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Changes in the Quality Attributes of Edible Vegetable Oils During Deep Frying Concerning Defence Ration

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ABSTRACT

Deep fat frying is a popular cooking method that can significantly alter the physico-chemical properties of edible oils. This unit operation is very common both in civil as well as institutional level training, recreational and feeding centres owing to the high liking of fried products among all age groups. Frying is a high-temperature process where food material is normally exposed to longer periods depending upon its moisture content and results in the desirable colour, aroma and taste that is most acceptable to the consumers. But the quality of oil changes each after the frying cycle and leads to the onset of various physicochemical changes resulting in the accumulation of toxic compounds that may pose potential health risks. Various edible oils from plant sources have varied stability against high-temperature exposure, hence, the selection of appropriate edible vegetable oils for deep frying is critical to ensure its safety during repeated use. The current article summarizes the available literature on the changes in quality attributes of edible vegetable oils during deep frying along with the mechanisms of oil degradation, including oxidation and hydrolysis, formation of trans fats, and major concerns during deep frying. This also covers various methods of assessing the quality of frying oils, inclusive of measurement of free fatty acids, peroxide value, polar compounds, and oxidative stability. The impact of deep frying on the nutritional value of edible vegetable oils, such as changes in fatty acid composition, effects of different frying conditions, such as temperature and time, on the quality of the frying oil and the loss of antioxidant compounds is also discussed rationally The facts and finding covered under present manuscript will be useful to food manufacturers and consumers in selecting appropriate edible vegetable oils for deep frying, maintaining the desired food quality, and ensuring the safety of various edible oils and their blends concerning both civil and the Defence supplies.

Keywords: Oxidation; Frying; Vegetable Oils; Quality; Polar compounds

1. INTRODUCTION

Defence forces are among one of the largest institutional consumers of various food commodities including edible vegetable oils viz. Refined oils of sunflower, ground nut, cotton seed, rape seed, soybean and mustard. Oils are used in various forms of food preparation like frying, salad dressing, marinating, etc. Different oils like sunflower, soybean, rice bran, mustard, groundnut, rapeseed, etc. are used for deep frying according to the consumer's preference. This preference is usually affected by the physical organoleptic parameters of oil such as colour, aroma, and flavour. At the commercial level parameters of oils like their oxidative stability, the shelf life it provides after frying, palatability, etc., are considered for the choice of oil. Different oils have different shelf life depending on their fatty acid profile, the more the degree of unsaturation less is the shelf life[1]. The type of frying oil, its chemical composition, as well as its physical and physiochemical properties, have an impact on frying and oil stability against oxidation and decomposition. Despite their high-fat content, fried foods are gaining more popularity, owing to crispy texture, appealing colour, and pleasant flavour[2]. The taste of fried food depends on the oil used for frying[3]. The synchronized heat and mass transfer during the deep-frying process contributes to desirable fried food quality, texture, and flavour.

Deep frying is the most used cooking method in the food industry[4]. It is the cooking process in which the food is immersed in oil at 150 °C to 200 °C[5]. During deep frying the heat is transferred from oil to food which causes the water inside the food to evaporate and a vacuum is formed inside the food which absorbs the fats from the oil. The process of deep frying also degrades oil quality fasters. During deep frying, there are many changes and reactions, which affects the quality of the oil. After the oil is heated for a longer period, it is subjected to processes like thermal oxidation, polymerization and hydrolysis. Degradation leads to undesirable compounds like free fatty acids, partial- and polymerized glycerides, short chain-, trans-, conjugated-, epoxy-, hydroxyl-, keto-, cyclic fatty acids from the degradation of hydroperoxides like aldehydes, hydroxy aldehydes and hydrocarbons[6]. This has a variety of effects on the oil's quality. These changes can be figured out by analyzing various quality

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parameters like free fatty acid (FFA), Peroxide value (PV) and iodine value, Saponification Value, Viscosity, Refractive Index, Color Index, etc.

Various changes occur in oil during frying of food items. The time and temperature vary according to the food item being fried. Human perception is used to judge the most accurate frying time for a food item to be perfectly fried. Good judgement is required to determine the optimal endpoint of deep fat frying[7]. A thorough understanding of the frying process aids in the optimization of manufacturing processes in terms of food quality, fat use life, and energy consumption. Installing a management system that includes all critical points of the frying process is required to ensure the good quality of the fried end product[8]. Many researchers have conducted frying studies using various food items as well as different oils as frying mediums to achieve the values of those critical points. Each of them has concluded that deep frying affects the quality of the oil.

