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Assessment of volatile compounds in deep-fried sunflower oil using electronic nose technique

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Abstract

Deep frying is one of the popular food processing techniques in which repeated frying of the same oil can result in the deterioration of oil and reduces the quality of fried foods. Oil deterioration is the result of various chemical reactions such as oxidation, polymerization, isomerization and hydrolysis. These reactions are associated with the change in the volatile profile. The volatile profile of sunflower oil before and after frying was analysed using fast gas chromatography electronic nose. The results shows that there were significant changes in the volatile profile of sunflower oil after deep-frying. There was a total of 96 and 102 volatile compounds found in fresh and fried oil respectively. Some volatile compounds found in the fresh oil got degraded and not found in the fried oil. Whereas some volatile compounds underwent chemical reactions and resulted in products which were not found in the fresh oil. The volatile markers of the chemical reactions during deep-frying process can be used to find whether the oil is fresh or used. This proves that the electronic nose can be an alternative technique to find the volatile profiles of oils besides other conventional techniques such as head space solid phase microextraction-gas chromatography.

Keywords: Volatile profile, volatile compounds, electronic nose, sunflower oil, deep-frying

1. Introduction

Deep-fat frying is one of the most popular food processing technique involving high temperature at about 180 °C (Chen *et al.*, 2014) [2]. Even though fried food products have desirable flavour, golden colour, crispy texture and good taste, oil is continuously getting exposed to the moisture and atmospheric oxygen during frying process, which results in many chemical reactions in the oil such as hydrolysis, oxidation, polymerization and isomerization (Q. Zhang *et al.*, 2012) [12]. Hence, adverse changes in the physicochemical, sensory and nutritional aspects of oil and food over continuous frying occur.

Lipid thermal oxidation involves a series of chain reactions of free radicals, which not only produces free radicals, peroxides, oxidised volatile products, but also deteriorate the quality of oil and food (Nayak *et al.*, 2016) [7]. Lipid oxidation is often associated with the changes in volatile profiles. The volatile characteristics of the oil gives effective information to assess the oil quality during frying (Perkins, 2007) [8]. The fast gas chromatography electronic nose technique can be used for the analysis of volatile composition of the oil during frying.

There are few studies on the effect of the frying on the physicochemical and sensory quality of the vegetable oils (Liu *et al.*, 2019) [5], but there is limited information on the volatile characteristics of the frying oil. Therefore, the objective of our present study was to compare the volatile composition of fresh oil and during deep-fat frying process. The frying media selected for the study was sunflower oil.

2. Materials and methods

2.1 Raw materials

The RBD Sunflower oil was procured from the local supermarket in Thanjavur, Tamil Nadu, India. The fresh potatoes for frying were procured from the local market in Thanjavur, Tamil Nadu, India.

2.2 Preparation of frying oil

Two litres of sunflower oil were taken in the electric fryer equipped with temperature control. The oil was heated to 180 °C and then, 100 grams of washed, peeled and sliced potatoes were fried in the oil for 5 minutes. After 25 minutes of maintaining the same temperature, next batch of potatoes were fried in the oil.

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This process was repeated for 20 hours and at the end of 20th hour, oil samples were collected and stored at -20 °C before analysis.

2.3 Volatile profile analysis

The Fast Gas Chromatography Electronic nose (Alpha MOS, France) was used to analyse the volatile composition of the frying oil samples. It has two columns: (i) a non-polar column (MXT-5) (ii) a slightly polar column (MXT-1701). The 2 grams of sample was taken in a 20 ml sealed vial with a magnetic plug. The sealed vial was placed in the autosampler. Each sample vial was incubated in the shaker oven at 50 °C, shaken at 500 rpm for 30 minutes (Xu *et al.*, 2019) [11]. The hydrogen gas was used as a carrier gas with a flow rate of 10 ml/min.

2.4 Calibration and compounds identification

An alkane standard solution containing n-butane to n-hexadecane was used for calibration to convert retention times to system independent components-Kovats indices. The peaks in the obtained chromatogram were compared with the AroChemBase library to detect volatile compounds. Also, the volatile compounds were selected based on the relevance index.

