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Review article

Unraveling the Challenges of Oxidative Stability: Methods for Assessing Oxidative Stability of Commercial Oils: A Review

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Abstract

Edible oils are among the most crucial nutritional constituents as these are utilized for frying or cuisine. Though, these oils are prone towards oxidative deterioration from manufacturing to transportation due to environmental exposure as well as storage conditions which result in generation of different types of oxidation products. The generation of primary and secondary products result in harmful impacts on human health and may also result in cardiovascular diseases in consumers. The mechanism of oxidative deterioration cannot be assessed easily due to complexity of the reaction under which it may take place. Different types of approaches have been proposed to determine the products generated as a result of oxidation so that safety for their user can be assured. Different types of analytical techniques can be employed in addition to chemical methods so that analysis of oxidative deterioration can be done completely. The proposed study is aimed to assess the oxidative stability of oils in addition to the factors which can influence oxidation of these oils under different conditions. This review also summarize the classical and advanced state of the art analytical techniques which has recently been developed in different possible ways and effectively can be employed for analysis of oxidative deterioration of edible oils. This article possibly will oblige as a reference in the assortment, establishing, and enhancement of approaches for investigating the oxidative stability of edible oil.

Keywords: Edible oils, oxidative stability, shelf-life, factors effecting oxidation, analytical techniques, oxidation products etc.

1.Introduction

The rate of food consumption is rising enormously as the population of world is increasing day by day [1]. Because of this fact the demand of edible oils also has been increased much more compared to the past [2]. Edible oils are among the major constituents of food products along with carbohydrates, proteins, minerals etc. Edible oils provide essential fatty acids and fat-soluble vitamins to our body and also give flavor to our food [3, 4]. As the demand of edible oils has been increased the maintenance of the quality has become a major concern for the manufacturing industry which is mainly dependent upon their oxidation [5].

One of the most important and largest classes of naturally present molecules is lipids which comprises of fatty acids, glycerol, glycolipids, phospholipids, sterol esters, waxes etc. [6]. Lipids containing food products are usually insoluble in polar solvents like H_2O and CH_3OH and become easily soluble in non-polar solvents like $CHCl_3$ and ethers etc. Fats are major kinds of lipids which could be defined as, esters of triglycerides. Both oils and fats are subsets of lipids and are composed of fatty acids, most of the oils befall in liquid state at room temperature and almost all fats are solid at room conditions [7].

Fats regulate many significant tasks which may involve, to meet high energy demand of body, impart delicious taste to our food, serve as a courier for many of the biological active compounds, serve as a medium for absorption of fat soluble enzymes like A, D, E & K, important part of body fluids and cell membranes, and serve as insulator for body [8].

In our everyday life one of the most ingested or consumed constituents around the world for cooking purposes are edible oils. Oils play a crucial role in everyday life of mankind besides of edible applications. Besides their nutritional value fatty acids find applications in many industries such as production of soaps, washing powder, cosmetics, and detergents, oleo-chemical industry and bio-fuels etc. [9, 10]. Major source of edible oils in terms of production in the whole world are from soybean and palm oil which together account for over 65%. Production of the edible oils has been enhanced abruptly during the last few years due to high consumption demand. Maximum level of production was about 126.02 million metric tons (MMT) of major edible oils in year 2010-11 which now has been reached up to 152.29 MMT by the year 2014-15. The production of palm oil has been increased from 48.84 to 63.29 MMT and soybean oil from 41.29 to 46.95 MMT which are major edible oils produced as compare to that of canola oil (23.46 to 26.76 MMT) and sunflower oil (12.43 to 15.29 MMT) [11].

Based upon fatty acids profiling edible oils are classified into saturated and unsaturated oils. In saturated fatty acids (SFAs) there is no double bond, while monounsaturated fatty acids (MUFAs) have only one double bond and polyunsaturated fatty acids (PUFAs) comprises of multiple double bonds present along the carbon chain [12]. Recently many researchers have elaborated that foodstuffs enriched in SFAs cause an increased level of cholesterol and low-density lipoprotein (LDL) which could promote the risks of many heart diseases. Furthermore a lot of research has been done which reveals the effects of these SFAs on the cancer or tumor development, obesity and other disorders [13-15]. In Asian countries, the majorities of SFAs are obtained from ghee, Vanaspati (hydrogenated fat), cheese and also from some cooking oils which includes coconut oil, palm kernel oils [16].

In contrast to SFAs intake of food products enriched in MUFAs as well as PUFAs are helpful in lowering the level of cholesterol and increased the level of high density lipoprotein and decrease the low density lipoprotein, which will resolve the health risk of coronary heart diseases [17-19]. Canola, rice bran, olive, mustard and groundnut are among those oils which are enriched with MUFAs. Likewise, sunflower, corn, soybean, linseed oils are enriched with many of essential dietary PUFAs which are vital for our health assurance. There is another type which is known as Trans fatty acids (TFAs) are generated during the production process of hydrogenated vegetable oils and might also be present in fats. This type of fat mostly includes UFAs that exhibit isolated double bonds (one or more) in the Trans form of configuration [20, 21]. Research work in clinical field reveals that a high intake of TFAs containing food products is directly linked with development of cardiovascular disease (CVD) by enhancing serum LDL cholesterol relative to SFA [22, 23].

According to the American Heart Association (AHA) the accepted or recommended limit of fats containing foodstuffs consumption should always be lower than 30 -35% of total calories required for energy demand, In this extreme limit, the consumption of SFAs should always be confined to 10%, MUFAs to about 15% and PUFAs to about 10% of total calories required for energy demand [24]. Likewise, TFAs level of consumption should be limited to 1% only of total energy. Therefore, maximum consumption limits of all types of fatty acids should be in the ratio of SFA: MUFA: PUFA, 1:1.5:1. But, consumption or use of only single type of edible oil alone cannot fulfill the intimate regulations, blending of two or more oils are generally advised for betterment of human health [25, 26].

1.1. Aims and objectives

This article is proposed by keeping some important points in mind which are as following;

- To analyze the oxidation challenges which occur from manufacturing to storage as well as utilization for

betterment of human beings.

- To analyze different factors which prone these oils towards oxidative deterioration after proper manufacturing.
- To analyze the potential of natural antioxidants which can be applied for the enhancement of oxidative stability and shelf life of these oils
- An overview of different chemical and state of the art analytical techniques which can be applied for analyzing oxidation products at different stages of oxidation assessment.
- Also overviewing of the advanced biosensor type approaches which can be applied for the analysis of oxidation.

2. Methodology

This review provide a comprehensive overview of analysis of oxidative stability of commercial edible oils which face the challenges of oxidative deterioration due to different environmental factors as well as storage conditions. This review was designed to elaborate these challenges of oxidative deterioration as well as its proper determination by applying different advanced techniques which has recently been developed. This review entails comprehensive data available on oxidative stability of edible oils mostly from 2000 and onward period also include some studies which has been conducted before 2000. This review was designed by overviewing a huge number of articles which provide detail study about oxidative stability analysis. The data collected for this study was mostly from different sites which include Google Scholar, Semantic Scholar, PubMed and Research Gate which has been published during the specified period of the time. So, as a whole this review article entails the comprehensive and complete overview regarding this problem of oxidative stability which occurred in edible oils during different storage conditions as well as their shelf-life analysis due to these factors.

3. Relationship between oxidative stability and shelf life of oils

Most of edible oils are unsaturated and are susceptible towards deterioration which in turn causes quality loss of these oils because maintenance of oils quality is mainly dependent on rate of oxidation [27]. The oxidative stability in case of edible oils is the resistance towards oxidation process from processing to storage [28]. The resistance towards oxidation is mostly expressed as time period taken by oil samples to reach the critical point; this oxidation may be abrupt acceleration of oxidation process or may be a change in sensor response [29]. As the rate of oxidation increases deterioration of oil occur at faster rate and cause generation of rancid odor and off-flavor which is prohibited for consumers [30]. The generation of rancid odor and bad smell is due to formation of some short chain molecules and polymers. As a result of oxidation loss of nutritional value occur consequently this will be of no importance for health or possibly may impose some negative effects on human health. Rate of oxidation also results in decline of shelf life or storage period of lipid containing food products [31].

The process of lipid oxidation is thought to be a major process or reaction which cause decline in vitality of food products. It merely provide bad smell and off-flavor to fat containing products but also cause generation of highly reactive O_2 species which is directly associated with highly dangerous carcinogenic, aging, and many other diseases like inflammation [32-34]. The phenomenon of oxidation may effect acceptability of sensors of human, and loss of nutritional values of fat containing foods and thus play pivotal role in assessing oxidation process, their uses and also predicting their shelf life [35, 36].

Furthermore the rate of increased lipid oxidation is responsible for the formation of oxides of cholesterols which will cause the formation of plaque in blood vessels, consequently risk of cardiovascular diseases increases [37]. During the whole process from the manufacturing to storage it is quite important to monitor the lipid oxidation rate and extent to which it may occur so that concerns towards acceptability of sensors and health hazards in case of human consumption may be resolved. Edible oils are mostly consisted of PUFAs which are susceptible towards any type of oxidation like auto-oxidation, thermal oxidation and photosensitized oxidation [38]. The

degree or extent of oxidation can be determined by using different types of methodologies which will determine the quantity of intermediates or products formed during specific stage of reaction [39].

Storage of edible oils is important factor after manufacturing properly because storage conditionings affect the rate of oxidation which directly alters quality of lipid containing food. Storage of edible oils under harsh conditions or improper environmental conditions may cause deterioration of lipid containing foods, these may include high temperature, presence of light, or direct contact with oxygen which readily increase the rate of oxidation and deterioration of oil samples [40, 41]. Primary products formed during oxidation of oils are hydro-peroxides which on further oxidation may cause formation of secondary products which include aldehydes, ketones and other small molecules which may cause food poisoning [42, 43]. The process of oxidation directly affects quality of oil containing food samples which in turn cause decrease in the shelf life of lipid containing products. As the rate of oxidation increases stability decreases as a result of which shelf life of edible oils also decreases. The oxidative stability index also determines the period or storage time during which our lipids containing food could be remain safe and after this period it will be of no use and could be harmful [44, 45].

There are many kinds of variable which could be helpful in predicting the shelf life of different edible oils or fat containing foodstuff. These may include type of processing, conditions at which samples are stored, sunlight exposure, type of material used for packing, presence or absence of oxygen, and presence of antioxidants which could affect the vitality and quality of edible oils and lipid containing food products [46]. However, research on shelf-life prediction or storage conditioning of edible fat/oils at room conditions, which are nearly the real storage conditions, but are not enough when compared with accelerated oxidative conditions or at harsh conditions [47].

4. Oxidation products of oils

Assessment of oxidation of lipids in foodstuff is a pertinent consideration because products formed during the process of oxidation are affiliated to distasteful sensorial and may cause biological impacts. Adequate assessment of products formed during lipid oxidation persist an insisting work because the phenomenon of oxidation is quite difficult and depends upon kind of lipid, the catalyst which promote oxidation, and ambient conditions [48]. Different methodologies have been adopted to evaluate the extent of oxidation in oils. Free fatty acids (FFAs) and peroxides are among the oxidation products formed at early stage. To monitor these products, acid value and peroxide value have been determined by performing chemical titration methods which act as primary indicators of oxidation products formation [49]. But if the conditions are favorable for oxidation of lipid containing samples then these product will further react and will be converted into secondary products like aldehydes, ketones and other small molecules which could be harmful for health. Thus storage of oil containing food products at specific conditions is necessary to protect them from environmental conditions and safe for human health [50].