2. DEEP FRYING OF FATS

2.1 Deep Frying Process

While deep frying, the oils or fats are heated above 150 °C, and the food item is immersed in the hot oil, causing heat transfer from the oil to the food item[5] (Fig. 1). Heat is transferred via conduction as well as convection[9]. Heat transfers within the oil via convection, whereas further it is transferred from the frying medium to the food item and within the food items by conduction[10].

2.2 Heat Transfer

Heat transfer occurs in four stages during the Deep-Frying process[9]. The first phase is when the temperature of the food item rises to the boiling point of water. The second phase is the surface boiling phenomenon, in which the onset of dehydration and evaporation of moisture from the surface of the food occurs. The third stage is the falling rate phase, in which all of the moisture from the core region moves to the exterior portion of the food item. The final stage is known as the bubble endpoint, and it is during this stage that water escapes in the form of water bubbles progressively. Rapid evaporation increases the pressure more than the capillary pressure of oil media inside and surface part of the food itembeing fried, resulting in the cracking of the thick crust[11]. These cracks serve as the oil entry point into the food item[12].

2.3 Moisture Loss

At first, moisture moves from the food's surface to the interface between the dry and wet layers of the food[10]. As the frying process continues, the rate of moisture loss from food decreases because of the reduction in moisture content, and so does the rate of moisture loss from food[10]. Moisture escapes at a rapid rate during the first 20 seconds[13]. Later, the rate is reduced significantly and reaches a constant rate at the end of the frying process[14]. At a constant time, the rate of moisture loss increases with the increase in frying temperature. This entire moisture loss process can be divided into three stages[15]. The first is the heating of food to the boiling point of water, followed by the evaporation of apparent moisture content. The evaporation of capillary water is followed by an increase in food temperature to that of the frying oil, as well as a reduction in drying rates. At the end, there is no driving force available for further evaporation at the frying temperature. Moisture transfer in the liquid mode is slower than in the vapour mode. While the water flows from the interior to the outer layers steam prevents oil from penetrating to the centre of the foods, resulting in a fried product with two distinct zones:1) The dehydrated surface, where the majority of the changes occur, and 2) the core, where the temperature does not exceed 100 °C[16].

2.4 Oil Uptake

Following the evacuation of water, the next mass transfer that occurs is the uptake of oil from the frying medium to the food item. The quantity of oil taken by food is proportionate to the moisture content the food item loses. The time-temperature combination used for frying is a major contributor to moisture content and oil uptake. When the temperature is high, it takes less time for the oil to be absorbed by the food item. Temperatures of 150 °C and 180 °C have no discernible effect[17]. Due to the high temperature, voids and capillary pores present in the food item crack open, causing rapid boiling and evaporation of water present in food. The escape of moisture from the food item creates internal pressure, causing oil to move into the food item through this pores[10]. The oil usually enters the food item gradually during the first[20] seconds of frying[13]. Until the steam is generated, it restricts the frying oil to penetrate voids. When the food item is cooled due to condensation there is a decrease in the internal pressure which causes a vacuum to pull the oil into the food item[18].

Several factors influence oil uptake into food items, including the residence time of the food item in the oil, the temperature of the frying medium, the shape and size of the food item, the components of the food item, and so on[19]. It has been discovered that the thinner the food item, the greater the oil uptake[20]. Even oil's gel strength and interfacial tension contribute to the rate of oil uptake in food products. Other factors, such as pre-frying treatments (blanching, coating) aid in regulating the frying rate[21].

3. CHANGES IN OIL DURING THE DEGRADATION OF OIL

3.1 Degradation of Oil

As the frying process progresses, oil begins to undergo some undesirable changes after a certain period and number of frying cycles. It goes through a series of

