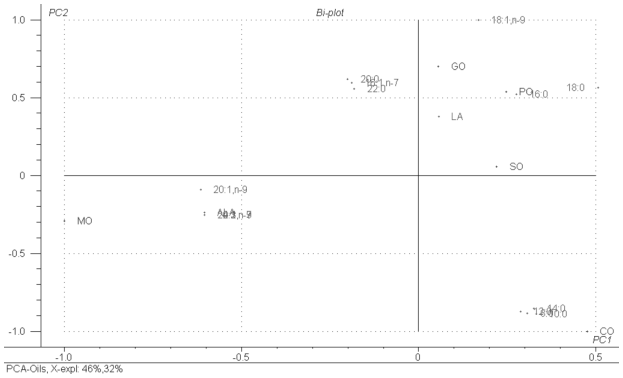


Fig. 1. Distribution of fatty acids in different Culinary oils (SO-Sunflower oil, GO-Groundnut oil, PO-Palm oil, MO- Mustard oil, CO-Coconut oil

Mustard oil (MO) and coconut oil (CO) were distinct from other oils by occupying extreme positions. The mustard oil was discriminated due to fatty acids 21:1 ω9 and 22:1 ω9.

PCA of fatty acid profiles of deep fried samples were also carried out. Plot of PC1 and PC2 was used in this study, since these two components summarized more variation (61%) in the data than any other pair of components. The bi-plot showed the pattern of samples in four different clusters (Fig. 2) with raw fish (RAW) in one group isolated from rest of the fried samples indicating the influence of cooking oil on fatty acid profile of fried samples. The fish fried in mustard oil (DFF-MO) along with mustard oil (MO) were discriminated by PC1 with the loadings indicating that there were significant contributions from fatty acids 20:1, 22:1 and 24:1 belonging to ω9. The location of other fried samples (DFF-SO, DFF-PO and DFF-GO) lies in between raw and the respective cooking oils (SO, PO, CO and GO) which clearly signifies the effect of oil composition on fried samples. Among these samples DFF-CO and CO was distinguished from DFF-GO oil and GO by PC1 due to high amounts of saturated fatty acids present in coconut oil.

Changes in peroxide value and thiobarbituric acid reactive substances (TBARS) of deep fried samples of Indian mackerel steaks in different culinary oils are given in Table 3. TBARS have been suggested as an empirical method to measure the secondary oxidative deterioration of fatty foods and measures

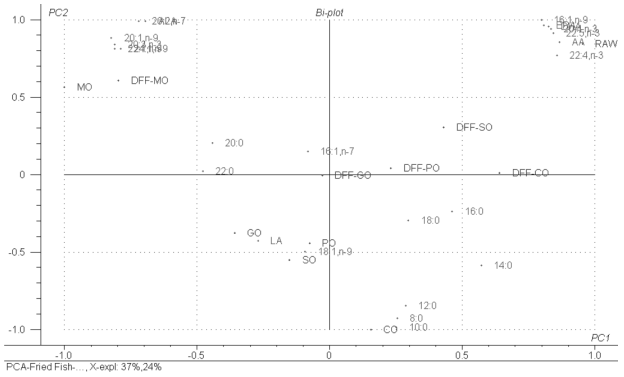


Fig. 2. Distribution of fatty acids of steaks deep fried in different oils (SO- Sunflower oil, GO- Groundnut oil, PO- Palm oil, MO- Mustard oil, CO- Coconut oil, DFF-SO- Deep fried in Sunflower oil, DFF-GO- Deep fried in Groundnut oil, DFF-PO- Deep fried in Palm oil, DFF-MO- Deep fried in Mustard oil, DFF-CO- Deep fried in Coconut oil)