There are two major reactions that may cause oil deterioration. Most of rancidity is caused by the reaction when oil reacts with oxygen and is known as oxidative rancidity. On the other hand oxidation may occur due to presence of moisture or enzymes [51]. For example presence of lipase enzyme cause liberation of fatty acids from the triglycerides and result in the formation of diglycerides and monoglycerides. As a result of this reaction FFAs are produced. Hydrolysis may be caused by a chemical action due to the presence of moisture and heat energy, this type of rancidity is known as hydrolytic rancidity [52]. The oxidative rancidity is main reaction of interest as it cause generation of off-flavor molecules and can be detected early as process of oxidation start to develop but not possible in hydrolytic rancidity [53, 54].

Rancidity of edible oil determine its extent of oxidation, different types of product are formed at different stage of oxidation. Primary oxidation product are produced as a result of reaction between alkyl radical which is formed due to presence of heat energy and light (initiation step) with O_2 as a result of

which peroxy radical is formed which attack UFA and peroxides in addition to free radicals are generated (propagation step) [55]. This type of reaction continues until there is no further O_2 present. On the other hand this reaction ends up when radical combine with a stable antioxidant or when two reactive and unstable species react with each other to form stable molecule (termination step) [56, 57].

4.1 Primary oxidation products

At early stage rate of reaction is slow and compounds generated during this period are peroxides, mostly hydro-peroxides are known as primary products. These oxidation products are also known as intermediate of lipid oxidation; these products are stable to some extent depending upon structure of lipid and in the absence of heat, light radiation, heavy metals or other radicals. Environmental conditions should be under control to prevent further deterioration; sometime antioxidants may be added to prevent oxidation [48]. Mechanism of hydro-peroxide formation as a result of oxidation is as mentioned in figure 1.

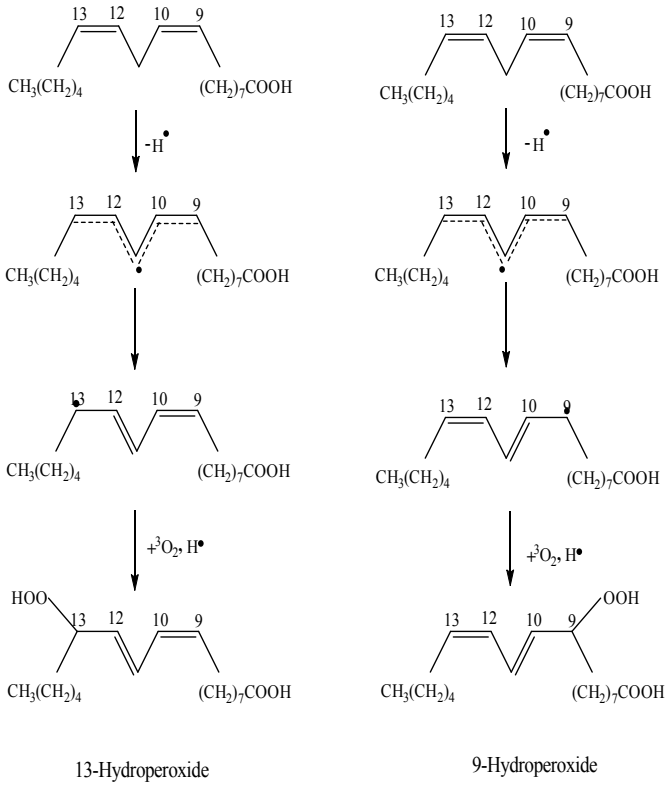

Figure 1: Mechanism of primary oxidation products formation during early stage of storage or oxidation [42].

4.2 Secondary oxidation products

Primary oxidation products are stable to some extent but in the presence of heat or radiation energy and radicals the primary products further take part in chemical reaction and are converted into secondary oxidation products. These products result by peroxide reaction alone or due to some chain reaction and lead to the formation of short chain molecules such as ketones, aldehydes or some volatile alcohols or acids, which result in the generation of rancid odor due to formation of these products [43]. The presence of antioxidants may cause the interruption of the chain reaction and slow down chain propagation step of oxidation. On the other hand some synthetic antioxidant may be added from outside to prevent oxidation such as phenols [52].

Mechanism of secondary oxidation product formation is given in figure 2.

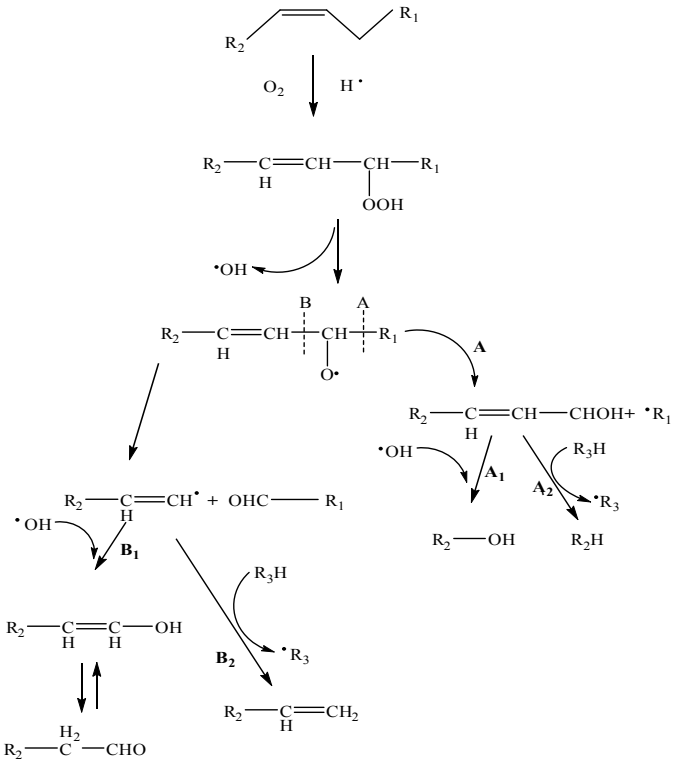

Figure 2: Mechanism of secondary products formation during later stage of oxidation [42]

5. Factors affecting oxidation of oils

To assure the extended shelf-life achievable for edible oils it is significant for us to be cautious of such factors which could impact oxidative stability of oils. These factors mutually influence the rate of oxidation of edible oils and this is not

fluent to distinguish the peculiar impact of each factor (Figure 3).

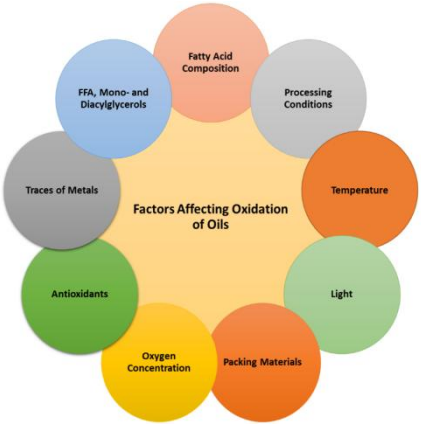

Figure 3: Description of the factors which effect oxidative stability of edible oils

5.1 Fatty acid composition

The composition of fatty acids tells us significant findings while glancing at relative stability of edible oils. For such oils which possess higher unsaturation in their chemical structure are more prone towards oxidation as compare to those having less unsaturation [58, 59]. The increment of double bond or unsaturation in composition of edible oil results in enhanced rate of oxidation of oil sample which in turn cause increased formation of clustered primary products at the apex of induction time period (Figure 4) [40, 47].

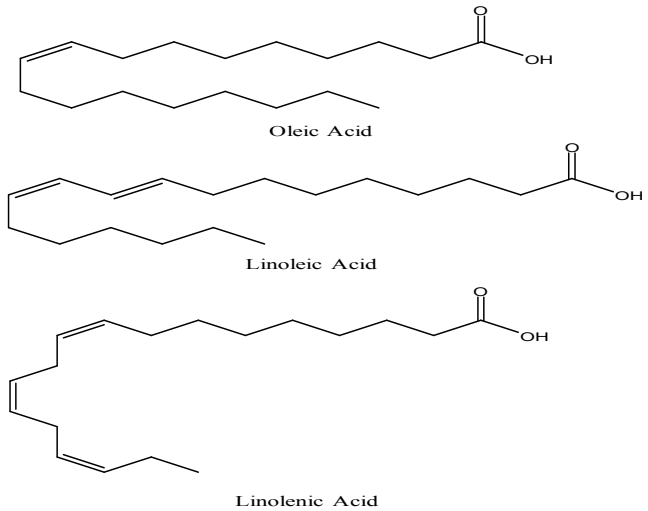

Figure 4: Structures of some of the unsaturated fatty acids which mainly influence oxidation.

UFAs containing oils are more prone towards oxidation as compare to SFAs or MUFAs containing oils. For example oils having oleic, linoleic and linolenic acid are at higher risk of oxidation [60, 61]. In these unsaturated fatty acids Linoleic acid has already been examined comprehensively and results have been concluded which shows that oil samples containing linolenic acid are about 10 to 100 folds more deceivable to phenomenon of oxidation in contrast to SFAs containing oils and monoenes (Figure 5) [62, 63].

For instance, when comparison was made among oxidative stability of regular canola and soybean oil with modified oils having lower linoleic acid in their composition then there was lesser percentage of polar components in modified oils after frying [64]. Likewise, resistance towards oxidation of corn oils with enhanced degree of saturation in composition was estimated. After storage corn oil which possess elevated saturation was more resistance towards oxidation in contrast to regular corn oil [65]. Moreover, edible oils which possess iodine value greater than 130 are less stable toward oxidation and deteriorate early. While, those which possess iodine value less than 20 are more resistant toward oxidation [66, 67]. By enhancing concentration of oleic and stearic acid, by genetic modification in seeds and by hydrogenation in soybean oil resistance towards autoxidation could be enhanced [68-70].

5.2 Processing of oil

The method applied for processing of oil also influence stability of oil towards oxidation. Unrefined oil possess higher resistance towards oxidation as compare to refined bleached deodorized (RBD) oil. The stability towards oxidation of unrefined oil is always higher in comparison to RBD oil to some extent because unrefined oil possesses greater concentration of naturally occurring antioxidant [72-74]. Similarly oxidative stability of walnut and macauba kernel oil extracted with supercritical CO_2 was considerably lesser than walnut and macauba kernel oil obtained by just pressed method [75]. The process of roasting of seeds of sesame before extraction of oil also increased resistance of oils towards oxidation, which simply may occur due to products formed as a result of Maillard reactions which act as antioxidants. The stability of oil also increases when temperature rises during roasting as well as expeller pressing of seeds [76, 77].