3. Results and discussion

3.1 Volatile compounds profile

The changes in the volatile composition of fried sunflower oil were identified and shown in the table 1. The overlaid chromatogram of fresh and fried sunflower oil was shown in the figure 1 and 2. A total of 96 and 102 volatile compounds were found in fresh and fried sunflower oil respectively. These volatile compounds can be classified into 6 groups. They are alcohols, aldehydes, ketones, acids, alkanes and furan. Most of these volatile compounds have been identified previously in the frying oils (Boskou *et al.*, 2006; Vichi *et al.*, 2007; Zhu *et al.*, 2016) [1, 10, 14]. The major volatile constituents of frying sunflower oil are aldehydes followed by alcohols, alkanes, acids, ketones and furans.

The amounts of aldehydes present in sunflower oil increased over time of deep frying. 2-Decenal, Citronellal, 2,4-Heptadienal, (E, E)-, 2-methylpropanal were not present in

the fresh oil and it was produced over time during deep-fat frying. The aldehydes such as nonanal, octanal and decanal were produced as a result of homolytic cleavages of oleate hydroperoxides on the alkoxy intermediate group. The hexanal and (E, E)- 2,4-decadienal were produced as a result of homolytic cleavages of linoleate hydroperoxides on the alkoxy intermediate group.

Alcohols are generally produced by the degradation of unsaturated fatty acids (Z. Zhang *et al.*, 2010) [13]. The amounts of alcohols present in sunflower oil also increased over time of deep frying. Among alcohols, 1-Octanol, 1-decanol, 4-ethylguaiaicol and thymol were not present in the fresh oil and it was produced over time during deep-fat frying. Studies have observed that 1-Octanol was produced by the C-8 compounds degradation during thermal treatment (Picardi & Issenberg, 1973) [9].

Ketones are usually produced by the result of enzymatic degradation reactions of polyunsaturated fatty acids, Millard reaction or amino acid degradation (Fratini *et al.*, 2012) [3]. The ketone content increased over time during the deep frying process. 2-Among ketones, heptanone, nonan-2-one, 5-Propyldihydro-2(3H)-furanone, gamma-nonalactone, were not present in fresh oils, but formed over deep-frying process.

Several aliphatic acids appeared after thermal oxidation, which were produced by further oxidation of their respective aldehydes (Morales *et al.*, 1997) [6]. 3-methylbutanoic acid and decanoic acid didn't exist in fresh oil, but formed during deep frying because of thermal oxidation of sunflower oil. These acids may be formed due to the thermal oxidation of aldehydes such as 3-methylbutanal and decanal respectively.

Though alkanes were present in the frying oil, it may not contribute to the flavour. Reason for it may be due to its high odour threshold values. The alkanes such as undecane and nonadecane were found in the frying sunflower oil. The amount of undecane increased with frying over time. This may be due to the homolytic cleavage of palmitic acid on C-C linkage which leads to the formation of volatile compounds. The furan present majorly in the frying sunflower oil was 2-pentyl-furan. This is formed due to the oxidation of linolenic acid. It offers undesirable flavor which is widely present in thermally oxidised oils (Lee *et al.*, 2007) [4].