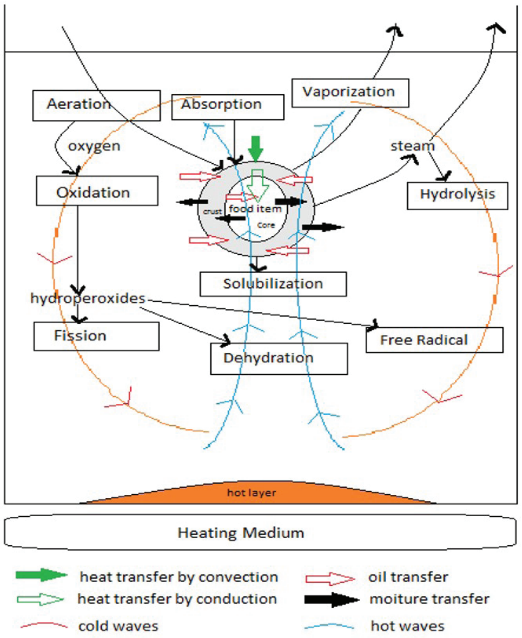

Figure 1. Heat and mass transfer during the deep frying process

complex physical and chemical reactions that result in a plethora of decomposition products. Thermal oxidation, hydrolysis, polymerization, and other processes in oil result in the formation of new non-volatile and volatile compounds. This absorption of degraded oil into food results in nutritional, sensory, physical, functional, and chemical changes in food quality. The food item cannot be fried to the required quality after a certain number of frying cycles. During storage, nonvolatile compounds disturb the flavour, quality, and texture of fried foods. Deep-fat frying reduces oil's unsaturated fatty acids while increasing foaming, colour, viscosity, density, specific heat, and free fatty acid, polar material, and polymeric compound content[5].

3.2 Thermal Oxidation

During deep frying, oxygen reacts with the oil, causing oxidation of oil[22]. Thermal oxidation of oil occurs at high temperatures in the presence of air and moisture[23]. Thermal oxidation has a chemical mechanism that is equivalent to that of autoxidation. Due to the presence of heat, thermal oxidation occurs faster than autoxidation[5]. Thermal oxidation starts with the removal of hydrogen to form radicals. The difference in oxidation rate is caused by the strength of the hydrogen-carbon bond in different fatty acids[23]. Further, when the lipid alkyl radical reacts with $3O_2$, it creates the lipid peroxy radical, which is a reactive radical[24]. At normal oxygen pressure, the reaction between lipid alkyl radical and $3O_2$ occurs very quickly, therefore the amount of lipid alkyl radical is very less when compared with the amount of lipid peroxy radical. The lipid peroxy radical takes hydrogen from other lipid molecules and reacts with it to produce hydroperoxide and a new lipid alkyl radical. The oxidation reaction is catalyzed by these radicals, and the free radical chain reaction is known as autoxidation. The rates of formation of lipid peroxy radical and hydroperoxide are solely determined by the availability of oxygen and the temperature. Finally, the radicals react with each other, resulting in the formation of nonradical species, and the reaction comes to a halt.

3.3 Hydrolysis

Esters of triglycerols and fatty acids make up fats and oils. Triglycerides are tri-esters made up of three fatty acid molecules bound together by a glycerol molecule. Fat or oil can be hydrolyzed to release triglycerides and fatty acids. During frying, water, steam and oxygen cause a variety of chemical reactions in both the frying oil and the food item[5]. For hydrolysis, short-chain fats and oil can easily react with moisture content of food item[25]. As a weak nucleophile, water attacks the ester linkage of tri glycerols, forming diacylglycerols, monoacylglycerols, glycerols, and free fatty acids. There are three steps to the hydrolysis reaction[26]. Triglycerides are first hydrolyzed into diglycerides, which are then hydrolyzed into monoglycerides, and finally, monoglycerides are hydrolyzed into glycerol. At each step, a free fatty acid is produced. In the oily phase, this reaction is a homogeneous first-order reversible reaction[27].

3.4 Polymerization of Oil

The type of oil used, the frying temperature, and the number of frying cycles all influence the formation of dimers and polymers. The formation of polymers increases as the frying temperature and the number of frying cycles increases[28]. Triacylglycerol dimers and polymers are a major decomposition product of the frying reaction. The polymerization process occurs at high temperatures in the range of 260 °C to 340 °C[29]. Heat treatment of olefins, triacylglycerols, diacylglycerols, mono and polyunsaturated monoacylglycerols, free mono- and polyunsaturated fatty acids, and phospholipids constituting oils, fats of animal, vegetable, or synthetic origin at a specific temperature and for a specific period can produce polymers. In deep frying, radical reactions such as dimerization and polymerization occur.