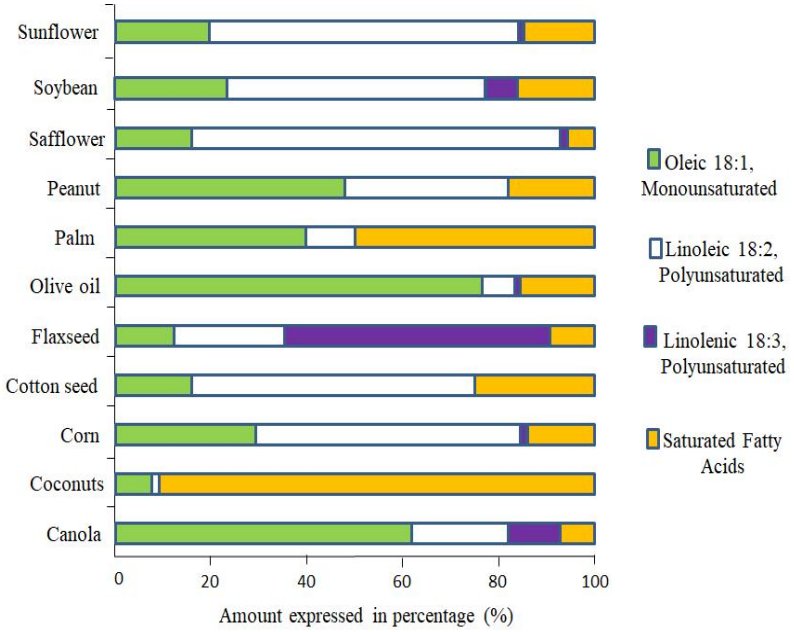

Figure 5: Fatty acid composition of some of the mostly used oils which has already been reported in the literature [71]

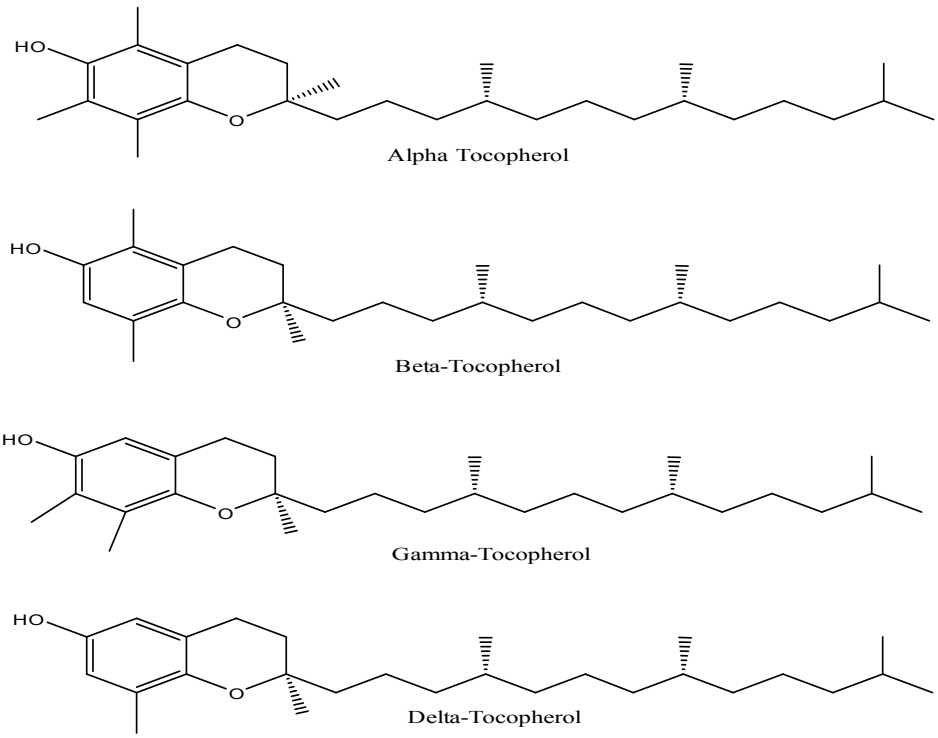

Figure 6: Structures of tocopherols which are present in edible oils and play role as an antioxidants during oxidative stability

5.3 Temperature

Temperature is also a factor which impacts at induction period of edible oils and causes decrease in shelf-life of edible oil, because reaction rate of fatty acid molecule with oxygen approximately becomes twice for each 10°C rise in temperature [78]. In the experimental storage study performed by Crapiste et al. it was cleared that peroxide and acid value rises at faster rate when was obtained at elevated temperature of 40 °C, 47 °C

and 67 °C. In case of storage of shortening blends obtained by (hydrogenation or solidifying fats) at 50 °C and 60 °C, the results indicate that peroxide values rises at much faster rate at 60°C temperature as compare to 50 °C. The results were also confirmed by performing sensory tests [79].

The process of autoxidation as well as degradation of peroxides formed at initial stages also rises as temperature for storage of oils is increased. For instance, hydro-peroxides degrade at faster rate at elevated temperature [80]. The formation of products as a result of autoxidation reaction is slower at lower temperature throughout the induction period terminal after which a sudden rise in oxidation reaction occur [81, 82]. The percentage of peroxides rises up to a certain level after which alternative increment of oxidation reaction occur. The concentration of polymerized contents also rises considerably after end up of induction time of autoxidation [83].

5.4 Light

Like process of autoxidation another type of oxidation occurs which also cause deterioration of edible oils is known as photo-oxidation. Presence of light at storage place of oils has a fostering impact on oxidation of oils [84]. The process of oxidation by exposure of light takes place in a different way in contrast to free radical mechanism of oxidation. The process of oxidation in the presence of light comprises stimulation of substrate that afterward reacts with fatty acids having unsaturation. For instance, riboflavin reacts with unsaturated fatty acids double bonds in the presence of light [85]. As Frankel (1985) illustrated another type of mechanism which involves oxidation of oils in the presence of light is by excited state of molecular oxygen. Effect of light is most significant factor as compare to temperature in case of singlet oxygen oxidation process. Form of light having short wavelength range has most adverse impact on oxidation of oil as contrast to those having longer wavelength [86]. Perhaps, the impact of light exposure on oxidation of oil alters fewer changes in composition as temperature rises during storage [81, 87].

5.5 Packing material

Type of packing material also affects vitality of edible oil. Selection of most proficient form of packing material for the storage of oil also cause resistance towards oxidation and make a huge difference of shelf-life. The process of oxidation occurs at faster rate in transparent glass as well as polyethylene tetra-phthalate (PET) bottles while slower in brown amber bottles [88]. Purified oil of sunflower seeds stays reliable for about 24 months while kept in container of polyethylene having higher density as well as closed cans without evolving obvious taste and smell [89]. For example, impact of different type of packing materials on oxidation of fatty acids in potato crunch was evaluated by exposure to fluorescent lighting and was noticed that light of visible region having wavelength higher than 380 nm cause deterioration of fatty acids containing crunches [90].

5.6 Oxygen concentration

The process of oxidation mostly occurs in the presence of oxygen as well as catalyst. Form of oxygen and amount present in oil also influence rate of oxidation [41]. Amount of oxygen dissolved in oil is associated with its partial pressure in sealed container of edible oil. For instance 1 g soybean can dissolve about 55 ŭg of oxygen at ambient condition [91]. Amount of dissolved oxygen in oil sample rises when pressure exerted by oxygen in the closed container is higher. Also rate of oxidation of lipids enhanced when concentration of oxygen dissolved in oil increases [41]. The impact of dissolved amount of oxygen on deterioration of edible oil become more prominent at harsh conditions such as elevated temperature, presence of light and traces of metals etc. At elevated temperature dependence of oxidation of oil on amount of dissolved oxygen become less due to decrease in solubility of oxygen in oil. But when percentage of oxygen is lower, then rate of oxidation depends only on amount of oxygen dissolved and becomes independent of concentration of lipid [54, 91].

5.7 Minor components

Major components of edible oils are triacylglycerol, in addition to these components they may also entail some minute constituents like, phospholipids, tocopherols, phenolic compounds, carotenoids etc. They may also entail traces of

metals, peroxides, free fatty acids, mono- and di-glycerides.

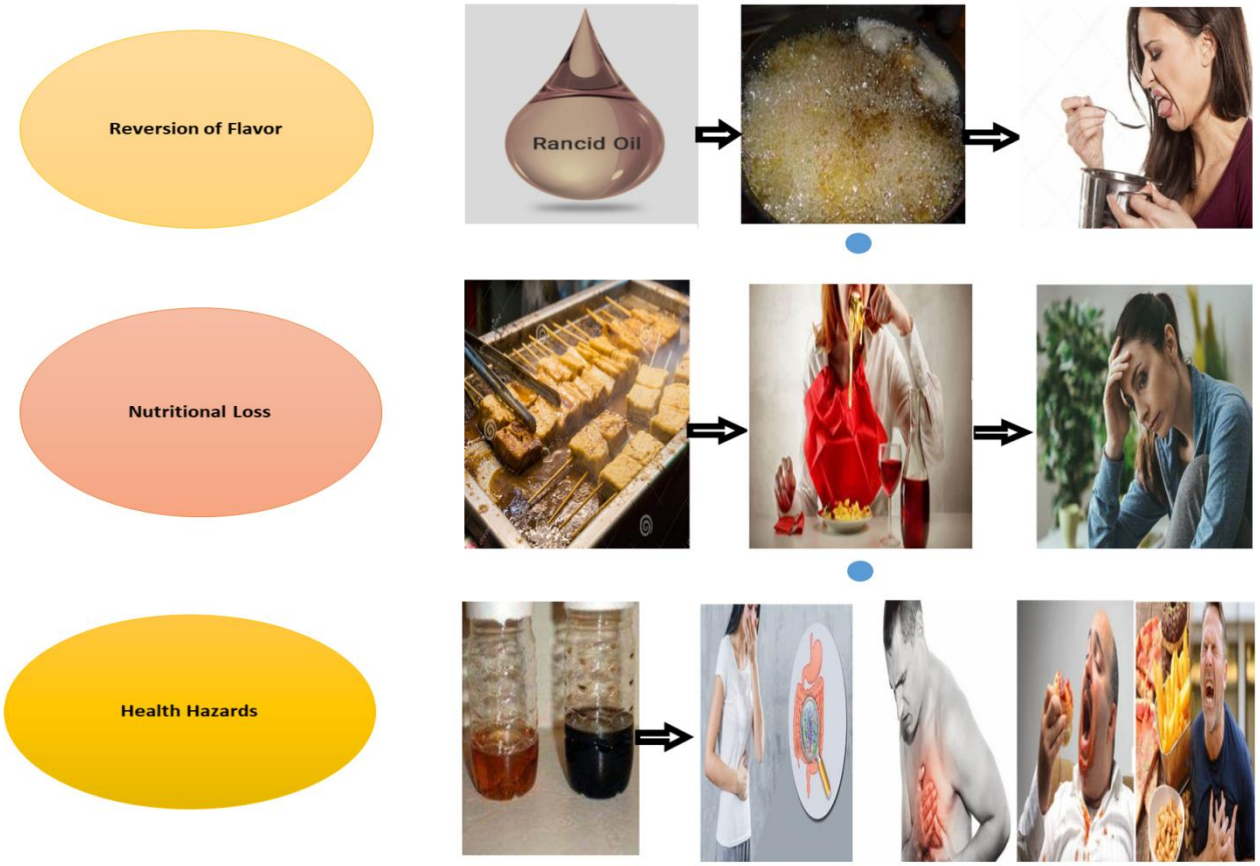

Figure 7: Different impacts of lipid oxidation on the food as well as human health.

Some of these minor constituents promote oxidation rate of fatty acids which results in deterioration of edible oil, some of these retard oxidation rate of edible oil and make them suitable for our health [48].

