

REVIEW OF LITERATURE

CHAPTER 2

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The human diet contains a wide range of different foods. Solid foods contain protein, carbohydrate and **fat (lipid)** as three macronutrients, along with a large number of important micronutrients (Gunstone FD, 2005). Dietary fat encompasses all the sources of lipids in foods, including those in plant and animal cellular membranes, as well as the readily recognized fats and oils. National Council for Applied Economics Research (NCAER, 2012) reported use of vegetable oils (excluding *vanaspati*) for cooking has grown from 7 kg in the 1990s to 13.5 kg in recent years in India. Fried food is a convenience food in most countries. Unfortunately, these are high in fat and contribute to fat-related diseases in societies with a high fat consumption (Mehta U and Swinburn B, 2001).

The present work has been undertaken to study the frequency of fried food intake by Gujarati housewives and its association with their morbidity profile, assess the sensory qualities of french fries and bhajias fried in cottonseed and groundnut oil at different intervals, determine the intermittent frying stability of cottonseed and groundnut oil.

This chapter focuses on the available literature for the various objectives of the study and divided into the following heads:

- 2.1 Global consumption and recommended intakes of edible oil
- 2.2 Edible oil consumption in India
- 2.3 Production of edible oil
- 2.4 Nutrition transition
- 2.5 Chronic diseases related to fats and oil consumption
 - 2.5.1 Per cent energy from oils in Indian diets
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2.1 Global consumption and recommended intakes of edible oil

The increase in the quantity and quality of the fats consumed in the diet is an important feature of nutrition transition reflected in the national diets of countries. There are large variations across the regions of the world in the amount of total fats (i.e. fats in foods, plus added fats and oils) available for

human consumption. The lowest quantities consumed are recorded in Africa, while the highest consumption occurs in parts of North America and Europe. The important point is that there has been a remarkable increase in the intake of dietary fats over the past three decades (Table 2.1.1) and that this increase has taken place practically everywhere except in Africa, where consumption levels have stagnated. The per capita supply of fat from animal foods has increased, respectively, by 14 g and 4 g per capita in developing and industrialized countries, while there has been a decrease of 9 g per capita in transition countries (Kennedy G, 2005).

Table 2.1.1: Changed trends in the dietary supply of fat from 1967-99

Region	Supply of fat (g/capita/day)				
	1967 - 1969	1977 - 1979	1987 - 1989	1997 - 1999	Change between 1967 - 1969 and 1997 - 1999
World	53	57	67	73	20
North Africa	44	58	65	64	20
Sub-Saharan Africa ^a	41	43	41	45	4
North America	117	125	138	143	26
Latin America and the Caribbean	54	65	73	79	25
China	24	27	48	79	55
East and South-East Asia	28	32	44	52	24
South Asia	29	32	39	45	16
European Community	117	128	143	148	31
Eastern Europe	90	111	116	104	14
Near East	51	62	73	70	19
Oceania	102	102	113	113	11

Source: Kennedy G, 2005

FAO (2011) reported annual average increase in vegetable oil consumption is 2.2%. This growth concentration is mainly projected to developing countries due to their solid economic performance and emerging economies, continued population growth and urbanization especially in Asia, notably India, China. However, in developed countries increase is weaker due to slow economic recovery, non-food uses i.e. for biofuel production (Thoenes P, 2011).

As reported by USDA (2012), Figure 2.1 depicts the global edible oil consumption based on world population growth and estimated growth in edible oil consumption with increase in world population. According to USDA 2012, edible oil consumption is projected to grow at slower rates in proportion with the future lower population growth, total edible oil consumption will increase from 145mn tones today to 660mn tones by 2050, and the % of palm oil of total consumption will increase from 36% to 58%.

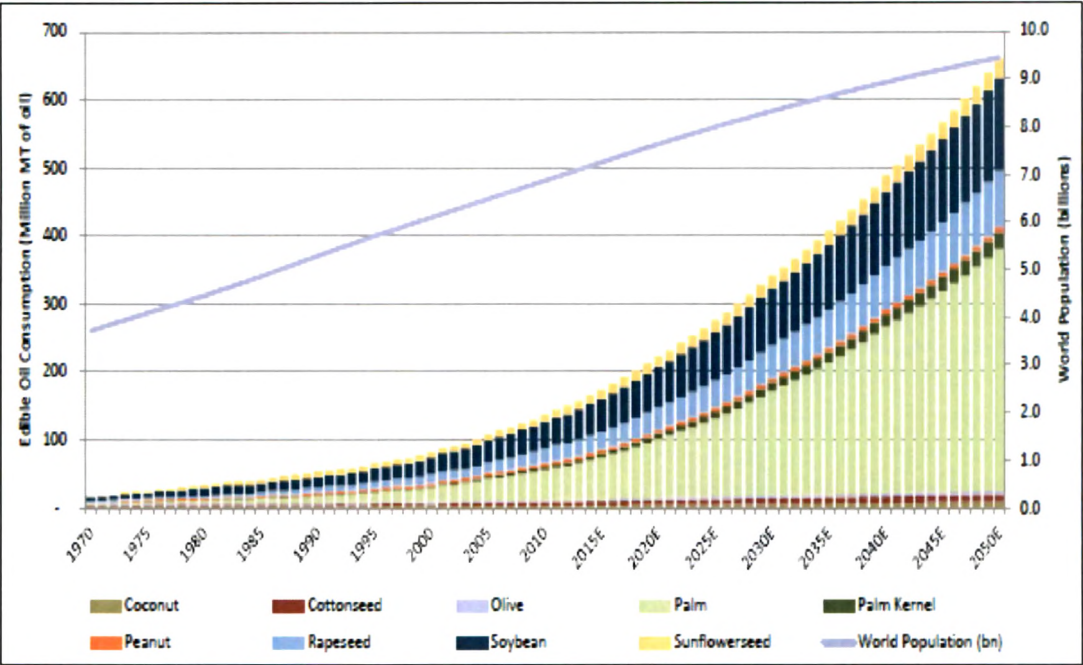


Figure 2.1: Estimated global edible oil consumption based on world population growth

Table 2.1.2: Average yearly oil consumption growth assumptions

	1971-1980	1981-1990	1991-2000	2001-2010	2011-2020E	2021E-2030E	2031E-2040E	2041E-2050E
Coconut	3.7%	1.6%	0.6%	3.2%	2.8%	2.3%	1.9%	1.5%
Cottonseed	0.2%	1.5%	1.9%	3.1%	2.7%	2.2%	1.8%	1.4%
Olive	2.0%	0.5%	4.0%	2.0%	1.7%	1.4%	1.1%	0.9%
Palm	10.7%	9.5%	7.1%	8.2%	7.2%	5.9%	4.8%	3.8%
Palm Kernel	3.8%	8.9%	8.3%	6.4%	5.7%	4.7%	3.7%	3.0%
Peanut	2.6%	2.8%	2.5%	1.5%	1.3%	1.1%	0.9%	0.7%
Rapeseed	6.4%	9.5%	6.3%	5.2%	4.6%	3.8%	3.0%	2.4%
Soybean	8.2%	2.6%	4.5%	4.8%	4.2%	3.5%	2.8%	2.2%
Sunflowerseed	5.2%	5.7%	1.1%	3.0%	2.7%	2.2%	1.8%	1.4%
Palm as % Total Consumption	12.5%	17.9%	24.7%	33.2%	39.0%	45.8%	51.4%	55.9%
Average Population Growth (Yearly)	1.8%	1.7%	1.4%	1.2%	1.1%	0.9%	0.7%	0.6%
Change in Population Growth					-11.9%	-17.9%	-19.6%	-19.4%

Source: USDA, 2012; U.S. Census Bureau, International Data Base, Internal estimates

Recommended guidelines for dietary fat intake

The World Health Organization/Food and Agriculture Organization (WHO/FAO, 2003) has recommended national dietary guidelines on fat intakes.