Table 1: Volatile composition of fresh and fried sunflower oil

Volatile compounds in fresh sunflower oil	Volatile compounds in fried sunflower oil	Retention index MXT-5-FID1	Retention index MXT-1701-FID2	#CAS	Sensory descriptors
Acetaldehyde	Acetaldehyde	441	469	75-07-0	Aldehydic; Etheral; Fresh; Fruity; Pleasant; Pungent
Propanal	Propanal	441	539	123-38-6	Acetaldehyde; Cocoa; Earthy; Etheral; Nutty; Plastic; Pungent; Solvent
Dimethyl sulfide	Dimethyl sulfide	471	569	75-18-3	Cabbage; Corn; Fruity; Gaseous; Gasoline; Green; Moldy; Onion; Sulfurous; Sweet; Tomato; Vegetable; Vegetable soup
ND	2-methylpropanal	495	601	78-84-2	Aldehydic; Baked potato; Burnt; Floral; Fresh; Fruity; Green; Malty; Pungent; Sharp; Spicy; Toasted
2-propanol	2-propanol	496	602	67-63-0	Acetone; Alcoholic; Ethanol; Etheral; Musty; Pleasant; rubbing alcohol; Woody
Butanal	Butanal	561	673	123-72-8	Chocolate; Cocoa; Green; Malty; Musty; Pungent
Butane-2,3-dione	Butane-2,3-dione	561	685	431-03-8	Butter; Caramelized; Chlorine; Creamy; Fruity; Pineapple; Pungent; Spirit; Strong; Sweet
Ethyl Acetate	Ethyl Acetate	602	673	141-78-6	Acidic; Butter; Caramelized; Etheral; Fruity; Green; Orange; Pineapple; Pungent; Solvent; Sweet
Butan-2-one	Butan-2-one	602	685	78-93-3	Acetone; Butter; Cheese; Chemical; Chocolate; Etheral; Fragrant; Fruity; Gaseous; Pleasant; Pungent; Sharp; Sweet
Ethyl Acetate	Ethyl Acetate	602	701	141-78-6	Acidic; Butter; Caramelized; Etheral; Fruity; Green; Orange; Pineapple; Pungent; Solvent; Sweet
Acetic acid	Acetic acid	602	788	64-19-7	acetic; Acidic; Odorless; Pungent; Sharp; Sour; Vinegar
Butan-2-one	Butan-2-one	615	685	78-93-3	Acetone; Butter; Cheese; Chemical; Chocolate; Etheral; Fragrant; Fruity; Gaseous; Pleasant; Pungent; Sharp; Sweet
1-Propanol, 2-methyl-	1-Propanol, 2-methyl-	630	742	78-83-1	Alcoholic; Bitter; Chemical; Fusel; Glue; Leek; Licorice; Musty; Oil; Solvent; Sweet; unpleasant; Winey
Isopropyl acetate	ND	667	701	108-21-4	Banana; Chemical; Etheral; Fruity; Sweet
3-methylbutanal	3-methylbutanal	667	742	590-86-3	Aldehydic; Almond; Apple; Cheese; Chocolate; Fatty; Fruity; Green; Herbaceous; Malty; Peach; Toasted
n-butanol	n-butanol	667	782	71-36-3	Alcoholic; amyl alcohol; Banana; Cheese; Fermented; Fruity; Fusel; Harsh; Medicinal; Oil; Rancid; Strong; Sweet
Pentan-2-one	Pentan-2-one	667	788	107-87-9	Acetone; Banana; Etheral; Fruity; fruity (sweet); Sweet; Thinner; Woody
Ethyl propanoate	Ethyl propanoate	701	742	105-37-3	Acetone; Fruity; Solvent
Ethyl acrylate	Ethyl acrylate	701	782	140-88-5	Acrid; Fruity; Harsh; Plastic; Pungent; Sour
2,3-Pentanedione	2,3-Pentanedione	701	788	600-14-6	Almond; Apple; Burnt; Butter; Butterscotch; Caramelized; Cheese; Creamy; diacetyl; Fresh; Fruity; grain; Malty; Nutty; Oily; Pungent; sickly; Sweet
Pentanal	Pentanal	701	803	110-62-3	Acrid; Almond; Berry; Fermented; Fruity; Green; Herbaceous; Malty; Nutty; Pungent; Rubber
Propylenglycol	ND	717	963	57-55-6	Alcoholic; Caramelized; Odorless
Ethyl isobutyrate	Ethyl isobutyrate	777	788	97-62-1	Alcoholic; ethereal (sweet); Fruity; Fusel; Rubber; Strawberry; Sweet
Methyl 2-methylbutanoate	Methyl 2-methylbutanoate	777	820	868-57-5	Apple; Chewing gum; Fatty; Fruity; Green; Lily; Powdery; Solvent; Spirit
Ethyl butyrate	Ethyl butyrate	777	855	105-54-4	Acetone; Banana; Bubblegum; Caramelized; Fruity; Pineapple; Strawberry; Sweet
Propanoic acid	ND	777	886	79-09-4	Acidic; Pungent; pungent (slightly); Rancid; Soy; Vinegar
Hexanal	Hexanal	777	896	66-25-1	Acorn; Aldehydic; Fatty; Fishy; Fresh; Fruity; Grassy; Green; Herbaceous; Leafy; Sharp; Strong; Sweaty; Tallowy; vinous
Pyrrrole	ND	777	936	109-97-7	Chloroform; Coffee; cracker; Nutty; Sweet; Warm
2-methylpropanoic acid	2-methylpropanoic acid	777	963	79-31-2	Acidic; Butter; Cheese; Dairy; Fatty; Phenolic; Pungent; Rancid; Sharp; Sour; Sweaty
Butanoic acid	Butanoic acid	804	963	107-92-6	Butter; Cheese; penetrating; Rancid; Sharp; Sweaty