5.7.1 Antioxidants

Antioxidants are present in oils in minor concentration are among the important constituents which play vital role in enhancing oxidative stability and nutritional importance of edible oils [92]. Edible oils naturally entail some antioxidants which includes phenolic compounds, tocopherols as well as tocotrienols, some carotenoids etc. These naturally occurring antioxidant play pivotal role in maintaining vitality of edible oil for human by neutralizing free radicals formed as a result of chain reaction [93]. There are about eight isomeric forms of vitamin E which are naturally present in edible oils, four of these isomeric form are tocopherols (α-, β-, γ -, and δ-) and other four are tocotrienols (α-, β-, γ -, and δ-). Each isomeric form of vitamin E has its unique biological capability and plausible impact on human health [94, 95]. These naturally occurring components anticipate deterioration of edible oils and enhance their stability toward oxidation which results in longer shelf-life of oil. The percentages of these antioxidants also play

vital role in prohibition of some diseases like Parkinson disease and ataxia which results due to deficiency of vitamin E [96].

5.7.2 Tocopherols

In analyzing capacity of tocopherols behaving as an antioxidant it is necessary to accommodate the conditioning for oxidation reaction which could impact their functioning as hindrance in the way of oxidation of lipids like, temperature, presence of oxygen or its concentration, light, state of lipids and percentage of tocopherols contents [97-99]. Most of percentage of these antioxidants degrades or lost during oil processing such as, extraction, purification, bleaching and deodorization. For instance in case of olive oil about 18%, rapeseed and soybean about 25% removal of tocopherols occur. Moreover in case of cottonseed, sunflower and peanut oil this percentage is quite high, which is about 36%, 37% and 40% respectively (Figure 6). But the percentage of naturally occurring tocopherols remaining behind is also enough to preserve these edible oils from deterioration as a result of oxidation under environmental conditions [100-102].

5.7.3 Synthetic Antioxidants

There are some artificial antioxidants which are intentionally dissolved in samples containing fats or oils to make them intact during different stages of refining. For instance tertiary-butyl hydroquinone (TBHQ) is an artificial antioxidant which is dissolved in oils to protect them from oxidation reaction occurred during purification and deodorization [103]. TBHQ possess brilliant resistance against secondary products which is determined by para-anisidine value and possess stabilizing effect on tocols. On the other hand TBHQ is also reported to be efficient in protecting unrefined oil from deterioration under storage conditions, which is quite usable for countries like Malaysia where transportation of crude oil is very far away and extended storage period is required before reaching to destinations [104].

5.7.4 Other type of antioxidants

The phenolic compounds are also present in composition of edible oil which possess multiple substitutions at benzene ring and could donate hydrogen atom to free radicals [105, 106]. For instance mono- and poly-hydroxyl phenolics are among the main constituents which could donate hydrogen atom. So any species which possess lesser reduction potential as compare to free radical will be able to transfer his hydrogen to free radical until reaction will become opposing [107]. Similarly chelating agents like EDTA, ascorbic acid, and phosphoric acid also cause resistance against oxidation in another way. They cause production of metal complexes which are insoluble or convert ions into insoluble complexes or can cause spatial hindrance in the generation of complexes among metals and oxidation products [108].

5.7.5 Free fatty acid and mono- and diacylglycerols

Oil samples in crude form entail some percent of FFAs, but during processing of oils like, refining percentage of these types of components decreases. For instance, oil obtained from sesame seeds entail about 0.72% FFA, but in case of oil obtained after bleaching by acid clay cause reduction of FFA to about 0.56% [109]. These contents present in edible oil behave as pro-oxidant and promote deterioration of oils. It is also concluded that FFA cause reduction of surface tension which result in more diffusion of oxygen into oil and decrease resistance towards oxidation [110]. In addition to triacylglycerol mono- and diacylglycerols are also entailed by oils in different ranges. These acylglecerols behave as promoter for oxidation of oil in the absence of light. These must be separated from oil during purification of oil to enhance stability of oil against oxidation [109, 111].

5.7.6 Metals

Traces of metals may also present in extracts of oils in their crude form like iron or copper. But on purification concentration of these metal traces decreases. Presences of these metals cause further oxidation of oils which is due to lower activation energy required for initiation of autoxidation to about 64~103 kJ/mol [112]. Metals present in oils react abruptly with fatty acids and generate free radicals of alkyl group. These could also generate reactive singlet oxygen which result in the formation of primary oxidation products [113]. Presence of ferric ion also results in degradation of phenolic compounds which acts as antioxidant, for instance, ferric ion

cause degradation of caffeic acid present in olive oil which oxidation decreases [114].

results in deterioration of olive oil and resistance towards .

Table 1: Applications of plant based materials which has been applied for enhancing oxidative stability of oils

Plant materials	Conc. of extract	Oils analyzed	Effect of extracts	References
Leaves of olive tree (*Olea Europaea L.*)	200 mg extract/kg of oil	Sunflower oil	Increase in total phenolic content and oxidative stability	[124]
Leaves of olive tree *(Olea Europaea L.)*	1000-1500 mg extract/kg of oil	Corn oil	Increase in total phenolic and carotenoid contents and antioxidant potential	[125]
Leaves of olive tree *(Olea Europaea L.)*	3% of extract	Olive oil	Increase in Total phenolic content and antioxidant potential	[126]
Leaves of rosemary *(Rosmarinus Officinalis L.)*	400 mg/kg of oil	Soybean, cottonseed and rice bran oil	Increase in oxidative stability especially reduction in peroxide value	[127]
Leaves of oregano *(Origanum Vulgare L.)*	0.1, 0.3 and 0.7% of extract	Soybean oil	Enhanced oxidative stability	[120]
Leaves of oregano (*Origanum Vulgare L.)*	400 mg/kg of oil	Sunflower oil	Enhancement of antioxidant potential	[128]
Essential oil of laurel *(Laurus Nobilis L.)*	0.01% /volume of oil	Extra virgin olive oil	Enhancement of oxidative stability	[129]
Leaves and flower of thyme (*Thymus Schimperi R.)*	0.1 and 0.2% extract	Soybean oil	Increment in induction period of oil	[130]
Leaves of basil (*Ocimum Basilicum L.)*	3000 mg/kg of oil	Soybean oil	Enhancement of oxidative stability	[131]
Leaves of basil *(Ocimum Basilicum L.)*	100 and 300 mg/kg of oil	Sunflower oil	Increment in antioxidant potential	[128]
Pepper powder *(Capsicum Annuum L.)*	10, 20, and 40 g/kg of oil	Extra virgin olive oil	Enhanced oxidative stability	[119]
Garlic powder *(Allium Sativum L.)*	20, 30, and 40 g/kg of oil	Extra virgin olive oil	Enhanced oxidative stability	[119]
Fruit extract of Carum Copticum	200, 400, and 600 mg/kg of oi	Canola oil	Enhanced oxidative stability and antioxidant potential	[132]
Essential oil of Carum Copticum fruit	100, 200, and 400 mg/kg of oil	Canola oil	Enhanced antioxidant potential	[133]
Sea buckthorn pomace and seed extracts	3000 mg/kg of oil	Canola oil	Enhanced antioxidant potential	[134]
Thyme and ginger	200 and 300	Sunflower oil	Reduction in oxidation and	[135]

extract	mg/kg of oil		increment in antioxidant potential	
Leaves extract of olive oil	25, 50, and 75 µg/mL of oil	Sunflower oil	Enhanced antioxidant potential and reduction of primary and secondary oxidation parameters value	[136]
vitamin E, phytic acid, antioxidant of bamboo leaves, rosemary extract, tea polyphenols, ascorbyl palmitate and tea polyphenol palmitate composites	Different conc. of these mixed antioxidants up to different proportion	High oleic acid sunflower oil	Enhanced shelf-life with addition of these antioxidants	[137]
Extracts of rosemary, sage, and savory, summer	0.1% of by volume of oil	Moringa oil	Enhanced antioxidant potential	[138]
Essential oil of rosemary	0.05. 0.1, 0.2 and 5.0% by volume	Sunflower, soybean oil and tallow fat	Enhanced shelf-life	[139]

6. Enhancement of oxidative stability of oils by using plant extracts

In addition to the naturally occurring antioxidant that are found in oils utilizing synthetic antioxidant complexes is one way to enhance the oxidative stability and overall quality of oil. Despite this, there are questions regarding their impacts on health of consumers, and there is evidence to suggest that these synthetic compounds may cause cancer [115, 116]. Because of this, a number of other potential approaches for improving oxidative stability of oils have been suggested. Specifically, the exploitation of natural antioxidants derived from subordinate torrents, foodstuff by-products, and other agro-food residues. Above all, considering that remaining from foodstuff processing accounts for 30.6 million tons per year, with 35% of that coming from fresh fruits and vegetables [117]

In spite of this, these by-products need to be processed, which involves the inclusion of chemicals (solvents). This is necessary not only for the extraction of phenolic compounds which behave as antioxidants, but also for other reasons. Because it is highly prospective that the extraction practice will also consequence in the release of other unwanted mixtures. But for betterment it is essential to search for natural sources of antioxidants in greater quantity. Alternatively, medicinal and aromatic plants (MAPs) appear to be an excellent candidate for the extraction of naturally occurring antioxidant compounds. Their exploitation, dating back to prehistoric times, by a variety of developments due to the numerous health and therapeutic properties they possessed [118]. There have been a number of studies that have focused on the addition of antioxidants derived from MAPs to oils to enhance their stability [119-123].

7. Oxidative stability of some selected oils

7.1 Soybean oil

Soybean is a type of plant which belongs to legume family and seeds of this plant are mostly utilized in soft food products like tofu and sauce. Seeds of this plant exhibit approximately 20% oil content [140]. The major constituents of soybean includes proteins and fatty acids. Among these fatty acids alpha linolenic acid, docosahexaenoic acid and eicosapentaenoic acid are of prime importance which control transfer of triglycerides into the blood [141]. On the other hand proteins present in seeds of soybean also have a vital role in reducing nourishing inadequacies and inhibiting the

diseases associated with hormones like prostate cancer [142]. Soybean possess some potential applications which involve maintaining temperature of body, Source for essential fatty acids, behave as medium for vitamins which are soluble in fats and source for omega-3 and vitamin E [143]. Seeds of soybean entail higher percentage of fats which are at the risks of deterioration and exhibit shorter shelf-life and may result in the development of offensive smell and taste because of decomposition of fatty acids during storage time, due to this reason quality maintenance is necessary [144]. During storage period of the oil, the rate of reaction among the UFAs and molecule of oxygen rises which result in enhanced deterioration of this oil and quality of food products for which it is used [145].

7.1.1 Composition of soybean oil

The major constituents present in soybean oil includes linoleic, linolenic and oleic acids which entail about 55%, 13% and 18% orderly of total composition of soybean oil. Other fatty acids are also present which include palmitic and stearic acid which cover about 10% and 4% of total oil composition. Due to presence of more unsaturation in composition soybean oil is more prone towards oxidative deterioration by oxygen present in the oil entailing container [142, 146]. As a result of oxidation FFAs are generated which can result in affliction of mitochondria. Due to damage of this organelle generation of energy decreased as mitochondria is power house for cells [147]. FFAs produced as a result of oxidation of lipids also facilitate further oxidation which could cause generation of offensive smell or taste in foodstuff [148].