Alkyl hydroperoxides (ROOH) or dialkyl peroxides are formed when triacylglycerols react with oxygen. RO-OH and ROO-R scission easily decompose them into alkoxy and peroxy radicals, respectively. Radical reactions and the Diels-Alder reaction produce cyclic polymers within or between triacylglycerol's degree of unsaturation and the frying temperature influences the formation of cyclic compounds in frying oil[30].

4. EFFECT OF DEEP FRYING ON QUALITY PARAMETERS OF OIL

4.1 Moisture Content

While deep frying, moisture from the food is released into the oil. The removal of moisture from the food item causes oil absorption into the food. The moisture content of the oil is affected differently when different foods are fried. Pre-frying treatments affect the moisture content and oil absorption of both the food and the oil. Many studies found that the initial moisture content was closely related to the oil content. The moisture content of the food being fried is one of the primary factors affecting the moisture content of the oil. When the food is immersed in hot oil, the moisture inside it starts to evaporate. The water vapors then rise to the surface of the oil, which leads to the formation of bubbles. These bubbles indicate that moisture is escaping from the food[68].

The initial moisture content of the oil also plays a role in the frying process. If the oil contains high levels of moisture, it can lead to more foaming and splattering during frying. This can cause the moisture content of the oil to increase rapidly. As the frying process continues, the oil degrades, and its ability to hold onto moisture decreases. The heat breaks down the oil, causing it to break down into its component fatty acids, which can then react with the water in the food[69-70]. This reaction can lead to the formation of volatile compounds, which can affect the flavor and quality of the oil. The frying temperature also plays a significant role in the moisture content of the oil. If the temperature is too low, the food will absorb more oil, resulting in a higher moisture content in the food[71-72]. If the temperature is too high, the oil can break down more rapidly, leading to a decrease in its ability to hold onto moisture. The duration of frying also affects the moisture content of the oil[73]. As the frying process continues, the oil becomes more saturated with moisture, which can cause it to break down more rapidly. This breakdown can cause the oil to smoke, leading to an unpleasant taste and aroma[74-75].

Krokida in 2001[31] proposed that, as the initial moisture content of the oil decreases, oil content also followed the same trend. Baumann[32] reported the final oil content of potato crisps was found to be proportional to the initial moisture content. T Zhang 2016[33] investigated the moisture loss and oil uptake rate of fried and twice-fried potato chips. He concluded that because oil uptake was faster in twice-fried food, the initial moisture content of the food item had no discernible effect on the final oil content. Food additives such as alginates and cellulose may have a significant impact on the amount of oil and moisture absorbed[34]. Because most studies compare treatments based on equal frying time rather than equal water loss, it is possible to draw incorrect conclusions about the treatment's and additive's relative effectiveness as an oil uptake barrier or reducer. As a result, to measure the reliance of oil uptake on moisture, a new oil uptake ratio (Ur) was employed[19.]

4.2 Color

The colour of the oil and the food item change during frying. The Maillard reaction is the primary cause of food colour change. Colour change in oil is easily detectable as a degradation change. The main reaction that causes colour formation in frying oil is nonenzymatic browning, which uses carbonyls from food products like starches, sugars, and lipid oxidation products as starting materials, as well as amino groups from proteins and amino acids[35]. E Yuki 1961[36] reported one of the causes of colour change is a free fatty acid produced by oil hydrolysis. Particles of fried foods that stick to the surface of heated pans were discovered to be broken down into smaller particles as a colouring substance as a result of overheating[37]. Browning was also aided by phospholipids ejected from fried foods[38]. The amino-carbonyl reaction is a well-known pathway for nonenzymatic food browning. Glycine, alanine, and leucine were found to discolour frying oil[39]. Totani in 2006[40] observed there was no effect on colour values of the oil with change in concentration of mineral content 0 and 15 ppm. However, after 10 hours of frying, oil containing 225 ppm minerals showed rapid colour deterioration.

4.3 Viscosity

The formation of dimers, trimers, polymers, epoxides, alcohols, and hydrocarbons, all of which contribute to the increase in viscosity, has a significant impact on the viscosity of oil[41-42]. The viscosity of the oil changes dramatically with frying time and temperature in deep fat frying operations. Oil viscosity rises not only with polymerization but also with the length of fatty acids or the type of oil. During frying, the viscosity of liquids and solid or semi-solid frying fats changes in different ways[43]. The viscosity of the frying oil is a key factor in determining how much oil sticks to the large cavities in the food product's crust. Higher viscosity results in a larger volume of oil in the fried food[44]. Tyagi & Vasishtha, in 1996[45] stated that oil viscosity increased regularly and was influenced primarily by frying temperature rather than frying medium (Table 1). The values of these attributes progressively increased with the oxidation accelerated by heat conditions. These findings demonstrated that oxidation and polymerization have a greater degradative effect in oil.