Table 3. Peroxide value and TBA value of deep fried fish in different culinary oils

| | Peroxide value meq $kg^{-1}$ | TBARS mg MDA $kg^{-1}$ |
|---|---|---|
| Raw fish | 2.02±0.01$^{c}$ | 0.36±0.08$^{a}$ |
| Sunflower oil | 1.21±0.14$^{a}$ | 0.42±0.03$^{a}$ |
| Coconut oil | 1.16±0.05$^{a}$ | 0.42±0.03$^{a}$ |
| Groundnut oil | 0.82±0.13$^{a}$ | 0.51±0.07$^{ab}$ |
| Palm oil | 1.15±0.16$^{a}$ | 0.38±0.08$^{a}$ |
| Mustard oil | 1.71±0.15$^{b}$ | 0.68±0.05$^{b}$ |
| P value | 0.01 | 0.02 |

Values are mean ± standard error; values within a column with different superscript letters are significantly different

* milli equivalents of O2 $kg^{-1}$ sample

malonaldehyde (MDA) as a marker of lipid oxidation. The peroxide value of deep fried samples was observed within the acceptable limit of 10-20 milliequivalents of $O_2$ $kg^{-1}$ sample and the TBA value was within the acceptable limit of 1-2 mg malonaldehyde $kg^{-1}$ sample. The deep fried samples showed a peroxide value in the range of 0.82-1.71 meq $kg^{-1}$ and TBARS value in the range of 0.38-0.68 mg malonaldehyde $kg^{-1}$ respectively. A significant decrease in peroxide value and a slight increase in TBA values were observed in all fried samples compared to initial values of raw sample (2.02 meq $kg^{-1}$ and 0.36 mg malonaldehyde $kg^{-1}$). Among the fried samples, only the mustard oil - fried sample showed a significant increase in peroxide value compared to others, which could be due to initial high lipid oxidation of mustard oil itself. However, in deep frying temperature within the product is less than 100$^{o}$C and time duration of frying was also short. This could have resulted a lower peroxidation in the sample. It could be also due to the sudden decomposition of initial hydroperoxides to various volatile and non-volatile products. Weber et al. (2008) reported that no significant changes in the fillets of silver catfish, but Aro et al. (2000) reported a decrease in the peroxide value in fried Baltic herring fillets. The initial hydroperoxides formed can exist only transiently at high temperatures and they will decompose into various volatile and non-volatile products (Saguy & Dana, 2003). The steaks deep fried in mustard oil showed a significant increase in TBARS value (0.68 mg malonaldehyde $kg^{-1}$) compared to other samples. The difference in

TBARS value in fried samples can be attributed to the difference in fatty acid composition as a result of frying in different culinary fats and to different susceptibility to oxidative deterioration of dissimilar fatty acids during frying. The high peroxide value observed in the mustard oil fried sample also resulted a significantly ($p<0.05$) higher TBARS value.

Texture characteristics of deep fried samples in different culinary oils are shown in Table 4. A significant variation ($p<0.05$) in hardness of samples deep fried in coconut oil and mustard oil was noticed. Chewiness showed a significant variation between the samples deep fried in coconut oil and mustard oil compared to samples fried in other oils. Cohesiveness showed a significant variation between the samples deep fried in coconut oil and palm oil with the samples fried in rest of the oils. Moisture loss and protein denaturation can affect the hardness of the sample significantly (Loewe, 1993). The relative interchange of fatty acids during frying may have an effect on the development of texture. The highest hardness of coconut oil - fried sample could be due to its high content of SFA (88.5%; Table 4) and their high melting point. Sample fried in palm oil has significantly ($p<0.05$) lower adhesiveness than samples fried in other oils. Cohesiveness is the parameter of texture profile analysis (TPA), which describes the ability of fillets to recover from deformation (Jon & Ole, 1999). However, the small changes in cohesiveness values (0.38-0.49) suggest that the frying of the sample in various culinary oils had no effect. Physical properties and eating quality of meat is affected by temperature and cooking time (Liu & Chen, 2001). Ngadi et al. (2007) reported that oil type and frying time have significant effect on the colour and texture of fried chicken nuggets.