Propyl propanoate	ND	818	855	106-36-5	Apple; Chemical; Fruity; fruity (sweet); Pineapple; Pungent; Sharp; Sweet; Winey
Butyl acetate	Butyl acetate	818	886	123-86-4	Banana; Bitter; Etheral; Fruity; Green; Pear; Pineapple; Pleasant; Solvent; Strong; Sweaty; Sweet
Furfural	Furfural	818	977	98-01-1	Almond; Baked; benzaldehyde; Bread; Fragrant; Sweet; Woody
ND	(Z)-3-hexen-1-ol	832	967	928-97-2	Earthy; Floral; Fresh; Fruity; Green; Leafy; Mossy; Oily; Petal
ND	Ethyl 2-methylbutyrate	861	885	7452-79-1	Apple; Blackberry; Cognac; Fruity; Green; Phenolic; Sharp; Strawberry; Sweet
ND	1-Hexanol	861	982	111-27-3	Alcoholic; characteristic; Dry; Fatty; Floral; Fruity; Fusel; Grassy; Green; Hay; Herbaceous; Leafy; Oil; Pleasant; Resinous; Sharp; Sweet; Toasty; woody (mild)
ND	3-methylbutanoic acid	861	1001	503-74-2	Acidic; Cheese; Fruity; Rancid; Sharp; Sour; Sweaty; Tropical
ND	2-Heptanone	895	982	110-43-0	Banana; Cheese; Coconut; Fruity; Gaseous; Gravy; ham (cured); Musty; Nutty; pear drop; Soapy; Spicy; Sweet; Toasted; Woody
ND	2,6-Dimethylpyrazine	901	982	108-50-9	Baked potato; Chocolate; Cocoa; Coffee; Corn; Ester; Etheral; Fried; Fruity; Malty; nut (roasted); Nutty; oxidized; Paper; Potato; Roast; Roastbeef; Sweet
ND	3-heptanol	901	1001	589-82-2	Green; Herbaceous
1R- (+)-alpha-pinene		908	936	7785-70-8	Aromatic; Harsh; Minty; Pine; Terpenic
3-Heptanone	3-Heptanone	908	963	106-35-4	Cinnamon; Fatty; Fruity; Green; Spicy; Sweet
Heptanal	ND	908	977	111-71-7	Aldehydic; Citrus; Fatty; fish (dry); Fresh; Fruity; Green; Heavy; Oily; Ozone; Pesticide; Pungent; putty; Rancid; Smoky; Solvent
(Z)-4-heptenal	(Z)-4-heptenal	908	987	6728-31-0	Biscuit; Creamy; Dairy; Fatty; Fishy; Green; Milky; Oily; potato (boiled); Sweet
Dihydro-2(3H)-furanone	Dihydro-2(3H)-furanone	908	1001	96-48-0	Aromatic; Caramelized; Creamy; Faint; Fatty; Oily; Pleasant; Sweet
Pentanoic acid	Pentanoic acid	908	1076	109-52-4	Acidic; Beefy; Cheese; penetrating; Pungent; Putrid; Rancid; Sour; Sweaty