4.4 Smoke, Fire and Flashpoint

Smoke, fire, and flash points are all indirect indicators of a fatty material's thermal stability when heated in contact with air. The temperature at which smoke is first detected in a laboratory apparatus is known as the smoke point. The lowest temperature at which enough vapour is released to form an ignitable mixture with air is known as a flash point[47]. The temperature at which volatile products can continue to burn is known as the fire point.

Because fatty acids are more volatile than glycerides, the content of free fatty acids determines the smoke, flash, and fire points of glycerides. The smoke point is the most useful metric for determining the quality of a frying oil because the smoke haze is primarily caused by Free fatty acids produced during the frying process[48].C M Li in 2005[49] studied the frying of potatoes in diacylglycerol- and triacylglycerol-rich oils and stated

Table 1. Change in viscosity (mPa.s) of oils due to frying

Food Item	Oil used	Initial viscosity	Final viscosity	Frying time/cycles	Reference
Peeled and sliced Potatoes	Palm olein	68.44±0.73	77.42±1.15 89.51±0.71	3 days 5 days	(Man *et al.*, 2010)[46]
	Canola	59.88±0.30	72.02±0.47 84.1±0.45	3 days 5 days	
	Palm olein+ Sesame (1:1 w/w)	61.63±0.27	72.76±0.18 80.73±0.27	3 days 5 days	
	Palm olein+ Canola (1:1 w/w)	61.70±0.49	74.80±0.15 81.65±1.22	3 days 5 days	
	Canola+ Sesame (1:1 w/w)	60.90±0.85	67.84±0.70 74.75±0.48	3 days 5 days	
	Palm olein+ Sesame+ Canola (1:1:1 w/w)	59.38±1.41	68.56±0.80 76.75±0.31	3 days 5 days	

that the smoke point of the diacylglycerol rich oil dropped more than that of the triacylglycerol-rich oils after 3 hours of frying. After frying in both oils, the flash point dropped as well, but less significantly than the smoke point. De Alzaa F, 2018[50] concluded that the production of polar compounds with temperature and time was more prominent for refined seed oils with higher initial smoke point values under various heating conditions.

4.5 Peroxide Value

One of the most commonly determined quality parameters during oil production, storage, and marketing is peroxide value[51]. It is the most widely used chemical method for determining the first stage of oil oxidation. PV should be combined with some method of monitoring secondary oxidation products to get a more complete picture of oxidation progress. Under normal conditions, the PV is a good indicator of lipid oxidation[52]. Park & Kim, 2016 soybean oil (SB[53] investigated the condition of frying oil used for frying chicken nuggets in different oils and concluded that the hydroperoxide, on the other hand, breaks down at high temperatures and forms secondary oxidation products during cooling. As a result, regardless of the frying oil, the PV rises with increased frying time. Sibel Karakaya[54], in 2011 on the other hand, conducted frying studies with various oils and observed a reduction in PV after 125 minutes of frying (Table 2). This lowering was caused by the formation of secondary oxidation products such as hydrocarbons, alcohols, ketones and aldehydes from extremely unstable primary oxidation products. Sunisa in 2011[55] fried chicken drumsticks in Palm Olein oil for 3 days completing 30 cycles per day, by the end of the first day of frying, the PV of chicken drumsticks had rapidly increased. As a result of the unstable compound, it decreased after reaching a maximum of 6.85±0.40 mg O_2/kg fat on the second day of frying (Table 2).

4.6 Free Fatty Acids

Due to the action of lipase, high temperature, and moisture, free fatty acids (FFA) are produced from triacylglycerol by cleavage of ester bonds. Their formation in edible oils occurs primarily during the production, storage, and frying of the oil. Additional sources of FFA are lipid degradation processes. Short-chain FFA can be produced by the secondary oxidation of unsaturated aldehydes or the cleavage of lipid hydroperoxides[57]. The amount of FFA in vegetable oils is determined by several factors, including raw material quality and variety, collection conditions, processing, storage, oil age, and

Table 2. Effect of frying on the Peroxide Value (PV-meq O_2/kg sample/fat) of oils during frying