7.1.2 Oxidation of soybean oil

There are different kinds of oxidation which could take place in fat containing products, these may include autoxidation, photo-oxidation, or may be due to enzymes known as enzymatic oxidation [149]. Among these reactions of deterioration of edible oil, autoxidation is major oxidation reaction which occurs due to auto-catalytic activity among UFAs and oxygen. As the unsaturation increases oxidation reaction occur quite easily, same in the case of soybean oil which possess higher percentage of unsaturation in its composition and can be attacked by oxygen quite easily [150]. Soybean oil possesses higher percentage of unsaturation in the form of linolenic and linoleic acids which exhibit more threat for oxygen attack [151, 152]. Fatty acids having two double bonds in its structure possess higher oxidation ability of about 10 to 40 folds as compare to the fatty acids which possess only one double bond [153]. In most of unsaturated fatty acids autoxidation takes place which consisted of three stages of initiation, propagation and termination. As a result of this type of oxidation hydro-peroxides are generated which assemble as primary products, also free radicals are generated which trigger further reaction. At last stage two radicals merge with each other which result in the formation of stable non-radical species [154]. Peroxides are the main products generated at early stages are degraded further into other products if conditions are favorable for further oxidation. Secondary oxidation products includes aldehydes as well as ketones which are carbonyl compounds and give offensive odor to the oil and cause deterioration of oil sample [155]. So fatty acid composition of this oil conclude that this oil will be less stable and deteriorated more easily as compared to the oil which possess lesser percentage of unsaturation.

7.2 Palm oil

Palm oil is obtained from palm tree fruit which resembles with fruit of date tree. Fruit of this tree composed of two parts, outer portion of the fruit is known as mesocarp and inner portion of the fruit is palm kernel. The fruit of palm tree is collected quite carefully before extreme ripening so that to avoid some damage. These collected fruit clusters are processed instantly so that percentage of free fatty acids could be reduced by enzymatic action [156, 157]. There are two major constituents which are obtained from fruits of palm tree. One is palm oil which is obtained from upper layer of fruit bunches while other is known as kernel oil which is produced from the inner portion of fruit [158]. Both these two oil products possess different physical and chemical features. Palm oil possesses palmitic acid as a major constituent and occurs in solid form at environmental conditions in cooler

areas and in the form of fluid in tropical regions [159]. On the other hand kernel oil is most stable oil as compare to other oils or fats because this oil entails lauric acid in higher percentage and also possesses very lower percentage of

Table 2: Applications of FTIR spectroscopy based techniques for the oxidative stability analysis of oils

Oils analyzed	Conditions	Major activity	References
Colza, corn, frying, and sunflower oil	Heat at 170° C each 3 h for 36-h	Oxidative stability and kinetics	[231].
Canola oil	Heating and frying potatoes	Oxidative products identification	[232].
Olive, corn and sunflower oil	Heating up to boiling	Oxidative degradation analysis	[233].
Sunflower oil	Heating of potatoes for 40h	Total polar compounds analysis	[234].
Soybean, rapeseed, sunflower and peanut oil	Heating from 50 to 260 °C	Acid value and peroxide value	[235].
Soybean, flaxseed, coconut, cottonseed, peanut, rapeseed, corn, rice bran, and camellia oil	4 °C from 1 month to 1 year	Free fatty acid value	[236].
Colombian crude oils	220 to 440 °C	Total acid no determination (TAN)	[237].
Palm and mustard oil	170-230 °C heating range	Compositional analysis after heating samples	[238].
Hazelnut and extra virgin olive oil	Heating at 180 °C for 24 h	Thermal stability	[239].

Walnut oil	Heating at 110 °C	Induction period determination	[240].

Table 3: Applications of NMR spectroscopy based techniques in analyzing oxidation of oils

Oils analyzed	Type of technique	Major activity	References
Sunflower oil	^{1}H NMR	thermo-oxidation, and hydrolytic processes	[265].
Fish oil	^{1}H NMR	Oxidative deterioration	[266].
Blends of raspberry with sunflower and corn oil	Low field NMR and ^{1}H NMR	Thermal and oxidative stability	[267].
Cold-pressed and commercially refined camellia oil	^{1}H NMR and ^{31}P NMR	Oxidative stability	[268].
Sunflower, soybean, peanut, and corn oil	Low field NMR and ^{1}H NMR	Primary and secondary oxidation products	[269].
Linseed and fish oil	1D and 2D Low field NMR	Thermal oxidation stability	[270].
Palm oil	^{1}H NMR	hydrolytic and oxidative degradation	[271].
Blends of vegetable fish and fungal oils	^{1}H NMR	Primary and secondary oxidation products	[272].
Virgin olive oil	^{1}H NMR	Stability and shelf-life prediction	[273].
Edible oils	^{1}H NMR	Cis Trans fatty acids	[274].

UFAs [160].

In most cases this oil is converted into fractions, to serve in variable form in the widespread markets. Palm oil is mostly fractionated into two products like palm-olein which is present in liquid form and other is known as stearin which is present in harder or solid form under normal conditions [161].

Like other oils there are also some minor constituents which are present in palm oil composition when obtained from palm tree fruits. When palm oil is fractionated into palm-olein and palm stearin the minor components like, FFAs, mono-, and diglycerides, antioxidant tocopherols, carotenoids, and products formed by oxidation are remained in olein fraction, some other components like metal traces and phospholipids are migrated with other fraction known as palm stearin [162].

7.2.1 Composition of palm oil

The major constituents of palm-olein oil are SFAs and MUFAs. PUFAs are present in very small percentage as compare to other oils. Palm oil is enriched with SFAs which include palmitic acid and stearic acid which make about 44% of total composition of palm oil. Other major components are MUFAs which includes oleic acid and contribute to about 42% of composition of palm-olein oil. PUFAs occupy only 12% of total composition of palm-olein oil which includes linoleic acid [158]. There are some other oils which contain higher percentage of MUFAs than palm oil but their oxidative stability is less than palm-olein oil because they entail lower percentage of saturated fatty acids which ranges from 6 to 11.8%. For instance, olive oil contain about 80% of MUFAs, sunflower with higher oleic content possess about 81.3% MUFAs, canola entail about 61% of oleic contents, but these are less stable than palm olein oil due to lesser percentage of SFAs [163, 164].

7.2.2 Oxidation of palm-olein oil

Different types of chemical reaction are effective in determining the oxidative deterioration of oils [42, 165]. In comparison to PUFAs containing edible oils palm-olein oil is most stable oil against oxidative deterioration. This is because of fatty acids composition of this oil which possesses balanced percentage of SFAs and MUFAs and very lower percentage of PUFAs which cause resistance towards oxidation of this oil in comparison to soybean, corn or other UFAs containing edible oils [164]. Minor constituents present in palm-olein oil are also responsible for quality assessment of palm oil. Among these constituents tocols are of prime importance which show resistance against oxidation of palm oil [166, 167].

In spite of the fact that palm oil is most stable oil against oxidation reaction but there are some factors which oppose the application of palm-olein oil for food cooking purposes. Diet rich in SFAs results in obesity which may also result in cardiovascular diseases [168]. Consumption of oil having higher percentage of SFAs also result in enhanced level of cholesterol in blood which may trigger heart diseases [169]. This type of oil is also associated with overweight which in turn cause loss of sensitivity of insulin thus is also associated with diabetes [170, 171]. So oxidative analysis of this oil conclude that this oil is more stable as compare to mostly unsaturated oils which is due to balanced composition of SFAs and MUFAs and lesser percentage of PUFAs

7.3 Canola and rapeseed oil

In Canada canola oil is acquired from the seeds of Brassica species such as, Rapa and Napes. The oil obtained from these varieties of Brassica possesses lower percentage of erucic acid and glucosinolates which are quite different from the composition of rapeseed oil [172]. Oil acquired from rapeseed possesses higher concentration of glucosinolates and erucic acid, because of this reason both of these oils inhibit different physicochemical properties and nutritional values [173]. Triglycerides are major constituents of all edible oils and fats, which are esters of glycerol with fatty acids molecules. But percentage contents of these glycerides may vary from one to other oil [174]. Analysis of canola oil expresses higher percentage of triglycerides to some extent in contrast to rapeseed and soybean oil. Canola possesses higher percentage of triglycerides which ranges from 94.5 to 99.2% of total composition of lipids, on the other hand rapeseed possess 91 to 99 % and soybean has 93 to 99% of total lipid composition [175, 176].

7.3.1 Effect of glucosinolates

In various studies it has been elaborated that higher level of glucosinolates may exert adverse effect especially when fed to red meat, brute and ruminative [177]. As a result of hydrolysis different products are generated these includes some compounds of sulfur and isothiocyanates. These

products thus generated intrude with iodine absorption from thyroid glands, result in diseases related to liver, disturb growth rate in the consumers and loss of body weight [173]. Due to these facts plant breeders ascertain that such type of varieties should be developed which possess low contents of glucosinolates. In 1950 Dr. Krzymanski discovered a perfect breed of rapeseed which possess very lower concentration of glucosinolates in its composition and could be used for foodstuff baking purposes [172].

7.3.2 Fatty acid composition of canola oil

To minimize the adverse effect of erucic acid which is present in rapeseed oil different modification has been done in seeds. As a result of modifications in breeds of rapeseed reduction in the percentage contents of erucic acid occured which result in enhanced percentage of octadecanoic acids [172]. Actually octadecanoic acid makes approximately 95% of total fatty acid composition of canola oil. Other breeds of canola has been established which possess about 2.1% of linolenic acid content in fatty acid composition [178]. As a result of low percentage of linolenic acid this oil possesses resistance against oxidation and show enhanced storage time as compare to the regular form of canola. Canola having lower percentage of linolenic acid also expresses enhanced frying performance and prolonged storage ability of fried foodstuff like potato chips. Similarly canola is modified which exhibit enhanced oleic acid contents from 60% to 85%. This oil also possesses better frying performance and excellent quality [64, 179].

By keeping in mind health prospect as well as flavor both form of canola oil show better results. In both high oleic acid containing canola and low linolenic acid containing canola possess better taste and health impact in the absence of Trans form of isomers [180]. Latterly, canola oil has been evolved which possess higher percentage of lauric acid and mostly utilized for candy wafers, whiting of coffee, whipped cream toppings, and fat filling [181]. Canola is the only edible oil which possesses fatty acids with sulfur as constitution of molecule. The structures of these types of fatty acid molecules imply the generation or proximity of these isomers [182, 183].

7.3.3 Stability of canola oil

Canola oil entails about 7 to 11% linolenic acid in fatty acid composition. Presence of this type of fatty acid prone canola oil in the same trouble as soybean and other PUFAs containing oils. Canola oil is also susceptible towards oxidation as well as flavor reversion and face storage problems. The reversion of flavor occurs mostly due to autoxidation and photo-oxidation of UFAs in oils which is known as oxidative deterioration. Oxidative stability of this oil is restricted due to UFAs, chlorophyll and it's degradation products, and also due to presence of traces of reactive species like as minor concentration of fatty acids which possess higher number of double bonds or more than three at least [184]. So canola oil face same problem of oxidative deterioration as soybean or other UFAs containing oils.

7.3.4 High-erucic acid rapeseed (HEAR) oil

In those countries where mostly canola is grown, rapeseed having higher percentage of erucic acid is utilized only for specific food purposes and mostly non-food applications. Its major application is as completely hydrogenated oil which blended with peanut butter in approximately 1 to 2 % to avoid oiling in western countries [185]. Commercially available rapeseed oil which possesses highest percentage of erucic acid is oil having 45 to 50% to erucic acid in its composition. As the melting point of oil which contain fully hydrogenated erucic acid is quite higher, so this fully hydrogenated oil is very useful in fixing oily liquid in array of crystal. Use of this type of oil is quite useful in inter-esterification stearin fraction of palm oil to generate compact fat margarine having zero or no Tran's isomer [186, 187]. Many examples for other applications of completely hydrogenated HEAR oil has been elaborated in 1960s and 1970s. Major purpose of these applications was to elaborate crystallization properties, either as hard stock for the preparation of shortenings in small quantity or as base stock for monoacylglycerols conversion [188].