Colour analysis parameters such as lightness (L*), redness (a*) and yellowness (b*) are shown in the Table 5. The final colour of the fried product depends on the absorption of oil and the chemical

Table 4. Texture characteristics of Indian mackerel steaks deep fried in different culinary oils

| Texture characteristics | Sunflower oil | Coconut oil | Groundnut oil | Palm oil | Mustard oil |
|---|---|---|---|---|---|
| Hardness (gf) | 501.87±50.57a | 940.41±12.08c | 552.52±32.40a | 496.60±15.33a | 780.45±98.46b |
| Adhesiveness (gs) | 0.30±0.62a | 0.36±0.64a | 0.77±0.56a | 0.18±0.41a | 1.16±0.38a |
| Cohesiveness | 0.47±0.01b | 0.38±0.03a | 0.49±0.02b | 0.38±0.04a | 0.49±0.01b |
| Resilience | 0.38±0.12a | 0.88±0.26a | 0.32±0.02a | 0.75±0.33a | 0.70±0.09a |
| Springiness | 0.99±0.07a | 1.00±0.13a | 0.90±0.03a | 0.98±0.10a | 1.02±0.03a |
| Stringiness | 2.97±0.10ab | 4.32±0.29c | 2.59±0.12a | 3.94±0.62bc | 2.56±0.08a |
| Gumminess | 239.18±30.04a | 360.52±24.44bc | 271.49±17.74ab | 187.44±24.30a | 386.12±56.58c |
| Chewiness | 232.60±19.20a | 354.10±24.88b | 242.61±9.96a | 181.21±16.24a | 391.50±45.00b |

*Values are mean ± standard error, values within a row with different superscript letters are significantly different ($p<0.05$)

Table 5. Colour parameters of deep fried Indian mackerel steaks in different culinary oils

| | Sunflower oil | Coconut oil | Groundnut oil | Palm oil | Mustard oil |
|---|---|---|---|---|---|
| L* | 47.5±0.99c | 31.0±0.59a | 32.13±0.20a | 30.05±0.46a | 35.69±1.45b |
| a* | 9.50±0.21a | 13.66±0.75b | 11.01±0.38a | 11.04±0.57a | 13.30±0.76b |
| b* | 28.13±0.50b | 21.10±0.08a | 21.02±1.34a | 20.75±0.14a | 24.32±3.35ab |

*Values are mean ± standard error, values within a row with different superscript letters are significantly different ($p<0.05$)

reactions of browning of reduced sugar and protein sources. Colour development during frying is the main parameter chosen by the consumers to control the optimal frying time. The ideal colour of fried food stuff is a light golden brown (Sanz et al., 2007). There was a significant ($p<0.05$) difference between samples fried in sunflower oil and samples fried in other oils. Low values of L* of these samples indicates the less light brown colour compared to samples fried in sunflower oil, while samples fried in mustard oil gives an average L* value (35.69) compared to others. It has been reported that fried pork loin chops in olive oil, sunflower oil, butter and pig lard showed significant difference ($p<0.05$) in lightness due to different types of frying fat used (Ramirez et al., 2004). However, Krokida et al. (2001) reported negligible effect of oil types on lightness of French fries. Therefore, the influence of oil on colour may be varied for different products.

It is evident from the study that the fatty acid composition of culinary oils selected for deep frying significantly ($p<0.05$) affected the fatty acid composition of fried fish. Frying of Indian mackerel in coconut oil could enhance the ω3/ω6 ratio compared to frying in other ω6 fatty acid rich culinary oils. Further, frying in coconut oil resulted an increased hardness of the texture which may be a favourable sensory attribute for the consumers. Deep frying did not bring any adverse changes in the lipid oxidation of fish steaks demonstrating the suitability of frying process. PCA offered a better understanding of the relationship between fatty acid composition of selected culinary oils for deep frying and fatty acid profiles of fried samples.

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