❖ *World Health Organization (WHO) Guidelines*

The WHO/FAO 2003 issued the following recommendations with respect to fat intake

- Saturated fat <10% of total energy, or <7% in high risk individuals
- <1% of energy from *trans* fatty acids
- 6–10% total energy from PUFA
- Maintain a balance of n-6 PUFA and n-3 PUFAs i.e. 5–8% and 1–2% of daily energy intake respectively, which corresponds to an n-6:n-3 PUFA range of 2.5:1–8:1.
- The WHO recommends PUFA/SAFA ratio of 0.8 to 1.0 and linoleic acid (omega 6) alpha linolenic acid (omega 3) ration of 5-10 in the diet.
- Total fat, no specific recommendation, but suggests up to 35% in highly active group, with diets rich in fruit, vegetables, legumes, and wholegrain cereal. Otherwise considerable lower fat intakes are recommended.
- Eat fish once or twice a week.

❖ *American Heart Association*

The American Heart Association recommends total fat intake to less than 25–35 per cent of total calories. A saturated fatty acid intake of not more than 10 per cent of total calories, a monounsaturated fatty acid intake in the range of 10–15 per cent and polyunsaturated fats up to 10 percent of total calories. Cholesterol intake should be less than 300mg/d (Krauss RM et al, 1996).

❖ UK Guidelines

In the UK, the following recommendations for dietary fat compositions, based on reducing CHD incidence, have been set (Hunty A, 1995; Food Standards Agency, 2004).

- Total fat <35% food energy (<33% including alcohol)
- Saturated fat <11% food energy (<10% including alcohol)
- *Trans* fatty acids <2% food energy
- Monounsaturated fatty acids- 13%
- Polyunsaturated fatty acids (including n-3 PUFA and n-6 PUFA) – 6.5%
- Long chain n-3 PUFA (LC n-3 PUFA, EPA+DHA) - 0.45 g/d (derived from 2 portions of fish per week, one oily)

Several countries have recommend allowances not only for the absolute amount of PUFAs, but also the balanced intake of n-6 and n-3 PUFA. These recommendations are summarized by Sugano M and Hirahara F (2000) shown in Table 2.1.3.

Table 2.1.3: Recommended dietary allowances of fats in the world

Country	Total energy intake from fats	Total PUFA	Omega 6 (LA)	Omega 3 (ALA)	Omega 6/Omega 3
% of energy					
WHO (1990)	15-30	3-7, ≤10	-	-	5-10
FAO (1994)	15-35	-	4-10	-	5-10
USA (1989)	<30	7	1-2	-	4-10
Japan (1995)	20-25	7-8	-	-	4
Canada (1990)	30 [#]	≥3.5	≥3	≥0.5	4-10

Note: [#] Intake of saturated fat should be ≤10% of energy

PUFA, polyunsaturated fatty acid; LA, linoleic acid; ALA, α-linolenic acid

2.2 Edible oil consumption in India

Edible oils constitute an important component of food expenditure in Indian households. Historically, India has been a major importer of edible oils with almost 30-40% of its requirements being imported till 1980s (ICRA, 2011).

India engrossed over 15 percent of global vegetable oil imports in 2002/03, making it the world’s leading importer, ahead of the European Union and China. Imports represent about 55 percent of India’s edible oil consumption and about half the value of its total agricultural imports (Figure 2.2.1) (Dohlman E, Persaud S and Landes R, 2003).

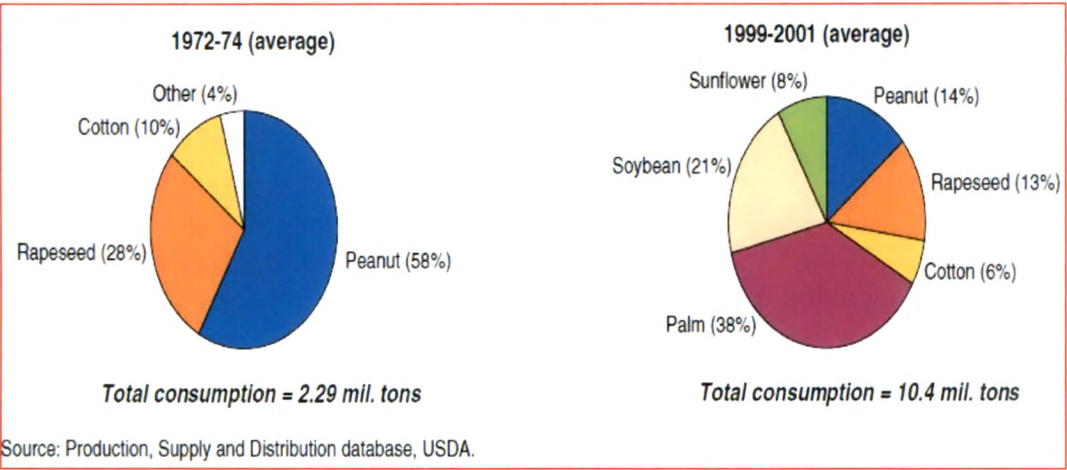


Figure 2.2.1: Dramatic rise India's average consumption of edible oil

USDA estimates, India is the third largest consumer of edible oils (after China and the EU-27 countries); and account for 11% of global edible oil demand and 16% of global imports in 2010/11. India’s annual per capita consumption has shown a steadily increasing trend from 4 kg in the 1970s to 10.2 kg in the late 1990s to current levels of ~13.5 - 14 kg (Figure 2.2.2) (ICRA, 2011).