1S- (-)-a-pinene	1S- (-)-a-pinene	951	977	7785-26-4	Fresh; Herbaceous; Pine; Resinous; Sharp; Terpenic; Turpentine; Warm
2,3-dimethylpyrazine	ND	951	1001	5910-89-4	Baked; Bread; Burnt sugar; Butter; Caramelized; Chocolate; Cocoa; Coffee; Dusty; Green; Leather; Linseed oil; Malty; Meaty; Nutty; oxidized; Peanut; Peanut butter; Pungent; Roast; Sweet; Walnut
Dimethyl trisulfide	Dimethyl trisulfide	951	1041	3658-80-8	Alliaceous; Cabbage; Cauliflower; Fishy; Meaty; Onion; onion (cooked); Rotten food; Sulfurous
Benzaldehyde	Benzaldehyde	951	1126	100-52-7	Almond; Bitter; Bitter almond; Burnt sugar; Cherry; Fruity; Oil; Sharp; Strong; Sweet; Woody
(-)-beta-. -Pinene	(-)-beta-. -Pinene	986	987	18172-67-3	Dry; Fresh; Green; Hay; Pine; Resinous; Terpenic; Turpentine; Woody; woody (dry)
Myrcene	Myrcene	986	1001	123-35-3	Balsamic; Etheral; Fruity; Geranium; Lemon; Metallic; Musty; Plastic; Pleasant; Resinous; Soapy; Spicy; Sweet; Woody
Butyl butanoate	Butyl butanoate	986	1076	109-21-7	Banana; Cherry; Fresh; Fruity; Green; Juicy; Pineapple; Sweet; Tropical
Trimethylpyrazine	Trimethylpyrazine	986	1091	14667-55-1	Baked; Baked potato; Bread; Burnt; Cocoa; Earthy; Green; Hazelnut; Musty; nut (roasted); Nutty; Peanut; Potato; Powdery
Octanal	Octanal	986	1116	124-13-0	Aldehydic; Citrus; Fatty; Floral; Fruity; Green; Lemon; meat (boiled); Orange; Orange peel; Pungent; Rancid; Soapy; Stew; Strong; Waxy
2,4-Heptadienal, (E, E)-	2,4-Heptadienal, (E, E)-	986	1162	05-03-4313	Aldehydic; Cinnamon; Fatty; Green; Hay; Nutty; Oily; Orange oil; Rancid; Vegetable
Hexanoic acid	Hexanoic acid	986	1212	142-62-1	Cheese; Fatty; Goat; Pungent; Rancid; Sour; Sweaty
(-)-beta-. -Pinene	(-)-beta-. -Pinene	996	1001	18172-67-3	Dry; Fresh; Green; Hay; Pine; Resinous; Terpenic; Turpentine; Woody; woody (dry)
Alpha-Phellandrene	Alpha-Phellandrene	996	1028	99-83-2	Citrus; Green; Minty; Spicy; Terpenic; Turpentine; Woody
Ethyl hexanoate	Ethyl hexanoate	996	1041	123-66-0	Anise; Apple; Banana; Berry; Fruity; fruity (sweet); Green; Pineapple; Strawberry;