Food Item	Oil used	Initial PV	Final PV	Frying Time/cycle	Reference
Potato chips	Hazelnut	10.17±0.83	14.32±1.09 10.64±0.96	50 min 125 min	(Sibel Karakaya, 2011)[54]
	Corn	3.02±0.00	3.92±1.04 5.58±0.63	50 min 125 min	
	Soybean	8.15±0.00	6.12±2.22 4.07±1.55	50 min 125 min	
	Olive	8.85±0.50	6.53±0.33 5.85±0.00	50 min 125 min	

Peeled and sliced potatoes	Palm olein	0.71±0.22	8.06±0.66	2 day	(Man, *et al*., 2010)[46]
			10.85±0.79	5 day	
	Canola	0.82±0.15	10.53±0.99	2 day	
			10.23±0.59	5 day	
	Palm olein+ Sesame (1:1 w/w)	0.45±0.05	2.59±0.08	2 day	
			4.16±0.66	5 day	
	Palm olein+ Canola (1:1, w/w)	1.37±0.05	6.46±0.31	2 day	
			11.47±0.36	5 day	
	Canola+ Sesame (1:1, w/w)	1.14±0.10	3.91±0.17	2 day	
			4.86±0.09	5 day	
	Palm olein+ Sesame+ Canola (1:1:1, w/w)	0.69±.018	4.04±0.06	2 day	
			5.88±0.14	5 day	
Chicken drumstick	Palm olein	Palm olein	5.93 ± 0.17	10 Cycle	(Sunisa, 2011)[55]
			5.93 ± 0.17	30 Cycle (1day)	
			6.85 ± 0.40	2 days	
			4.58 ± 0.37	3 days	
Keropok lekors	Palm oil	2.13 ± 0.00	14.26 ± 0.41	5 Cycle	(Kamisah, *et al.*, 2012)[56]
	Soybean oil	2.53 ± 0.00	16.95 ± 0.39	5 Cycle	

deterioration status. The amount of FFA in Waste Cooking Oils (WCO) is even higher because high temperature and exposure to air during frying promote triglyceride hydrolysis and oxidation, which increases the amount of FFA in the oil. According to several publications, many food processors uses FFA value as an acidity indicator of oil[58]. Many studies have used acidity as one of the preferred oil quality parameters, demonstrating the importance of acidity when heating and frying (Table 3). Basiron, in 2005[59] noted the fact that the level of FFA in Palm oil is relatively higher than in other edible oils, but this value is within the legal FFA content limit of 0.1 per cent for refined edible oils

4.7 Total Polar Compound

Hydrolytic, oxidative, and polymerization reactions are triggered by food moisture content, oxygen in the atmosphere, and high frying temperatures. These reactions cause changes in the composition of frying oils, resulting in the release of free fatty acids, diglycerides, and polymeric triglycerides. Total polar compounds are the name given to this group of compounds. The primary and secondary oxidation that occurs during the frying process is strongly linked to the formation of polar compounds, and TPC indicates oil deterioration[61].TPC increased significantly with frying time during deep frying, which could be due to frying conditions promoting cyclization,

Table 3. Effect of frying on the free fatty acid value (FFA-% Oleic acid) of oils

Food Item	Oil used	Initial FFA	Final FFA	Frying Time/Cycles	Reference
Peeled and sliced Potatoes	Palm olein	0.09±0.00	0.21±0.01	3days	(Man, *et al*., 2010)[46]
			0.32±0.01	5days	
	Canola	0.05±0.02	0.16±0.01	3days	
			0.22±0.01	5days	
	Palm olein+ Sesame (1:1, w/w)	0.79±0.05	1.41±0.03	3days	
			1.87±0.08	5days	
	Palm olein+ Canola (1:1, w/w)	0.05±0.01	0.14±0.01	3days	
			0.21±0.01	5days	
	Canola+ Sesame (1:1, w/w)	0.85±0.02	1.25±0.06	3days	
			1.46±0.01	5days	
	Palm olein+ Sesame+ Canola (1:1:1, w/w)	0.62±0.05	0.98±0.03	3days	
			1.21±0.01	5days	
Wheat dough	Soyabean Oil	0.017± 0.001	0.062±0.001	13 Cycles	(Chung, *et al*., 2004)[60]
			0.115±0.004	37 Cycles	
			0.174±0.001	61 Cycles	
	Sesame oil: soybean oil, (20:80 v/v)	0.264±0.007	0.309±0.007	13 Cycles	
			0.562±0.003	37 Cycles	
			0.884±0.003	61 Cycles	

polymerization, pyrolytic, hydrolytic, oxidative, and other chemical reactions[62]. According to the FSSAI, vegetable oil/fat with TPCs of more than 25% should not be used for frying[63].