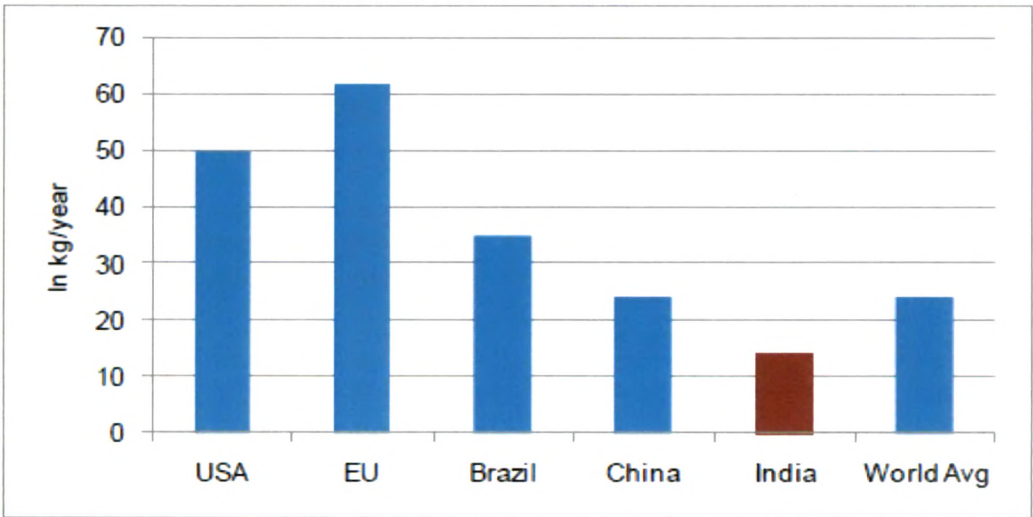


Figure 2.2.2: Per capita consumption of edible oils (2009-10)

However, it still ranks well below the world average of around 24 kg (per capita figures including consumption of bio-energy).

Indian edible oil consumption pattern is the variation in preferences across regions, driven by taste and availability. For instance, soybean oil is mainly used in northern and central regions of India due to the local availability of soybeans. Mustard oil is largely consumed in north-eastern, northern and eastern regions of India, as its pungency is a desired and inherent part of the local cuisine. In terms of volume, palm, soybean and mustard/rapeseed oil are the three major edible oils consumed in India and together account for 75% of the total edible oil demand (Figure 2.2.3) (ICRA, 2011).

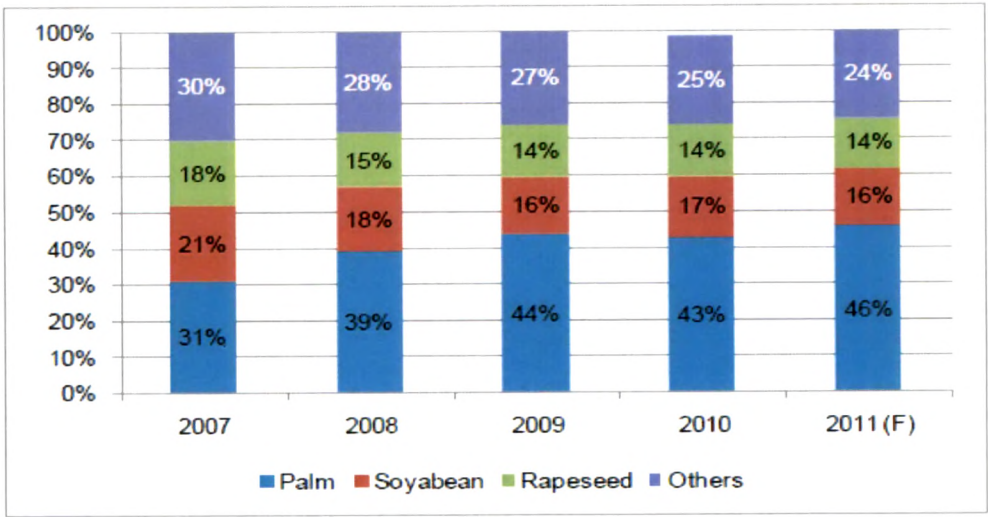


Figure 2.2.3: Domestic consumption trend

USDA predicted the edible oil consumption in 2010/11 increase by 5 percent to around 15.7 million tons due to increasing population and good supply conditions. The per capita edible oil consumption in India is increasing and is estimated at 13.4 kg for 2009/10, which however, is far below the world average per capita consumption of 20.98 kg (Figure 2.2.4). The vegetable oil deficit in 2010/11 was around 8.7 million tons and met through imports (USDA, 2010).

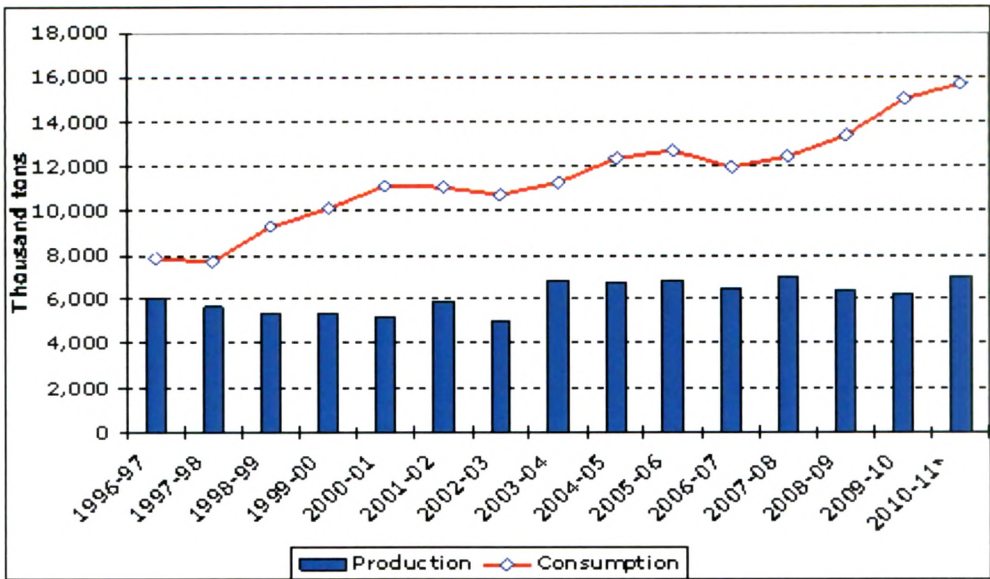


Figure 2.2.4: Edible oil production and consumption (1997 through 2011)

The pattern of edible oil consumption in India has traditionally been region-specific. Coconut, peanut and sunflower oil are widely consumed in south India, **peanut and cottonseed oils are used in Gujarat**, rapeseed oil in north east India, and soybean oil in central India (USDA, 2010).

2.3 Global production of edible oil

Worldwide 12 oil crops constitute over 95% of total vegetable oil production. From 1979 to 1999, oil crops have been one of the most dynamic agricultural sectors growing at a rate of 4.1% per year (Minihane AM and Harland JL, 2007). Hawkes C (2006) reported, FAOSTAT data world oil crop production increased by over 60% between 1990 and 2003 as shown in Table 2.3.1.

Table 2.3.1: World oil crops primary production (Mt)

1980	1990	1995	2000	2003	2004
49,298,300	75,410,698	91,875,399	110,043,440	123,168,460	132,726,738

Source: Hawkes C, 2006

Between 1994 and 2004, edible oil production in China increased nearly two-fold, soybean oil production in Brazil by one-half and Argentina by twofold, and palm oil production in Malaysia increased by two-thirds (Beckman C, 2005). Similar trends are seen for consumption. During this time frame, vegetable oil consumption in the United States and Western Europe increased by just one-quarter, whereas it doubled in China and increased by **one-half in India**. Overall, between 1982/84 and 2000/02, vegetable oils contributed more than any other food group to the increase of calorie availability worldwide (70 kcal/capita/day). Vegetable oils can thus clearly be implicated in rising dietary fat intakes worldwide (Drewnowski A, Popkin BM, 1997).