7.4 Cottonseed oil

In Turkey agricultural production cotton is most

consequential marketable crop and biggest congenital source of natural fibers. In addition to source of fibers seeds of cotton possess eloquent percentage of oil which may vary from breed to breed of cottonseed. But in most breeds of cottonseed percentage contents of oil vary from 12 to 25% [189-191]. The amount of oil acquired from seeds of cotton as by-product was utilized to compensate demand of edible oil in Turkey and was utilized for different cooking purposes. After sunflower oil consumption, cottonseed is the most prevailing oil being utilized.

Table 4: Applications of gas chromatography (GC) based techniques for analysis of oxidation of oils

Oils analyzed	Techniques for extraction	Detector	Major activity	References
Rapeseed oil	HS-Trap-GC-MS	Mass selective	Volatile products	[286].
n-3 PUFA-rich oils	HS-SPME-GC-MS	Mass selective	Volatile products	[287].
Blends of cold-pressed black cumin oil and sunflower oil	HS-SPME-GC-MS	Mass selective	Volatile products	[288].
Soybean, sunflower, and olive oils	MDES-UALLME-GC-FID	FID	Heptanal and hexanal	[289].
Corn oil	DI-SPME-GC-MS	Mass selective	Minor oxidative products	[290].
Olive, Pomace, sunflower and palm olein	GD-ME-DLL-ME	Mass spectrometer	Secondary oxidation products	[291].
Soybean, palm sunflower, coconut, mustard, and rice bran oil	SHS-GC-FID	FID	Hexanal	[292].
Soybean, rapeseed, peanut, sunflower, olive and camellia	TGA-GC-MS	Mass spectrometer	Volatile oxidation products	[293].

Rapeseed oil	HS-SPME–GC × GC–TOF-MS	Mass spectrometer	Volatile products	[294].
Marine and edible oils	GC-TQ/MS	Mass spectrometer	Furan fatty acid identification	[295].

Table 5: Applications of high performance liquid chromatography (HPLC) based techniques for the analysis of oxidation of oil.

Oils analyzed	Techniques	Major activity	References
Rapeseed oil	RP-HPLC	Malondialdehyde, 4-hydroxy-hexenal, and 4-hydroxy-2-nonenal	[302].
Sunflower with varied fatty acid composition	NP-HPLC-DAD	hydroperoxy-, keto- and hydroxy-dienes	[83].
Canola oil	HPLC-MS/MS	Isomeric hydro-peroxides	[298].
Olive, soybean, sesame and sunflower oil	HPLC-UV-FLD	Malondialdehyde	[303].
palm olein, soybean, canola and sunflower oil	HPLC-RID	Total polar components	[304].
Sunflower and corn oil	RP-HPLC	2,4-decadienal as major	[305].
Olive oil	HPLC-SFD	Malondialdehyde	[306].
Canola oil	HPLC-UV	Carbonyl compound	[307].
palm, soybean and olive oil	HPLC, PU	Total polar components and polycyclic aromatic hydrocarbons	[308].
Edible oils	HPL-UV	Oxidation of 2-tert-butyl-1,4 benzoquinone	[309].

In most commonly used edible oils in Turkey, sunflower standing first with approximately 1.38 million tons, and cottonseed oil comes second with approximately 1.28 million tons average demand followed by soybean, peanut and

rapeseed oil with some less percentage [192].

Cottonseed oil in its unrefined form possess odor which strongly resemble with odor of walnut and peanut oil but appearance is faint to some extent or having pale color. The color of unrefined oil of cottonseed may fluctuate from brownish yellow to dark reddish which is due to presence of sufficient percentage of pigments transfer to oil extract during extraction process of this oil [193, 194]. In addition to the essential fatty there are also some other constituents which are present in oil of cottonseed which includes, phospholipids, pigments, gossypol, sterol etc. which account for approximately 2% of total fatty acid composition [195].

In addition to essential fatty acid cottonseed oil is also enriched in minerals which are also necessary for proper health. It entails vitamin B and other vitamins which are readily soluble in fats and oils for instance, vitamin A, E, D and vitamin K [196].

7.4.1 Fatty acid composition and oxidative stability

Composition of fatty acids play a pivotal role in determining oxidative stability of edible oils, similarly fatty acid profile of cottonseed oil is one of the unique characteristics which influence vitality of this oil [192]. This oil contain both saturated as well as unsaturated fatty acid in 1:2 ratio. It is elaborated as hydrogenated oil which occur naturally in this oil due to higher concentration of PUFAs. In all breeds of cottonseed most percentage of UFAs ranges up to 70% of total composition. In this percentage about 52% are PUFAs which include linolenic acid, while 18% are MUFAs which includes oleic acid. On the other hand approximately 26% are SFAs which includes palmitic acid and stearic acid. This profile of fatty acid composition enhances oxidative stability during frying performance without performing any additional processing [197]. In contrast to other edible oils vitality and stability of cottonseed oil is dependent upon composition of fatty acid as well as unsaponifiable substances remaining in the oil [198]. The presences and percentage of these components fluctuate due to some factors which include environmental conditions, variety or breed of cottonseed, processing and also storage conditions [199, 200]. These facts conclude that cottonseed oil is stable as compare to soybean but more easily prone towards oxidation as compare to palm oil which is due to higher percentage of UFAs as compared to palm oil.

8. Impact of lipid oxidation on food quality and human health

Degradation of fatty acid as a result of oxidation is a customary issue and possess long term frugality concernment in most of food industries because it influences most of foodstuff regardless of fatty acid tenor. Therefore detection of oxidative degradation of majority of foodstuff could be done with the help of sensory organ if food products contain 0.5% or lesser fat contents in them [49, 201]. As elaborated earlier proneness of oxidative degradation of fatty acids in foodstuff mainly based upon some factors such as, fatty acid profile, environmental conditions, methods used for processing of oil, presence or absence of antioxidants and other minor components like traces of metals etc. [202, 203]. Oxidative deterioration of fatty acids always contribute dilemma during oil processing as well as storage conditioning [204]. There are some major impacts of lipid oxidation which are as following;

8.1 Reversion of flavor

As a result of oxidation primary oxidation products are formed which on further reaction are converted into secondary products. For instance carbonyl compounds are formed which exhibit negative impact and decline taste of foodstuff because of these secondary products. Due to oxidative deterioration of PUFAs varieties of volatile components are generated which possess specifically offensive smell and taste [205, 206]. For instance, soybean oil which is unsaturated in nature could easily experience reversion of taste as a result of photo-oxidation on exposure to visible or ultraviolet light as well as on heating [207, 208]. It has already been proposed that oxidation of alpha linolenic acid in oil is impeccable for the generation of 2-pentylfuran and its isomeric forms, which may generate objectionable flavor or taste in the food product containing this [45, 209, 210]. Similarly in case of butter which possesses unsaturated

carbons and linolenic acids in composition is also at the risk of oxidative deterioration and may prone towards oxidation and generate such products which are responsible for the production of such compounds which give offensive odor to the butter. For example oxidation of butter can result in formation of Pantanal, heptanal, and butanoic acid which give off-flavor to foodstuff [211].

The process of oxidation may also result in loss of nutritional constituents which are helpful for proper growth of body. The process of oxidative deterioration of lipids may cause reduction of nutritional importance by decomposition of compulsory fatty acids as well as vitamins which are soluble in lipids such as vitamin A, D, E, and K and also by reducing

8.2 Nutritional implications

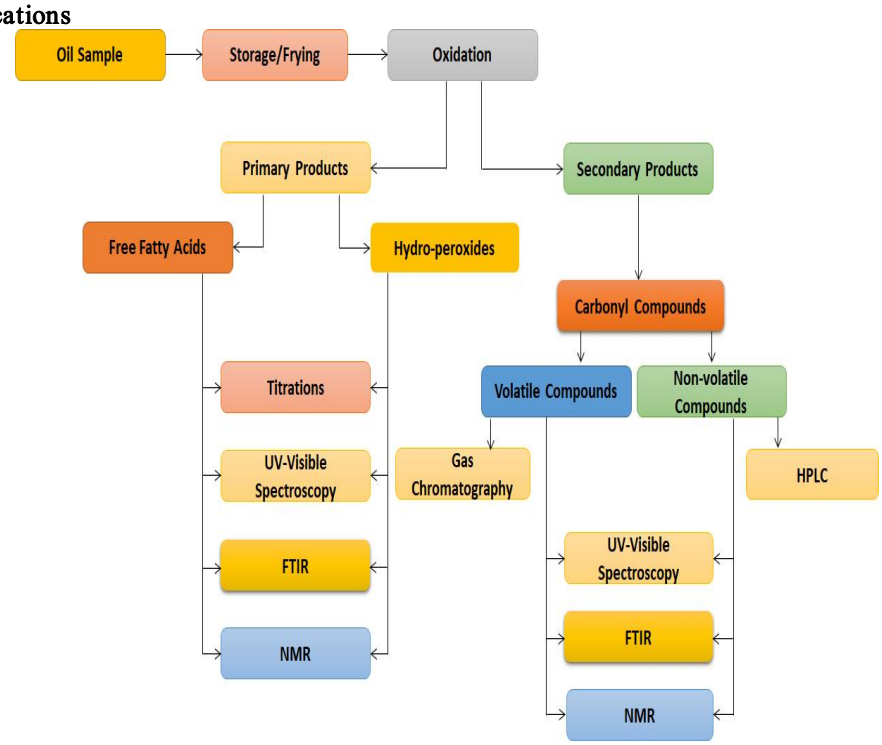

Figure 8: List of classic and advanced analytical techniques which can be applied for the oxidative stability of edible oils during different stages of oxidation.

Table 6: Applications of Thermogravimetric analysis techniques (TGA) based approaches for the analysis of oxidation of oils

Oils analyzed	Heating conditions	Major activity	References
Sesame oil	0–400 °C	Thermal and oxidative stability	[315].
Favela oil	110-250 °C	Thermal and oxidative stability	[316].
palm, rapeseed, sunflower, linseed oil	1, 5, 7.5, 10, 15, 20 °C/min	Thermo-oxidative stability	[314].
Olive, sunflower and crease oil	10 °C /min	Oxidative stability and thermal profile	[317].
Blends of sesame and sunflower oil	100, 110, 120, and 130 °C	Thermal and oxidative stability	[318].
Sunflower Soybean Jatropha and Waste oil	10 °C /min	Thermal stability determination	[319].
Nectarine and Kernel oil	261 °C	Oxidative stability and thermal behavior	[320].

Blackberry, Chokeberry and Raspberry	50–700 °C	Thermal stability analysis	[321].
Sunflower oil	100 °C	Oxidative stability evaluation	[322].
Rice bran and Karajan oil	5 °C min^{-1}	Oxidative stability	[323].

energy caloric percentage [212]. During process of oxidation some free radicals and metabolites are also generated which remain in oil and transfer into foodstuff and may abuse unsympathetic impacts on heath of mankind [213, 214].