4.8 Iodine Value

The Iodine Value(IV) can be defined as a measurement of the relative degree of unsaturation in oil. It can be determined using the combination of halogen. Iodine value provides an idea of quality factors such as melting point and oxidative stability because of its relation with the degree of unsaturation. Oils having high iodine value are more vulnerable to thermal oxidation during deep frying.[64] Alireza in 2010[65] fried potatoes in various oil and its blend and found a decrease in IV with the duration of deep frying. He also observed that the addition of antioxidants reduced the degree of unsaturation. Josphine Chebet 2016[66] conducted frying studied and recorded maximum decreases in IV of soybean oil. He also recorded a small decrease in IV after 6 hours of storage; the

Table 4. Effect of frying on the total polar compound (%TPC) of oils

Food Item	Oil used	Initial TPC	Final TPC	Frying Time	Reference
Potato Chips	Hazelnut	2.77±0.00 2.77±0.00	3.32 ± 0.47 3.98±0.77	50 min 125 min	(Sibel Karakaya, 2011)[54]
	Corn	2.99±0.00 2.99±0.00	3.65 ± 0.00 4.20±0.15	50 min 125 min	
	Soybean	2.72±0.00 2.72±0.00	2.95 ± 0.00 4.31±0.00	50 min 125 min	
	Olive	3.98±0.015 3.98±0.015	3.76 ± 0.16 4.31±0.00	50 min 125 min	
Peeled and sliced Potatoes	Palm olein	8.50±0.74	20.10±0.65 25.43±0.53	3 days 5 days	(Man, *et al.*, 2010)[46]
	Canola	6.94±0.56	20.20±0.53 26.78±0.90	3 days 5 days	
	Palm olein+ Sesame (1:1, w/w)	9.94±0.27	16.93±0.64 24.33±1.03	3 days 5 days	
	Palm olein+ Canola (1:1, w/w)	8.18±0.74	16.01±0.30 24.80±0.73	3 days 5 days	
	Canola+ Sesame (1:1, w/w)	6.00±0.18	15.18±1.16 21.75±1.31	3 days 5 days	
	Palm olein+ Sesame+ Canola (1:1:1, w/w)	10.63±0.78	15.48±1.00 22.95±0.48	3 days 5 days	

Table 5. Effect of frying on the Iodine Value (IV) of oils

Food Item	Oil used	Initial IV	Final IV	Frying time/ cycles	Reference
Peeled and sliced Potatoes	Palm olein	57.27±0.35	54.56±0.31 52.81±1.05	3 Days 5 Days	(Alireza, *et al.*, 2010)[65]
	Canola	101.36±0.32	98.08±0.33 94.1±0.34	3 Days 5 Days	
	Palm olein/sesame oil	78.62±0.29	75.22±0.23 73.77±0.18	3 Days 5 Days	
	Palm olein/canola oil	77.97±0.23	74.7±0.20 73.64±0.29	3 Days 5 Days	
	Sesame oil/canola oil	101.42±0.14	98.2±0.24 96.17±0.1	3 Days 5 Days	
	Palm olein/sesame oil/canola oil	88.8±0.38	85.07±0.25 83.61±0.19	3 Days 5 Days	