Total production of oil crops is predicted to increase from 104 to 217 million tons between 1999 and 2030 (Table 2.3.2) (Kennedy G, 2005).

Table 2.3.2: FAO predicted values of world production of major oil crops

Source	Production of oil crops in oil equivalent (million tonnes)			
	1964/66	1984/86	1997/99	2030 (predicted)
Soybeans	5.8	17.2	27.7	58
Palm oil	2.1	8.7	21.6	49
Rapeseed	1.7	7.1	14.5	32
Sunflower	3.4	7.5	10.3	21
Groundnuts	4.8	6.1	9.4	20
Coconuts	3.1	4.3	6.0	12
Cottonseed	3.4	5.0	5.3	9
Sesame seeds	0.7	1.0	1.2	3
Other oil crops	3.7	4.8	7.6	13
Total	29.0	62.0	104.0	217

Source: Kennedy G, 2005

The prime use of the commercial oils and fats produced by the agricultural industry is as food for humans. This represents 80 per cent of the total (122.5 million tons in 2002/03) i.e. around 98 million tones, equivalent 19.7 kg/person/year or 54 g/person/day. These figures are obtained by dividing total annual production by world population. Average values may vary

between countries for example: total disappearance per person in 2002/2003 (including that used as animal feed and in the oleo chemical industry) is 50.9 kg for United States, 50.5 kg for EU-15, 16.4 kg for China, and 11.5 kg for India. The fats we consume are of animal and vegetable origin (Gunstone FD, 2005).

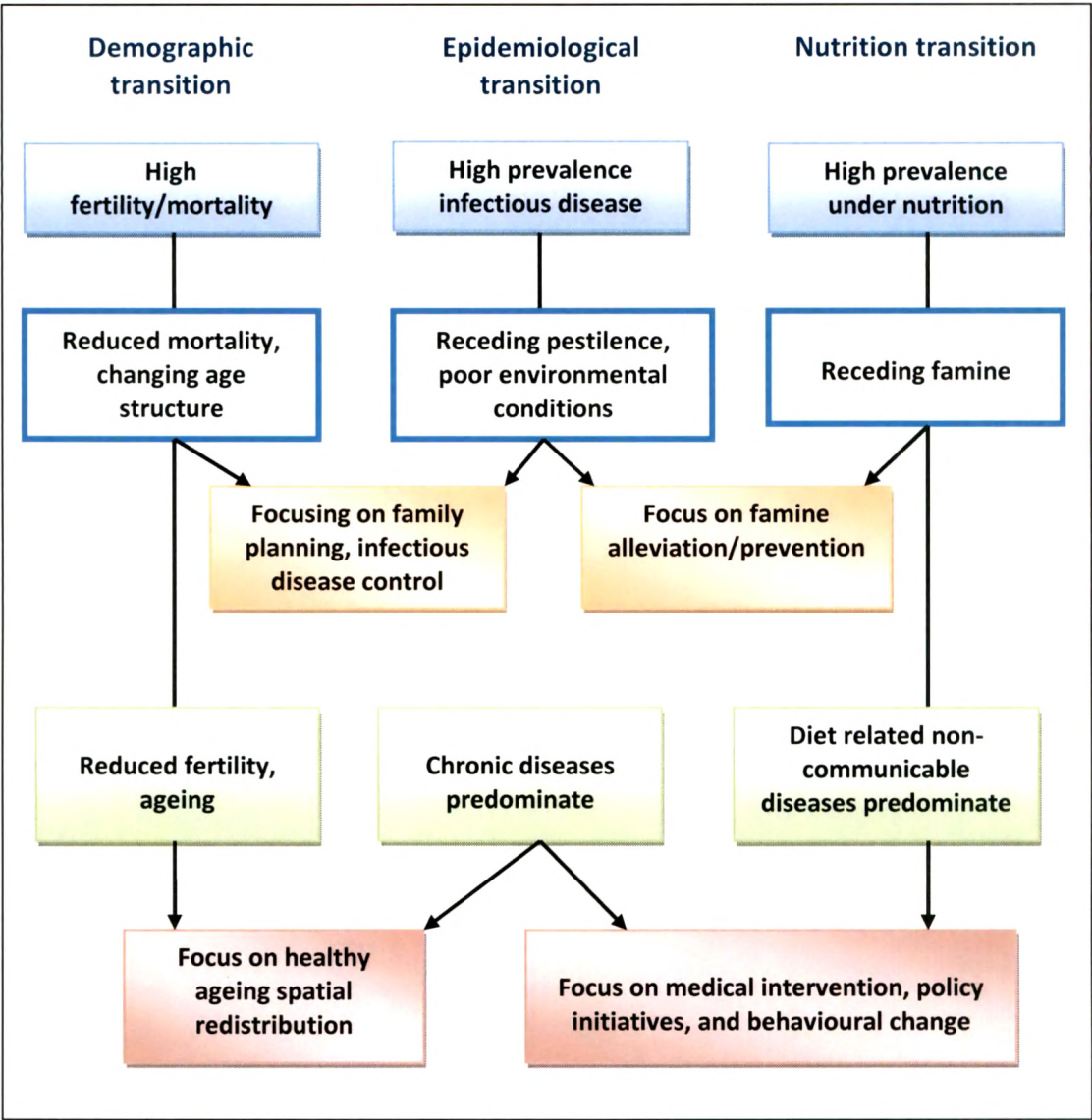
Review report by Dohlman E, Persaud S, and Landes R (2003) stated, India itself is the world's fifth largest producer of soybean oil. India is the world's leading importer of edible oils and is likely to remain an important source of global import demand for the foreseeable future. A large population and steady economic growth are important contributors to India's increasing edible oil consumption and imports.

2.4 Nutrition transition

Worldwide 3 types of transitions have been occurring over the past 3 decades (Figure 2.4.1): 1) the demographic transition, 2) the epidemiological transition, and 3) **the nutrition transition** (Kennedy ET, 2005).

The **demographic transition** has been caused by declining fertility rates and increased life expectancy. This has resulted in changes in the age structure of both developing and industrialized countries. India is in the phase of a rapid demographic transition. Life expectancy is increasing while birth rates are on the decline. The aged population (over 60 years) will constitute 13.3% of the 1333 million total populations by 2026 (Shetty PS, 2002).

The **epidemiological transition** is linked to the demographic transition. Disease patterns worldwide are shifting from communicable to non-communicable diseases (NCD). The burden of chronic disease is increasing rapidly, including in some of the poorest countries of the world. WHO estimates that by 2020, chronic diseases will account for ~75% of all deaths worldwide (WHO, 2003). Evidence of epidemiological transition is obvious in India with NCDs contributing increasingly to premature deaths in adults, particularly in urban areas.



Source: Kennedy ET, 2005

Figure 2.4.1: Stages of health, nutritional and demographic change

Rural-urban differences in non insulin dependent diabetes mellitus (NIDDM) and coronary heart disease (CHD) within a region or state in India show variants in disease risk depicted in Table 2.4.1, suggesting that internal migration, urbanization and exposure to changing diet and lifestyles increase the risk of chronic disease (Shetty PS, 2000).