					Sweaty; Sweet; unripe; Waxy; Wine gum
Z-3-Hexen-1-ol, acetate	Z-3-Hexen-1-ol, acetate	996	1076	3681-71-8	Apple; Banana; Fresh; Fruity; fruity (sweet); Grassy; Green; Sharp; Sweet
Alpha-Terpinene	Alpha-Terpinene	996	1091	99-86-5	Citrus; Etheral; Fruity; Gasoline; Lemon; Medicinal; Woody
ND	Hexyl acetate	998	1073	142-92-7	Acidulous; Apple; Banana; Citrus; Ester; Fruity; Green; Herbaceous; Rubber; Spicy; Sweet; Tobacco; wine (sweet)
ND	2,4-Heptadienal, (E, E)-	998	1170	05-03-4313	Aldehydic; Cinnamon; Fatty; Green; Hay; Nutty; Oily; Orange oil; Rancid; Vegetable
ND	Trans-hex-2-enyl acetate	1009	1116	2497-18-9	Apple; Banana; Fresh; Green; Sweet; Waxy
p-Cymene	ND	1026	1076	99-87-6	Aromatic; Balsamic; Citrus; Fresh; Fruity; Fuel; Gasoline; Herbaceous; Lemon; Mild; Pleasant; Solvent; Spicy; Sweet; Weak; Woody
1, 8-cineole	ND	1026	1091	470-82-6	Camphor; Herbaceous; Licorice; Medicinal; Menthol; Minty; Pine; Sweet
Octanal	Octanal	1026	1104	124-13-0	Aldehydic; Citrus; Fatty; Floral; Fruity; Green; Lemon; meat (boiled); Orange; Orange peel; Pungent; Rancid; Soapy; Stew; Strong; Waxy
Acetylpyrazine	Acetylpyrazine	1026	1116	22047-25-2	Biscuit; Bread; Chocolate; Coffee; Corn; Corn chip; cracker; Hazelnut; Nutty; Popcorn; Roast
(Z)-2-octenal	(Z)-2-octenal	1026	1162	20664-46-4	Earthy; Fatty; Fruity; Green; Leafy; Walnut
Benzeneacetaldehyde	Benzeneacetaldehyde	1026	1188	122-78-1	Cocoa; Floral; Grassy; Green; Hawthorn; Honey; Hyacinth; Rose; Sweet
Benzyl alcohol	Benzyl alcohol	1026	1202	100-51-6	Aromatic; Balsamic; Faint; Floral; Fruity; Phenolic; Rose; Sweet
1, 8-cineole	ND	1043	1091	470-82-6	Camphor; Herbaceous; Licorice; Medicinal; Menthol; Minty; Pine; Sweet
Acetophenone	Acetophenone	1043	1188	98-86-2	Almond; Cheese; Chemical; Floral; Glue; Hawthorn; Jasmine; Musty; Orange; Orange blossom; Pungent; Sweet
L-Limonene	L-Limonene	1055	1041	5989-54-8	Citrus; Minty; Orange; Pine; Terpenic; Woody
Gamma-Terpinene	Gamma-Terpinene	1055	1116	99-85-4	Citrus; Etheral; Fruity; Gasoline; Herbaceous; Lemon; Oily; Sweet; Terpenic; Turpentine; Woody
Benzeneacetaldehyde	ND	1055	1188	122-78-1	Cocoa; Floral; Grassy; Green; Hawthorn; Honey; Hyacinth; Rose; Sweet
5-ethylidihydro-2(3h)-furanone	5-ethylidihydro-2(3h)-furanone	1055	1212	695-06-7	Coconut; Coumarin; Sweet; Tobacco; Tonka broadbean
ND	1-Octanol	1068	1170	111-87-5	Aldehydic; bread (toasted); Burnt matches; Chemical; Fatty; Floral; Fresh; Green; Herbaceous; Metallic; Mushroom; Orange; Rose; Sulfurous; Waxy
ND	Nonan-2-one	1068	1198	821-55-6	Baked; Cheese; Earthy; Fatty; Fresh; Fruity; Green; Ketonic; milk (hot); Musty; Soapy; Sweet; Varnish
ND	Tetramethylpyrazine	1112	1170	1124-11-4	Burnt; Chocolate; Cocoa; Coffee; Grassy; Hay; Musty; Nutty; Roast
ND	2-Phenylethanol	1112	1278	60-12-8	Floral; flower; Honey; Lilac; Perfumery; Rose; Spicy
n-nonanal	n-nonanal	1138	1188	124-19-6	Aldehydic; Chlorine; Citrus; Fatty; Floral; Fresh; Fruity; Gaseous; Gravy; Green; Lavender; Melon; Orange; Orange peel; Orris; Peely; pungent (slightly); Rose; Soapy; Sweet; Tallowy; Waxy
Maltol	Maltol	1138	1302	118-71-8	Baked; Caramelized
Benzoic acid	ND	1138	1317	65-85-0	Balsamic; Faint; Odorless; Pleasant; Urine; weak (very); Winey
5-Propylidihydro-2(3H)-furanone	ND	1138	1372	105-21-5	Fatty; Fruity; Nutty
ND	Citronellal	1172	1242	106-23-0	Aldehydic; Citrus; Dry; Fatty; Floral; Fruity; Green; Lemon; Pepper; Rose; Sweet; Waxy
ND	Benzyl acetate	1172	1278	140-11-4	Burnt; Floral; Fresh; Fruity; Jasmine; Sweet; vegetable (boiled); zucchini (boiled)
ND	p-methylacetophenone	1172	1318	122-00-9	Almond; Bitter almond; Cherry; Coumarin; Floral; Harsh; Hawthorn; Hay; Sweet
ND	5-Propylidihydro-2(3H)-furanone	1172	1354	105-21-5	Fatty; Fruity; Nutty
ND	Ethyl Octanoate	1202	1242	106-32-1	Anise; Apple; Baked fruity; Fatty; Fermented; Floral; Fresh; Fruity; Green; Leafy;