8.3 Health hazards

When rancid oil is used for frying or cooking purposes it imparts toxic effect to food and our body, on the bases of consumption of this type of foodstuff different kind of nutritional ramification may occur. There are some common diagnostics which appear due to toxic deteriorated fat containing foodstuff like unfavorable development of body, diarrhea, muscle weakness due to scar muscle fibers, liver enlargement, yellow fat disease which occur due to lower level of vitamin E or antioxidants and higher level of unsaturation in fats, and consequent scarcity of vitamins like A and E [215].

There are also some validations which indicate that foodstuff enriched in products of lipid oxidation are entailed in injuries of blood vessels, narrowing of blood vessels due to formation of plaque and blood clots in vessels which are highly risky for health. In an experiment it also has been explained that cyclic molecules generated as a result of oil heating at high temperature could cause toxicity in the rats even at lower percentage of about 0.01 % in diet (Figure 7) [216, 217].

9. Methods for the analysis of oxidative stability

Oils and fats are among major constituents of foodstuff along with proteins, carbohydrates as well as minerals [9]. Assessment of quality and stability of edible oils are two factors which are interrelated to each other. Evaluation of vitality of edible oils is quite necessary, but both the sellers and consumers are withstanding the issue regarding evaluation of quality that they prefer for baking or frying their food products (Figure 8). They should be aware of satisfactory quality of edible oil when purchasing either it is safe to use or not and for how much time period it will remain safe [218, 219]. To keep vitality or stability of edible oil satisfactory both dealer of raw material and buyer should proficiently subscribe to the protocols needed for analysis in industry [220].

9.1 Volumetric methods

These methods are applied to determine the primary oxidation products of edible oils produced as a result of oxidation at early stage of storage. These methods include free fatty acid value and peroxide value by performing acid base and iodometric titrations respectively.

9.1.1 Free fatty acid value by titration

The determination of FFA based on the principle of acid base titration in which ethanolic potassium hydroxide solution is applied as a titrant against free fatty acids present in the oil sample as a result of deterioration occurred. Acid value is measured and each unit of acid value is approximately equal to 0.503% of free fatty acid so, acid value of oil is approximately double of FFA value [221]. Determination of free fatty acid value is of primarily significance because firstly it gives information regarding decomposition or deterioration of oil, secondly presence of free fatty acid could exhibit pro-oxidant impact which is associated with percentage of FFA [110, 222].

9.1.2 Peroxide value by titration

The determination of peroxide value is among the most widely used procedure for elaborating the deterioration of edible oil as a result of oxidation reaction at early stages [223]. The PV is mostly described as, mille-equivalents of peroxide oxygen contents as a result of oxidation per one

kilogram of oil. Number of different analytical procedures has been developed for the determination of peroxide values. One of the most commonly applied methods for PV value determination is based upon oxidation ability of peroxides of lipid molecules to produce iodine molecule after reaction with potassium iodide salt. Furthermore it was reported that value of peroxide greater than 7.5 suggested enough deterioration of edible oil and generation of carbonyl compounds which cause induction of offensive smell in fried chips [224]. The range of PV exhibit quite better relationship with aroma log but this is true only at early stages of storage period because oxidation yields only primary products but on further oxidation reaction then these unstable primary products are converted into secondary products [225, 226].

9.2 Spectroscopic methods

9.2.1 Analysis by FTIR spectrophotometer

FTIR spectroscopic method has successfully been applied in order to overcome the limitations of analysis time, accuracy and precision as faced by using classical volumetric methods for determining oxidative deterioration of edible oils [227]. As in other sample analysis by this approach particular peaks appeared when deteriorated oil is analyzed. Hu et al. applied FTIR spectrophotometer in combination with quartz cuvette for infrared wavelength to determine free fatty acids by measuring acid value of various oils which occurred due to oxidation of fatty acids at early stage as primary oxidation products [228]. Shang et al. also used the same configuration to determine peroxide value of various commercial oils as hydro-peroxides are primary indicator of lipid oxidation and quite helpful in predicting shelf-life of edible oils [229].

In addition to primary oxidation products analysis this techniques was also applied for analyzing secondary oxidation products which are generated due to deterioration of soybean and corn oil when the sample of these oils were subjected to different heating effect. Like primary products the enhanced deterioration was determined due to peak shift in spectra of these oils when were compared with fresh oil samples [230]. In addition to this type of FTIR arrangement, attenuated total reflectance with FTIR (ATR-FTIR) has also effectively been applied for analysis of simple corn, sunflower, and colza and a mixture of different oils after high temperature treatment [231].

9.2.2 Analysis by using UV-Visible Spectrophotometer

9.2.2.1 Iodide oxidation method

The primary oxidation products such as, the percentage of hydro-peroxide contents have also been evaluated by using a spectrophotometric iodide based approach. The lipid or fatty acid containing sample is dissolved in an acidic solution before being combined with iodide in this uncommon procedure [241]. Iodide is converted to iodine via the lipid hydro-peroxide. The produced tri-iodide anion is distinguished spectrophotometrically at 350 nm which is produced as a result of an excess reaction between the developed iodine and iodide. Fe (II) was utilized by Bloomfield as a catalyst in this process. The short response time reduces interference from side reactions, while the closed conditions eliminate intervention from ambient oxygen [242, 243].

9.2.2.2 Conjugated dienes and trienes value

As a result of oxidation at early stages peroxides are formed from deterioration of fatty acids which are unstable to some extent and may be stabilized due to displacement of double bonds delocalized electrons, and converted into conjugated molecules known as dienes and trienes [244]. These structures are stable to some extent as compare to peroxides and show absorbance in ultraviolet region at wavelength of about 235 nm and 270 nm orderly which can be determined by using spectrophotometer [245].

The value of conjugated dienes is usually described from the prospect of dienoic acid present in the edible oil which also represents percentage of primary oxidation. This dienoic acid mostly shows absorbance limit in UV region ranging from 232 to 234 nm. For the determination of CV values mostly iso-octane is used as a solvent and absorbance is measured [34]. These conjugated molecules proliferate to a specific level in edible oil and then are stabilized as these molecules are subjected to further decomposition and are converted into further products. Major products generated at this level are

trienes. The detection of such type of secondary products is also possible with the help of spectrophotometer. Mostly the absorbance region of these products lie at wavelength of about 268 nm, but this should be minded that in this region of wavelength, overlapping of many compounds may take place [39, 246].

9.2.2.3 Anisidine value

The major products generated as a result of secondary oxidation are carbonyl compounds such as, aldehydes. These products are mainly responsible for the generation of rancid odor [247]. This methodology for oxidation products determination utilized reaction of generated carbonyl compounds with anisidine solution in the proximity of acetic acid.

Table 7: Applications of differential scanning calorimetric methods for the analysis of oxidation of oils

Oils analyzed	Heating conditions	Major activity	References
Linseed oil	(90, 100, 110, 120, 130, 140 °C)	Oxidative stability was determined by activation energy and induction period	[331].
Virgin coconut oil A mixture including virgin coconut and refined soybean/ refined safflower oils	25 °C and 10 °C/min	Determination of thermodynamic nature	[327].
Cold-pressed linseed, rapeseed, camelina black cumin evening primrose hempseed milk thistle poppy, pumpkin and sunflower oil.	5 °C/min	Oxidative stability in comparison with Rancimat test	[329].
Soybean and sunflower oils enriched with herbal extracts	(4, 7.5, 10, 12.5 and 15.0°C/min)	Oxidation kinetics parameters	[204].
Echium oil	(50, 60, 70, 80, 90, 100 and 110°C	effect of hydroxytyrosol and rosemary extract on oxidation	[330].
Blackberry, Chokeberry Raspberry Seeds and Oils	2 °C/min to 160 °C temp.	To analyze thermal properties	[321].
Olive corn and sunflower oil	(110, 120, 130, 140 °C)	Oxidative stability determination	[332].
Different cultivars of flaxseed oil	2 and 5 °C/min	Thermo-oxidative analysis	[333].

Amaranth and Quinoa Oils	(100, 110, 120, 130, 140 °C)	kinetic parameters of oxidation process	[334].
Different cultivars of Camelina sativa L. seed oils	(1, 2, 5, 10, 15 °C min^{-1})	Thermo-oxidative stability analysis	[335].

Table 8: Applications of sensor based approaches for the analysis of oxidation of oils.

Detection system	Major activity	References
Reagent kit based on spectrophotometer	Acid value and peroxide value	[352].
Wavelength-shift-based Colorimetric Sensor	Peroxide value	[353].
Perovskite nanomaterial based multiplex-mode Fluorescence Sensor	Acid value, moisture content and 3-chloro-1,2-propanediol	[354].
High-performance fluorescent sensor based on $CsPbBr_3$ quantum dots	Total polar compounds	[355].
Chitin based calorimetric sensor	Aldehyde detection	[356].
Paper based colorimetric sensor soaked with eutectic solvents	Malondialdehyde analysis	[357].
Nanofiber mat prepared from polyvinyl alcohol and Schiff's reagent	Aldehyde detection	[351].
Composite films based sensor	Aldehyde detection	[358].
Electronic nose coupled with artificial neural network	Shelf-life prediction	[359].

4-hydrazinyl-7-nitrobenzofurazan fluorogenic probe	Malondialdehyde analysis	[360].
Screen-printed electrode	Free fatty acid value	[361].
Gold nanocluster based fluorometric biosensor	Prooxidant activity analysis	[362].
Digital Image Colorimetry	Peroxide value determination	[363].
Paper based analytical device	Peroxide value determination	[364].

This result in the formation of Schiff bases and yellowish coloration is appeared in the reaction mixture which shows absorbance at about 350 nm. The value of absorbance rises about 4 to 5 times if aldehydes possess conjugated double bond along with double bond of carbonyl group [248].

This procedure of secondary oxidation determination is supposed to be quite easy and rapid. Para-anisidine value along with peroxide value helps us to measure total percentage of oxidation or oil deterioration. This totox value give confirmation regarding history as well as present quality of edible oil, thus allow observer to evaluate total extremity of oxidation or deterioration in foodstuff [249]. The anisidine value has been conferred as better characteristic for determination of secondary products because it is associated with peroxide value, Thiobarbituric acid value and other analytical method quite nicely [250].

9.2.2.4 Thiobarbituric acid (TBA) assay

Malondialdehyde is major product formed as a result of oxidation of primary products and this is also most widely utilized marker to elaborate oxidation process of edible oils. TBA forms a complex molecule with MDA whose value could be expressed by applying spectrophotometer. The reaction between MDA and TBA takes place mostly at elevated temperature and lower pH which result in the formation of complex molecule which behave as chromophore and possess highest absorbance at about 532 nm [251].

There are different types of protocols which could be applied in analysis of foodstuff. For instance, there exist some protocols which could be applied like, heating sample directly, distillation of sample, and extraction of lipids by using organic or aqueous acid, accompanied by reaction of acid with TBA [252]. The most commonly applied protocol includes homogenization as well as centrifugation in acidic median for example, tricholoacetic acid and ensuring reaction with TBA at elevated temperature [253]. This method has been recommended as most reliable and perceptive procedure for the evaluation of rancidity or deterioration of edible oil as compare to other test like determination of hexanal and anisidine value [254, 255].