Table 2.4.1: Urban-rural differences in chronic disease risk in developing societies

	NIDDM prevalence, Tamil Nadu (%)	CHD prevalence, Delhi (%)	CHD prevalence, Moradabad (%)	Cancer incidence, Delhi vs. Barshi, 100,000
Urban	8.2	9.7	9.0	118.8
Rural	2.4	2.7	3.3	57.6

Source: Shetty PS, 2000

The concept of the **nutrition transition** focuses on large shifts in diet and activity patterns, especially their structure and overall consumption (Popkin BM, 2006). The nutrition transition involves populations shifting from a traditional grain-based diet to one with increased variety including more fat and sugars. The change in dietary patterns is related to urbanization. As populations shift from rural to urban living, dietary patterns diversify to include more energy dense foods. The shift in diet occurs at the same time that levels of physical activity are decreasing (Kennedy ET, 2005).

These poor quality diets are associated with rising rates of overweight, obesity and diet-related chronic diseases, like heart disease, diabetes and some cancers. More people now die of heart disease in developing countries than in developed, and the problem is becoming more serious among the poor (WHO, 2005). Low quality diets are also associated with under nutrition in the form of micronutrient deficiency, which, in turn, lowers immunity to infectious diseases. Poor diet quality is thus associated with a dual burden of malnutrition and disease.

Shetty PS in 2002 reported that in India higher-income groups consumed a diet with 32% of the energy from fat while the lower income groups consumed only 17% energy from fat.

Dietary transformation can be described as "increased consumption of brand-name processed and store-bought food, an increased number of meals eaten outside the home and consumer behaviors driven by the appeal of new foods

available". The process of diet transformation in India can be seen as in two separate stages (Pingali P and Khwaja Y, 2004; Hawkes C, 2006):

◆ **Income-induced diet diversification**

At the start of the process of faster economic growth, diets diversify but maintain predominantly traditional features.

◆ **Diet globalization**

As globalization begins to exert its influence, we see the adoption of markedly different diets that no longer conform to the traditional local habits.

The links between globalization and diet suggested by analysts have the following mechanisms (Figure 2.4.2) are central to the globalization/diet nexus (Beaglehole R Yach D, 2003; Evans et al, 2001; Hawkes C, 2005; Lang T, 1999).

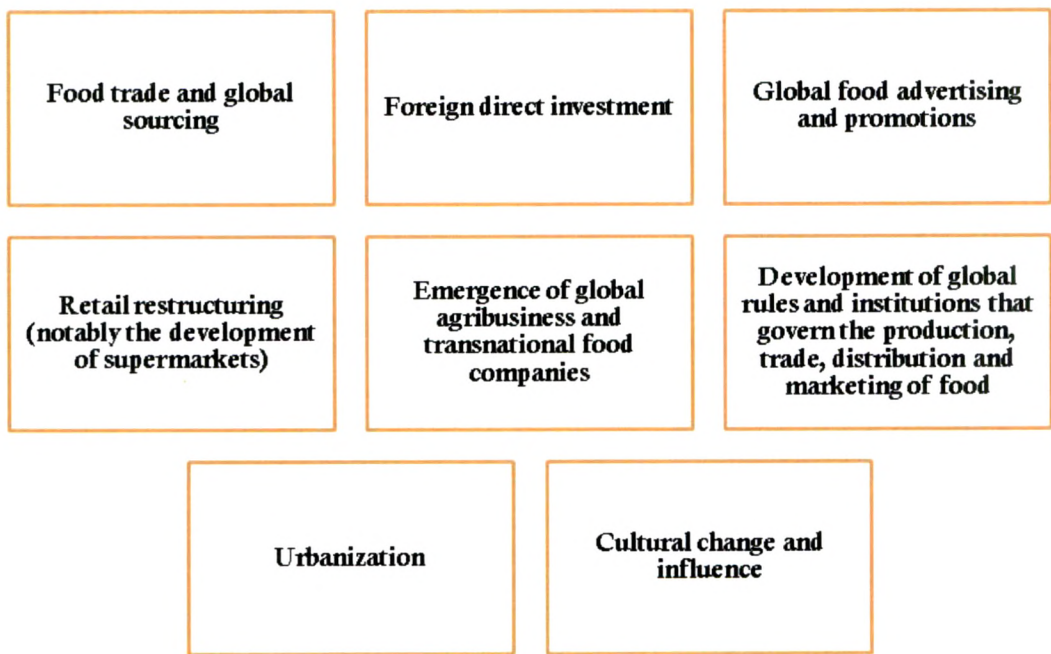
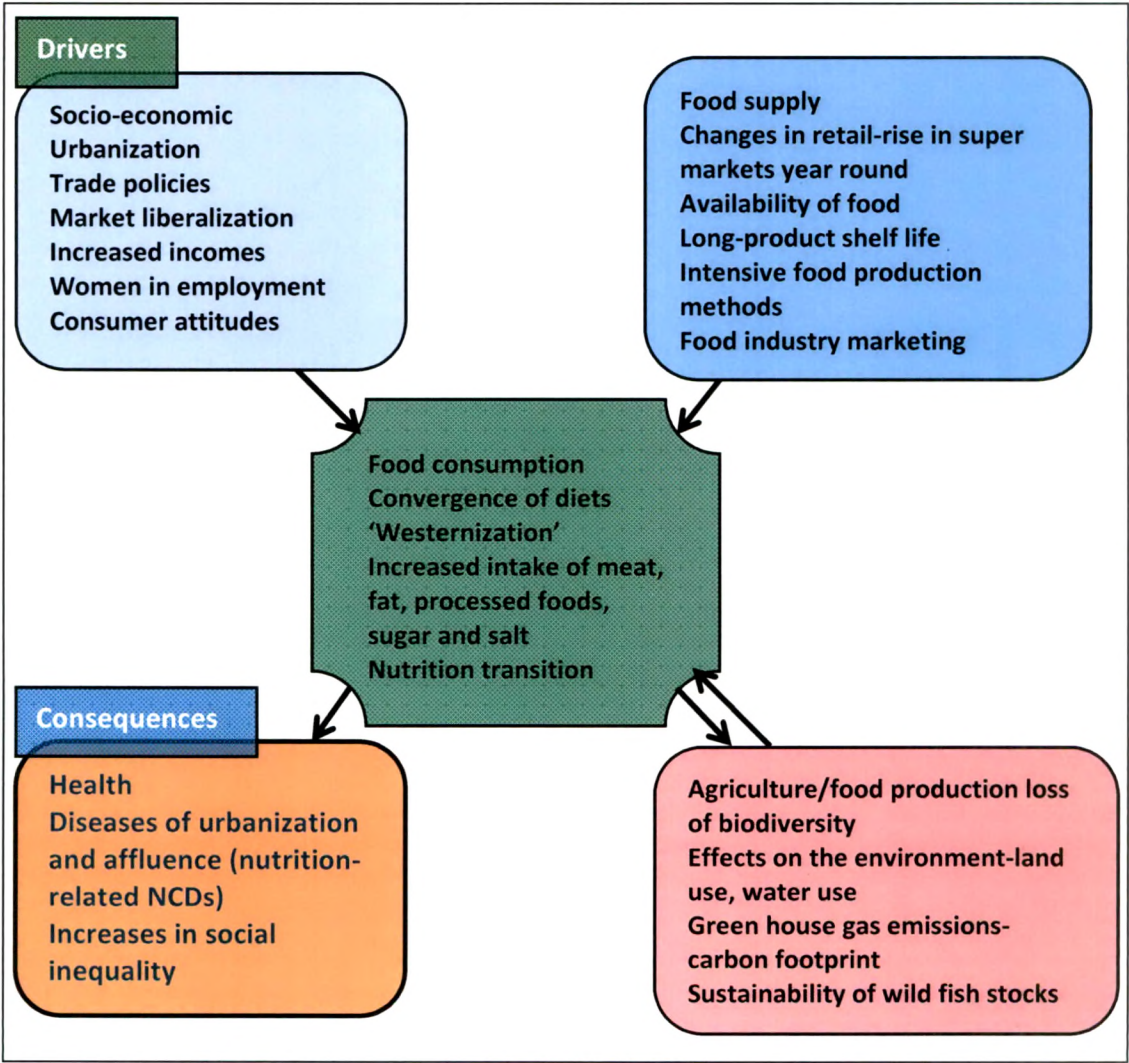