					Menthol; Soapy; Sweet; Waxy; Winey
Decanal	Decanal	1202	1302	112-31-2	Aldehydic; Burnt; Citrus; Fatty; Floral; Green; Herbaceous; Lemon; Orange; Orange peel; Soapy; Stew; Sweet; Tallowy; Waxy
Methyl salicylate	Methyl salicylate	1202	1317	119-36-8	Berry; Minty; Peppermint; Sweet; Warm; Winey; Wintergreen
Nerol	Nerol	1202	1372	106-25-2	Citrus; Floral; Magnolia; Marine; Rose; Sweet
Ethyl maltol	Ethyl maltol	1202	1401	08-11-4940	Candy; Caramelized; Cotton candy; Jam; Strawberry; Sweet
Geraniol	ND	1228	1401	106-24-1	Citrus; Floral; Fruity; Geranium; Pleasant; Rose; Sweet; Waxy; Wet
ND	Undecane	1228	1413	1120-21-4	Fatty; Floral; Fresh; Fruity; Green; Ketonic; Musty; Orange
ND	Nonadecane	1228	1413	629-92-5	Fatty; Floral; Fruity; Orange; Soapy; Sweet; unripe; Waxy
p-Anisaldehyde	ND	1228	1463	123-11-5	Anise; Floral; Hawthorn; Minty; Powdery; Sweet
ND	L-Carvone	1260	1400	2244-16-8	Bread; Caraway; Herbaceous; Minty; Spicy
ND	2-Decenal	1260	1354	3913-71-1	Aldehydic; Fatty; Floral; Green; Orange; Rose
ND	1-Decanol	1275	1400	112-30-1	Citrus; Fatty; Floral; Fruity; Orange; Soapy; Sweet; unripe; Waxy
ND	4-ethylguaiaicol	1275	1412	2785-89-9	Clove; Floral; Phenolic; Smoky; Spicy
ND	4-Octanolide	1275	1462	104-50-7	Caramelized; Coconut; Creamy; Dairy; Fatty; Fruity; Herbaceous; Pungent; Roast; Sweet; Tonka broadbean; Waxy
ND	Thymol	1275	1492	89-83-8	Aromatic; Earthy; Herbaceous; Medicinal; Phenolic; Spicy; Thyme
Ethyl nonanoate	Ethyl nonanoate	1296	1372	123-29-5	Fruity; Rose; Rum; Tropical; Waxy
Undecan-2-one	Undecan-2-one	1296	1401	112-12-9	Creamy; Dusty; Fatty; Floral; Fresh; Fruity; Green; Ketonic; Musty; Orange; Orris; Rose; Strong; Tallowy; Waxy
2,4-Decadienal, (E, E)-	ND	1296	1463	25152-84-5	Aldehydic; Citrus; Cucumber; Deep-fried; Fatty; Fried; Green; Melon; Oily; Potato; Pungent; Waxy
Anisyl alcohol	Anisyl alcohol	1296	1499	105-13-5	Floral; Powdery
ND	2-pentyl-furan	1296	1530	3777-69-3	Creamy; Fatty; Meaty; Peach; Rancid; Soapy; Sour
Indole	Indole	1296	1570	120-72-9	Animal; Burnt; Earthy; Fecal; Floral; Jasmine; Mothball; Musty; Sweet
ND	Anethole	1300	1412	4180-23-8	Anise; Herbaceous; Licorice; Oil; Spicy; Sweet
ND	Decanoic acid	1300	1462	334-48-5	caprylic; Citrus; Creamy; Fatty; Meaty; Peach; Rancid; Soapy; Sour
ND	Nonyl acetate	1309	1400	143-13-5	Fruity; Leafy; Sweet; Waxy
ND	Eugenol	1334	1492	97-53-0	Balsamic; Camphor; Clove; Floral; Herbaceous; Honey; Spicy; Sweet; Warm; Woody
ND	Gamma-nonolactone	1334	1571	104-61-0	Coconut; Creamy; Fruity; Oily; Peach; Strong; Sweet; Waxy; Woody
Dodecanal	Dodecanal	1400	1499	112-54-9	Aldehydic; caprylic; Citrus; Fatty; Floral; Green; Herbaceous; Lily; Oily; Soapy; Waxy
Methyl cinnamate	Methyl cinnamate	1400	1548	103-26-4	Balsamic; Cherry; Cinnamon; Fruity; Strawberry; Sweet
Methyl eugenol	Methyl eugenol	1400	1597	93-15-2	Carnation; Cinnamon; Clove; Fresh; Mild; Spicy; Sweet; Warm
Delta-Nonalactone	Delta-Nonalactone	1400	1615	3301-94-8	Coconut; Coumarin; Creamy; Milky; Sweet
Vanillin	ND	1400	1692	121-33-5	Aromatic; Chocolate; Creamy; Pleasant; Sweet; Vanilla
(E)-Cinnamic acid	ND	1415	1736	140-10-3	Floral; Honey; Sweet; Woody
Delta-decalactone	ND	1487	1736	705-86-2	Coconut; Creamy; Dairy; Fresh; Fruity; Oily; Peach; Sweet
Pentyl octanoate	ND	1497	1548	638-25-5	Cognac; Fatty; Orris; Sweet; Winey
Myristicin	Myristicin	1497	1692	607-91-0	Balsamic; Mild; Spicy; Warm; Woody
Rheosmin	Rheosmin	1528	1463	5471-51-2	Balsamic; Berry; Floral; Fruity; fruity (sweet); Jam; Raspberry; Sweet; Warm
4-Undecanolide	ND	1595	1815	104-67-6	Apricot; Coconut; Creamy; Fatty; fatty (strong); Fruity; Ketonic; Peach
Ethyl tetradecanoate	ND	1815	1887	124-06-1	Etheral; Oily; Orris; Sweet; Violet; Waxy