9.2.3 Analysis by nuclear magnetic resonance (NMR)

Many of the research groups' practiced the ^{1}H and ^{13}C NMR spectroscopy for food products analysis especially edible oils [256, 257]. They have proven that this approach is extremely helpful in determining the degree of oxidation of the lipid fraction and in giving details on the types of major functional groups and concentration of the primary and secondary oxidation products identified in oils [258-261]. In addition to identification, this technique is also proven a valuable approach in quantification of oxidation products of fatty acid produced as a result of oxidation during different storage periods [262]. Also this method possesses decent relationship with conservative analysis approaches for instance TBA has already been described [263]. In recent years, a number of multi-

dimensional NMR approaches have been fabricated, including diffusion ordered spectroscopy, nuclear overhauser effect spectroscopy, and correlational spectroscopy. The uses of these instruments needs a lot of time owing to the procurement procedure even if they offer an improved consignment than one-dimensional spectra, which enhances the categorization of dietary lipid samples [261, 264].

9.2.4 Analysis by chromatographic techniques

9.2.4.1 Analysis by gas chromatography

The determination of volatile products which are generated as a result of further oxidation of primary oxidation products can be efficiently done by performing gas chromatographic analysis. Most of these products involved hexanal and pentanal determination as these are among most commonly produced oxidation products [275, 276]. This analytical technique also provides useful evidences regarding fundamental pathway of reaction through which oxidative deterioration has been occurred [277]. Appropriate GC techniques have been devised for direct oil injection onto the column but there are some drawbacks of this method as it results in reduction of column life as well as unstable chromatographic baseline which results in inaccurate results [278, 279]. As a result, the separation of volatile products produced by oxidation was instigated by means of a U-tube that is coupled to the GC [280]. Vacuum distilling the volatiles keen on a cold trap before GC exploration is alternative preference for on-column injection [281].

In addition to these approaches, another method was developed by utilizing solid phase microextraction (SPME) and GC for analyzing oxidation of lipid containing food products. Aforementioned abstraction of volatile components by using SPME has been deemed an eco-friendly approach for analysis as this development involved exclusion of harmful solvents. Additionally, the outcomes were well correlated with the anisidine value [282-284]. Xia & Budge (2018) developed a GC-MS technique in combination with solid phase extraction and trimethylsilyl derivatization process for illustration of hydroxy fatty acid which are produced as a result of oxidative deterioration of edible oils. This approach also facilitates imminent quantifications of these oxidative products. Additionally, the usage of EI and PCI spectra enabled the interpretation of both saturated as well as unsaturated hydroxy FA which in turn can provide information of specific fatty acid oxidation [285].

9.2.4.2 Analysis by liquid chromatography

In addition to volatile components there are also nonvolatile components which can be generated as a result of oxidative damage of lipid containing food products. These types of products can be identified and quantified by using liquid chromatographic techniques in combination with UV or MS detecting systems [296, 297]. Kato et al. (2018) utilized the liquid chromatography tandem mass spectrometry for the determination of different form of isomeric hydro-peroxides which not only influence quality of edible oil but also are not analyzed by peroxide value. In addition to this, this approach was quite helpful in determining mechanism of oxidative deterioration of edible oils [298]. In addition to primary oxidation products analysis, it is also possible to analyze secondary oxidation products and their differentiation from hydro-peroxides which are produced at later stage of oxidation by using liquid chromatography [299].

In addition to normal phase chromatography reverse phase HPLC can be applied for the analysis of oxidation products. This approach can be applied for the analysis and differentiation of conjugated dienes and peroxides isomers which is based upon geometrical isomerism [300]. Gotoh et al established an approach for the determination of peroxide values for edible oil quality check in the colored samples of lipid containing food samples. The working of this approach was based upon the reaction of lipids with triphenylphosphine which result in the formation of a complex which exhibit absorbance at 260 nm. When these samples are analyzed by using HPLC having UV detector then the peroxides were identified and quantified by this method [301].

9.2.5 Thermal techniques

9.2.5.1 Thermogravimetric analysis

Thermogravimetric analysis may also be used to investigate the thermal degradation of oils caused by oxidation of lipids.

Weight variation in response to oxygen uptake and thermal degradation are two methods used to analyze the oxidative deterioration in the oil containing food product [310-312]. Gao & Birch proposed that TGA is comparatively simple, easy and lesser time taking technique and can be applied for the estimation of beginning of oxidation in different edible oils (i.e., flaxseed, hemp, and canola oil) [313]. Hoki oil's shelf life was determined by using TGA and Arrhenius extrapolation equation to be 0.56 years, although DSC projected it to be 1.39 years [312]. Li et al. (2018) employed TGA to make comparison among the oxidative stability of numerous edible oils for instance, sunflower, palm, linseed, and rapeseed oils [314].

9.2.5.2 Differential scanning calorimetry

DSC has been developed to assess the oxidation resistance of fat-containing food products. It is a thermal analytical approach that advantages such as high sensitivity, quickness, and small amount of sample [324]. In comparison to previous approaches, this accelerated technique enables the continuous tracking of thermal activity in the oxidative deterioration process [325]. In comparison to the Rancimat approach, this technique also required shorter stability assessment duration. Ramezan et al. performed this technique for the analysis of various commercial oils at varied temperature conditions and compared the results with the Rancimat results and suggested the DSC as a better option because of its advantages over Rancimat method [326].

According to the results of DSC, Srivastava et al. revealed the thermodynamic configuration of virgin coconut oil amalgamated with other refined oils such as soybean and safflower oil [327]. Belayneh et al studied Camelina seed oil to determine the influence of different extraction techniques such as, cold press, soxhlet, and supercritical CO_2 extractions on the oil's oxidative stability [328]. Symoniuk et al observed the thermal oxidative stability of various selected cold-pressed oils by applying this technique [329]. Lately, Echium oil has been investigated to perceive the influence of extract of rosemary and hydroxytyrosol on the oxidative stability of this oil (Table 7) [330].

9.2.7 Determination of oxidation by using Sensors

American oil chemists' society (AOCS) has industrialized numerous methods to measure and evaluate the level of oxidative deterioration of edible oils, for instance the Para-anisidine value, acid value or free fatty acid value, peroxide value, and others. These methods of analysis are easy, but these methods are mostly time taking and disparaging. They moreover cause prospective risks to the surroundings and human healthiness owing to higher amount of solvent waste [201]. To overcome these issues there is need to develop other methods. The most obvious development of action is to depend on an automated system like an E-Nose, which not merely simulate human olfaction but as well has the ability to find and categorize harmful vapors using a complex process. A device called an E-Nose can quickly identify some of the dangerous products which are produced as a result of oxidation [336]. The stability or durability of numerous food products has been determined by applying olfactory device which include tomatoes [337], apples [338, 339], meat products and raw milk samples [340], valerianella [341], deep-fried potatoes [342], Rice [343], and cultivated foodstuffs [344-347]. Pattern recognition techniques and facts examination are compulsory to distinguish the indicators or their patterns to categorize the data. The E-Nose detected signal pattern can be examined by exploiting artificial neutral network (ANN) and statistical software like discriminant factorial analysis (DFA) and principle component analysis (PCA) [336].

Visual detection by the color variation of gauge strips or films is a supreme scheme to enable excellence evidence about foodstuffs analysis. The approach is mainly based upon computer visualization which has been successfully applied for analyzing the oxidative deterioration of edible oils of foodstuffs which possess oil contents [348]; on the other hand, rare other assessment approaches have been developed which depend on human visualization and not rely on apparatuses and computers. Robins and his colleagues developed Schiff reagent (colorless solution) which is comprised of pararosaniline hydrochloride and sodium sulfite and can be applied for analysis of oil containing foodstuffs. After exposure to secondary oxidation

products especially aldehyde, this colorless solution turned into reddish purple or bluish purple [349]. On the basis of this reaction, polyvinyl alcohol (PVA) and Schiff's reagent based amalgamated films have been developed with the help of solution casting process. These films can be applied to identify the existence of aldehyde which is the foremost secondary product produced as a result of extensive deterioration of lipids. The purpose of the PVA/reagent Schiff's based films was to monitor lipid oxidation in foodstuffs. But, these films' response interval to oxidation products (i.e., aldehydes) was too extended, approximately 1 hour, and these fabricated films were not proven so effective for the estimation of oxidative deterioration of foodstuffs (Table 8) [350, 351].

10. Conclusion

Edible oils are among major constituents of food so their proper quality assurance is quite necessary for human use. The maintenance of the quality is a major concern after proper manufacturing which is mainly dependent upon the oxidation. There are different factors which prone these oils towards oxidative deterioration which includes fatty acid composition, storage conditions and presence of minor components. On the other hand there some other minor components present in edible oils and prevent them from oxidative deterioration and extent their shelf-life. Similarly there is another approach which include the addition of plant based extracts which can be added to these oils which also prove helpful in enhancing the oxidative stability of these edible oils. The proper analysis of the oils after extraction and manufacturing is required after time to time interval so that we can protect them from oxidation and usefulness for human health. There are number of different approaches which can be employed for the analysis of different oxidation products during different stages of the storage. These approaches are quite helpful in the analysis of different oils and their oxidation products which provide useful information regarding their usefulness for the human and their adverse effect on health. However, these techniques are quite useful but there are some factors which limit their applications for analysis of large number of samples. So, there is need of proper analysis of these oils after specific time intervals by developing new methods which are precise, accurate and less time taking.

11. Future Perspectives

There are number of protocols which are proposed by AOCS for their proper analysis. These methods have no limitations but these methods required large volume of solvents and more time to conduct. Moreover, these methods required proper laboratory for performance which is not possible for all the consumers to analyze these edible oils. In order to overcome such types of issues analytical techniques has been developed and successfully applied for the analysis of these oils. These include spectroscopic, chromatographic as well as thermal techniques which have been applied in recent past for the oxidative study of these oils. These techniques also provides results with quite accuracy and timely as compared to the conventional chemical methods. But these techniques are quite expensive and also required highly pure solvents for analysis which is also a major issue regarding analysis of deteriorated oils. On the other hand these analytical instruments required highly trained persons who can perform these analysis, everyone cannot conduct these analysis. In addition to these analytical techniques electronic noses have been fabricated based upon sensory evaluation method which can also provide information about the oxidation products of the edible oils. These types of methods have been proven helpful in analyzing the oxidative stability of these edible oils.

In addition of these methods there is another emerging field which is proving quite helpful in every field of life which is known as biosensor. There are different types of sensors which could be applied for the analysis of different food products and make assurance about their usefulness for human and other consumers. Different types of sensors has been developed which could also analyzed oxidation products quite easily and within short frame of time. But the already developed sensors are not quite enough to analyze oxidation products of edible oils. As the process of oxidation of edible oil is complicated process which could proceed differently under different conditions and result in different types of products which could

impose negative health impacts.

There is need to develop biosensors which could be applied for analysis of different kinds of oxidation products. As there are different types of products could be generated as a result of oxidation so different types of biosensors should be developed which could analyze different products produced under different conditions. There is need to develop biosensor according to the type of products produced so that accuracy could be enhanced. In addition to this simple type of biosensor should be developed so that everyone can use it easily and accurately. Like lactometer simple type of instrument should be developed so that quality of oil could be analyzed at the cooking areas such as restaurants and bakeries.

Declaration

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Conflicts of Interest

The authors declare that they have no conflict of interest.

Authors Contribution

Iqbal Ahmed convinced the main idea and wrote the manuscript. Muhammad Furqan Farooq, Iqra Rani, Ijaz Hussain, Hunain Zulfiqar revised manuscript and prepared figures and other improvements. Hira Zulfiqar and Abid Jan helps in scientific writing of paper.

Data Availability statement

The data presented in this study are available on request from the corresponding author.

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