Figure 2.4.2: Mechanisms to the globalization and diet nexus

A difficulty in arresting the effects of the nutrition transition is due in part to the paradox that while the diet associated with the nutrition transition (high fat, sugar and salt) is unhealthy, it is also more diverse and pleasurable (fat and sugar are two of the most pleasurable elements of the diet in terms of taste preferences). This then is part of the challenge: to provide more varied and tasteful diets while ensuring that these diets and a healthy activity level reduce the incidence in obesity, adult-onset diabetes and cancer related to nutrition and exercise. The relationship between recent food consumption patterns, some of their drivers and possible consequences are outlined in Figure 2.4.3 (Kearney J, 2010).



Source: Kearney J, 2010

Figure 2.4.3: The drivers and consequences of food consumption changes with economic development

2.5 Chronic diseases related to fats and oil consumption

The food we eat plays a critical role in our overall health. The amount and composition of fat in the diet is an important determinant of the pathobiology of many of illness conditions. Dietary fat related health problems can be categorized in three ways:

a) Total fat intake

A high dietary fat consumption is a major contributor to obesity for a variety of physiological reasons (Miller WC et al, 1990; Swinburn B and Ravussin E, 1993). There are multiple health consequences from obesity, the most important being type II diabetes.

Colditz GA et al (1995) reported that excess body weight is by far the most potent modifiable factor for type II diabetes.

The risk of certain cancers may be increased by total fat intake. Epidemiological studies have shown that a high total fat intake is linked to increased rates of breast, colon, and prostate cancer (Armstrong B and Doll R, 1975; Mc Keown-Eyssen CE and Bright- See E, 1984).

The American Cancer Society (1996) has suggested a 50% reduction in fat intake (from 40 to 20% of energy intake) would significantly reduce the incidence of cancer of the colon, breast, and other cancers.

Total fat intake is much smaller contributor to coronary heart disease (CHD) than the type of fat (Kennel WB et al, 1986; Grundy SM, 1988). Total fat intake may influence some of the major risk factors for CHD particularly through its impact on obesity and type II diabetes.

A study on high fat meal association with atherosclerosis revealed that a high-fat meal impair vasoactivity and transiently impair endothelial function (Vogel RA, Corretti MC and Plotnick GD, 1997).

b) Type of fat intake

Dietary fat composition is arguably the most important dietary factor contributing to the pathology of CVD and diabetes. Links to cardiovascular disease (CVD), degenerative and inflammatory arthritis, cancer and osteoporosis, and the recognition of fats or their derivatives as biological effectors of human pathologies have fueled efforts to characterize the behavior of lipids in vivo. Initially, the association of cholesterol and saturated dietary fat with increased risk of CVD spurred dietary recommendations to reduce the intake of animal fat and to increase the intake of plant oils. However, mounting evidence is now showing that with increased dietary intake of plant oils, such as corn, safflower, and soybean (especially the partially hydrogenated form), which are high in LA, the dietary ratio of n-6/n-3 fatty acids has increased significantly during the past years (Minihane AM and Harland JI, 2007). The high intake of n-6 with an inadequate amount of n-3 fatty acids in the diet could contribute to the development of some cancers and other chronic diseases.

Numerous dietary factors have been implicated in the pathogenesis of hypertension, and measures to control blood pressure have included reducing the intakes of salt and alcohol, as well as fat intake in obese persons (Nurminen ML, Korpela R, Vapaatalo H, 1998).

Strong association was found between hypertension and obesity. The presence of excess polar compounds in the cooking oil and the use of sunflower oil were related to the risk of hypertension, whereas the concentration of monounsaturated fatty acids in the serum phospholipids was negatively related to this risk (Soriguer F et al, 2003).

Elaidic acid, one of the principal *trans* isomers produced during industrial hydrogenation of edible oils, adversely affects plasma lipoproteins (Sundram K, 1997), including higher intake of trans fat is strongly associated with coronary heart disease (Oh K et al, 2004).

c) Degraded fat and potential health effects

i) Direct toxicity

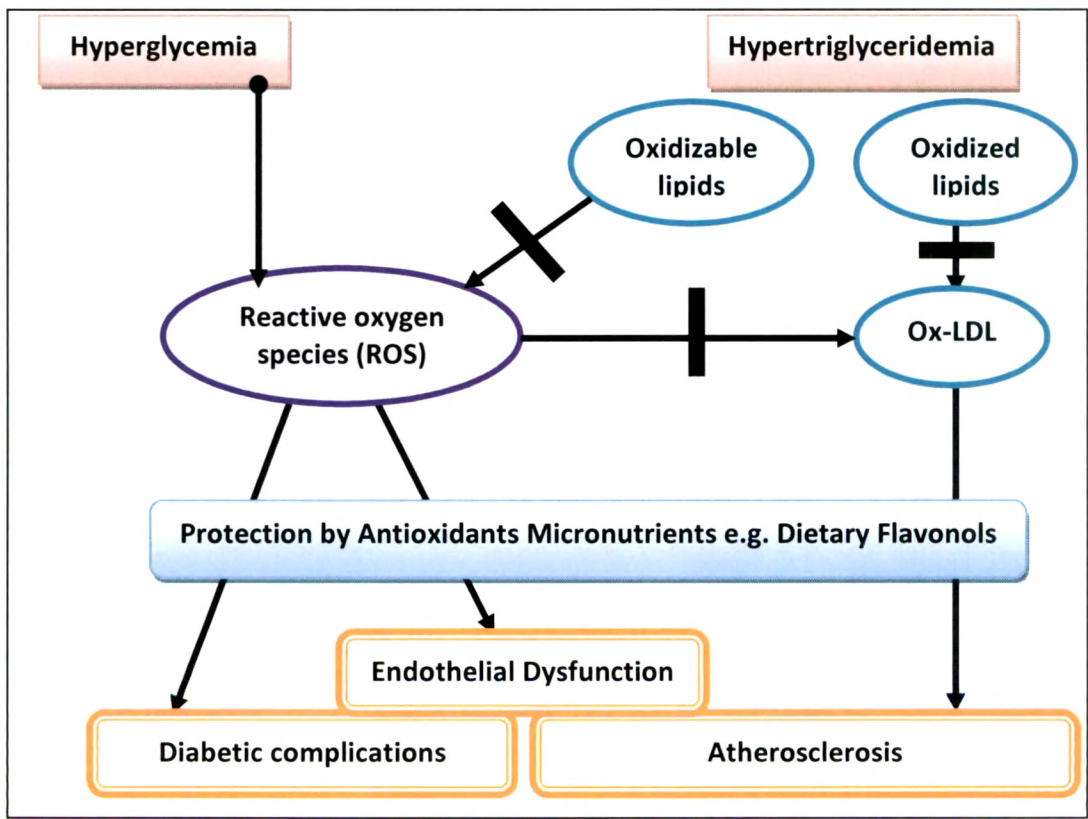
A number of reactions occur in the frying fat when foods are fried, causing oxidative and hydrolytic degradation and polymerization of the fat.