ND - Not detectable

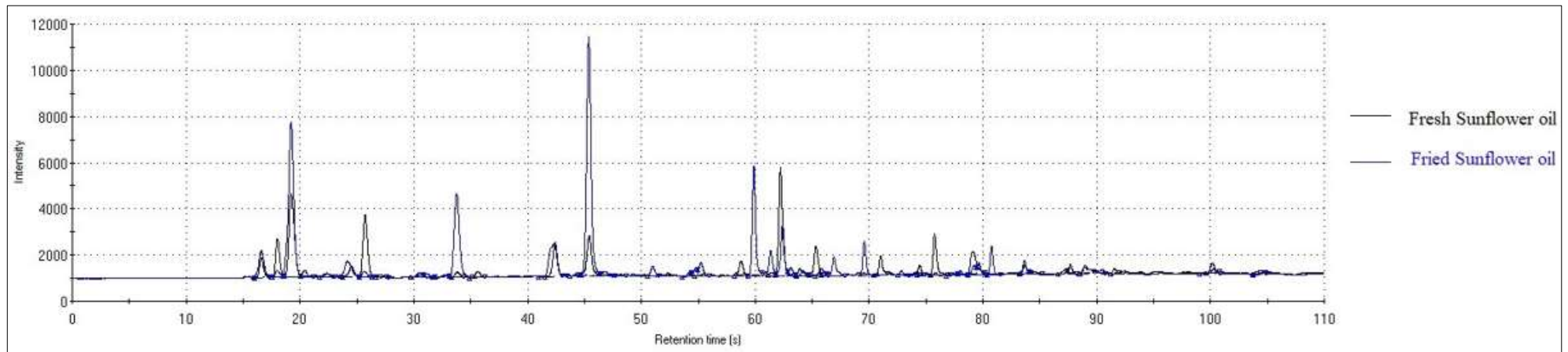


Fig 1: Overlaid chromatograms of fresh and fried sunflower oil - MXT-5-FID-1

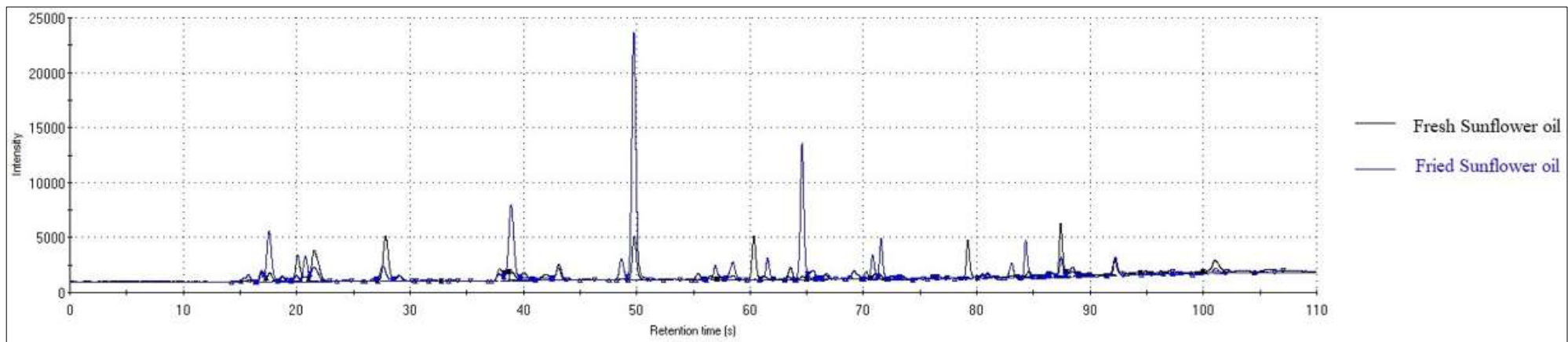


Fig 2: Overlaid chromatograms of fresh and fried sunflower oil - MXT-1701-FID-2

4. Conclusions

The volatile profile changes in sunflower oil after deep-frying was studied. Results of the volatile compounds suggested that the major volatile compounds were formed from the oxidation of linolenic and oleic acids. The volatile markers of the chemical reactions occurring during deep-frying found this study can be useful to indicate whether the oil is fresh or oxidised. This study also proves that the electronic nose can be an effective alternative method to determine the volatile profiles of oil besides other conventional methods such as head space solid phase micro extraction-gas chromatography.

5. Conflict of interest

The authors have no conflict of interest.

6. References

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