Chicken	Palm	50.8 ±0.72	48.2 ±2.45	6 hrs	(Josphine Chebet, 2016)[66]
	Corn	132.0±0.40	124.4±1. 50	6 hrs	
	Peanut	104.1±3.32	99.0 ±2.69	6 hrs	
	Soy-bean	129.4±1.00	121.8±3. 02	6 hrs	
	Sunflower	126.9±1.67	124.4±1. 91	6 hrs	
Chips	Palm	50.8 ±0.72	48.2±3.1 8	6 hrs	
	Corn	132.0±0.40	124.5±3. 51	6 hrs	
	Peanut	104.1±3.32	101.5±1. 80	6 hrs	
	Soy-bean	129.4±1.00	116.7±2. 94	6 hrs	
	Sunflower	126.9±1.67	124.4±2 .78	6 hrs	
Fish	Palm	50.8 ±0.72	45.7 ±2.20	6 hrs	
	Corn	132.0±0.40	116.7± 4.16	6 hrs	
	Peanut	104.1±3.32	98.9 ±2.45	6 hrs	
	Soy-bean	129.4±1.00	111.7± 2.29	6 hrs	
	Sunflower	126.9±1.67	121.8± 1.47	6 hrs	
Smokies	Palm	50.8 ±0.72	48.2 ±1.63	6 hrs	
	Corn	132.0±0.40	122.9±3 .27	6 hrs	
	Peanut	104.1±3.32	101.5±1 .88	6 hrs	
	Soy-bean	129.4±1.00	126.9±1 .91	6 hrs	
	Sunflower	126.9±1.67	124.4±3 .02	6 hrs	
Mandazis	Palm	50.8 ±0.72	50.8 ±1.47	6 hrs	
	Corn	132.0±0.40	124.4 ±2.61	6 hrs	
	Peanut	104.1±3.32	96.4 ±2.45	6 hrs	
	Soy-bean	129.4±1.00	96.4±2. 12	6 hrs	
	Sunflower	126.9±1.67	121.8±2 .20	6 hrs	

Table 6. Effect of frying on the Saponification Value (SV) of oils

Food Item	Oil used	Initial SV	Final SV	Frying Time/ cycle	Reference
Were collected from some food supply markets in Libya and home kitchen uses.	Sunflower Corn Olive oil	21.09 21.54 19.41	22.44 22.27 21.15	Not specified Not specified Not specified	(Adel Imhemed Alajtal, 2018)[68]
Peeled and sliced Potatoes	Soybean oil	195.1	200.2 205.1 210.1	28 hr 52 hr 70 hr	(Tyagi & Vasishtha, 1996)[46]

decrease was maximum after 5 days of storage (Table 4). Maria Dolores Guillen in 2011[67] stated the decrease rate of IV is directly proportional to the oil surface and inversely related to the oil volume involved in the frying.

4.9 Saponification Value

The average relative molecular mass of oils and fats is determined using the Saponification value. Adel Imhemed Alajtal, in 2018[68] collected oil samples before and after frying and found no discernible difference in SV before and after frying and discovered that frying has no measurable impact on SV (Table 5). Tyagi & Vasishtha in 1996[45] found little change after a very long period of heating, this could be explained by the formation of a disproportionately larger number of secondary oxidation products (e.g., carbonyl compounds) as a result of the conversion of primary oxidation products (Table 5).

5. CONCLUSION

Deep frying causes numerous physical and chemical changes in both the oil and the food. Many factors influence it, including the type of oil used, the composition and dimensions of the fried food product, the frying time and temperature, the type of fryer or vessel, pre-frying treatment, oil additives, and so on. It begins with heat and mass transfer, which is primarily affected by moisture loss and oil uptake, followed by the leaching of other minor compounds present in food into oil. Further frying results in oil degradation, which includes thermal oxidation, hydrolysis, and polymerization. After a certain amount of time, the oil becomes unfit for further frying. Certain oil quality parameters, such as moisture content, colour, viscosity, Peroxide Value (PV), Iodine Value (IV), free Fatty Acids (FFA), total polar content, and so on, can be used to assess the usability of the oil. These parameters serve as indicators of various oil degradation factors. All of these factors, from the selection of oil to the point at which the oil begins to degrade, have an impact on the quality of fried food items. To obtain a perfect fried product with desirable aroma, texture, taste, and appearance, all physical and chemical changes with all critical points influencing deep frying must be studied. There is still room to explain the complex reactions and interactions that occur during the deep-frying process, which is characterized by the simultaneous action of numerous process, oil, and food variables.

Blended oils have gained popularity in recent years as people have become more health-conscious and aware of the potential risks associated with consuming large amounts of certain types of oils. Blending different oils can help balance out the nutritional content and improve the overall health benefits of the oil. Looking ahead, the use of blended oils is likely to continue to increase as more people become aware of the advantages of this approach. Consumers will likely demand more transparency from manufacturers about the composition of their oils and the specific health benefits they offer. In conclusion, the inclusion of blended oils in the diet offers several advantages, including better nutrition and reduced risk of health problems associated with certain types of single source oils. With more research and education, people will become increasingly aware of the potential benefits of using blended oils, leading to their continued popularity in the years to come.

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