In vitro techniques have shown that hydroperoxides do not inhibit lipase activity, though the reaction of lipid peroxides with enzyme protein may reduce its biological activity (Miyashita K, Tagaki T and Frankel EN, 1990).

Hydrolysis of oils used in frying revealed that significantly reduced level of total hydrolytic products are produced from most degraded oils (Nus M, Sanchez-Muniz J and Sanchez-Montero JM, 2006).

ii) Oxidized fat and heart disease

Postprandial oxidative stress is characterized by an increased susceptibility of the organism toward oxidative damage after consumption of a meal rich in lipids and/or carbohydrates (Figure 2.5.1) (Bowen PE and Borthakur G, 2004).



Source: Tsai WC et al, 2004

Figure 2.5.1: Postprandial oxidative stress and its relation to atherosclerosis and diabetes

Studies have reported that cooking fats that have been repeatedly heated and cooled increase the dietary atherogenic, the forerunner to cardio vascular disease; pathogenic conditions of the digestive tract; mutagenic and genotoxicity, properties that often signal carcinogenesis; and teratogenicity, the property of chemicals that leads to the development of birth defects on those who consume them. Although opinions about the direct effect of ingesting individual fat breakdown products vary, the consensus seems to be that thermal oxidation products formed in fats used over extended time period are potentially harmful (Fenton D and Eyres L, 1984; Grootveld M et al, 2001).

Structural changes in fats and oils increased at high temperature, results in producing thermal oxidation products. Due to repeated frying, thermally oxidized oils contain complex mixtures of products such as oxidized TG (Triglyceride) monomers, TG dimers, and TG polymers. These products are associated for change in physicochemical properties of fats. Consequently, the oil/water interface may vary and the lipolytic activity of the lipase may be altered (Nus M, Sanchez-Muniz J and Sanchez-Montero JM, 2006).

In vivo studies reported as the presence of dimers and polymers increased in oxidized oils, declines its digestibility and part of polymers are eliminated in the feces (Potteau B et al, 1977). True digestibility of non-oxidized TG was greater than that of oligomers. As the number of uses increased polar compounds increased in palmolein thus reducing the digestibility ratio (Gonzalez-Munoz MJ, Bastida S and Sanchez-Muniz FJ, 1998).

Study by Sheehy PJA, Morrissey PA and Flynn A (1994) on chicks fed on thermally-oxidized sunflower oil reported that chronic ingestion of oxidized lipids may contain free-radical-scavenging activity and deplete α -tocopherol in the gastrointestinal tract, plasma and other tissues.

Lipid oxidation products have attracted much attention because of the wide variety of degenerative processes and diseases associated, including

mutagenesis, cell transformation and cancer; atherosclerosis, heart attacks and chronic inflammatory diseases (Figure 2.5.2) (Saguy IS and Dana D, 2002; Dobarganes MC and Marquez-Ruiz G, 2003; Dobarganes MC and Marquez-Ruiz G, 2006; Kanner J, 2007).

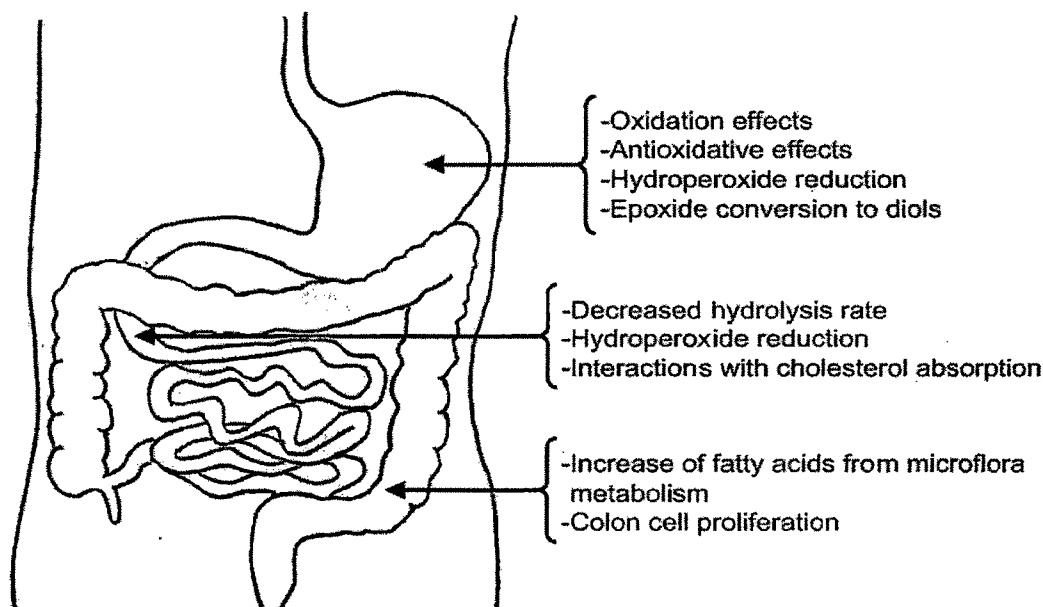


Figure 2.5.2: Main changes and effects reported for dietary oxidized lipids in the gastrointestinal tract

Marquez-Ruiz G, Gracia-Martinez MC and Holgado F (2008) stated that dietary oxidized lipid molecules must be studied before absorption, so as to gain insight into the nature of compounds which are mainly absorbed and available to exert any biological effect in circulatory system and target organs.

2.5.1 Per cent energy from oils in Indian diets

The amount of fat needed by an individual should be able to meet the requirements of essential fatty acids, provide palatability and yet should not produce any adverse effects. It is estimated that about 15-20g of visible fat meets both the requirements of essential fatty acids and 3-6% of the total energy needs. It is recommended, that fat should not exceed than 30%, derived from calories i.e. more than 50 g per day (ICMR, 2002).

The consumption of visible and invisible fats varies in diet of different income group. Diets of high income group (HIG) families have about 10 (en) % of invisible fat provided by cereals, pulses and milk, besides other sources. Visible fat intake is about 16 (en) % which makes it is a total of about 26 (en) %. Invisible fat intake in the middle income group and lower income group is 8 (en) and 6 (en) % respectively while that for the rural population is 8 (en) % (Nigam A, 2000).

Table 2.5.1 shows the composition of some regional meals and it is seen that a south Indian meal has the highest fat content as compared to other regional meals (Nigam A, 2000).

Table 2.5.1: Fat composition of some regional Indian meals

Recipe	Fats (g)
South Indian Meal	28.1
Gujarati Meal	24.5
Bengali Meal	24.8
Punjabi Meal	21.9

Source: Nigam A, 2000

Comparison of past and present diets shows that as the composition of the diet has changed with time, its nutritional quality has deteriorated despite an apparent increase in overall food quantity (Hooper GR, 1999).

Ramachandran P (2008) describes the interstate difference that in most of the states of India, energy intake was higher in rural areas than the urban areas though the differences were not large. In Bihar, Chattisgarh and Assam energy intake was higher among urban population. Energy intake was lower in states like Maharashtra, Tamil Nadu, Karnataka, Gujarat and Madhya Pradesh and higher in Haryana, Punjab, UP and Rajasthan.

In all, states fat consumption was higher in urban areas as compared to rural areas. However, substantial interstate differences were observed in fat intake. Low fat intake in states like Orissa, Chattisgarh and Assam, was observed, which are predominantly rural and have low per capita income; and is higher

in the prosperous urbanized states like Gujarat, Haryana and Punjab. Nutrition education aimed at reducing fat intake and health education aimed at improving physical activity are urgently needed in states with high fat and high energy intake to lessen the prevalence of obesity in different age groups including children and women of urban areas (Ramachandran P, 2008).

Recent study by Misra A et al (2011) reported that change in nutrition over the past 30 years (1973–2004), has resulted in a 7% decrease in energy derived from carbohydrates and a 6% increase in energy derived from fats.

In 1998, Beare-Rogers J et al suggested some improvements to the dietary fat in India possibly be accomplished by:

- ❖ using oils with moderate levels of linoleic acid, such as groundnut, rice bran, or sesame oil;
- ❖ adding an oil or fat with a low level of linoleic acid, such as palm oil, to an oil with a high level of linoleic acid, such as safflower, sunflower, cottonseed, or soya bean oil;
- ❖ using a preferred oil along with mustard oil to increase the *n*-3 fatty acid content and moderate the intake of erucic acid from the mustard oil;
- ❖ combining soya bean oil with palm oil in equal proportions;
- ❖ using oils with minor components, such as antioxidants, which contribute to their nutritional benefits;
- ❖ consuming foods rich in *n*-3 linolenic acid, such as some vegetable oils and green leafy vegetables, and (for non-vegetarians) eating fish.

2.5.2 Fried and takeaway food consumption in India and its association with metabolic disorders

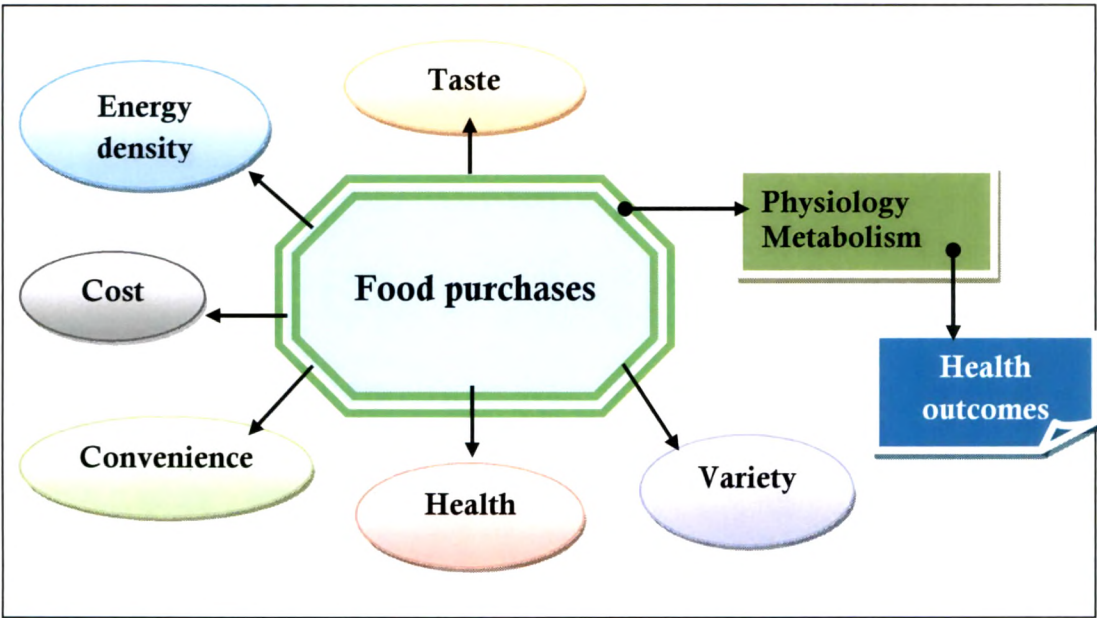
How do people make food choices?

Food choices are made on the basis of taste, cost, and convenience, and, to a lesser extent, health and variety (Glanz K et al, 1998).

Taste refers to the sensory appeal of foods, such as palatability, aroma, and texture. The concepts of taste and energy density are intertwined, because the most energy-dense foods are usually the most palatable and vice versa (Drewnowski A, 1998). Energy density of foods is defined as the energy per unit weight or volume (kcal/100g or mega joules/kg).

Cost refers to the purchase cost/unit of energy (Euros/1000 kcal or dollars/mega joule) or the purchase cost of a daily diet (Euros of dollars/day) (Drewnowski A, 1998).

Convenience refers to the time spent on buying, preparing, and cooking food. Variety refers to the innate drive to secure a varied diet, whereas health refers to concerns with nutrition, chronic disease, and body weight (Drewnowski A, 1998) (Figure 2.5.2.1).



Source: Drewnowski A, 1998

Figure 2.5.2.1: The influences on food purchases: consumer and marketing approach

The fat content of the diet has a clear effect on dietary habits. Fat content influences diet palatability, determines food choices, and appears to have a major influence on food consumption. According to clinical reports, dietary management of plasma lipid disorders is marked by poor adherence to very-

low-fat diets; additionally, “cravings” of dieting women for sweet, fat-rich desserts pose a major obstacle to weight reduction (Drewnowski A, 1990).

Subjects in the Women’s Health Trial reported that using little or no fat to flavor foods was among the most difficult health habits to adopt and sustain (Kristal et al, 1992). Additionally, laboratory studies also suggest that energy-dense foods and energy-dense diets have a lower satiating power and may result in passive overeating and therefore weight gain (Drewnowski A and Darmon N, 2005). Away from home foods and restaurant meals are a potential cause of obesity (McCrory MA et al, 1999; Diliberti N et al, 2004).

Fat is a concentrated source of energy that is reinforcing to the hungry organism. High-fat foods have an undeniable sensory appeal, whether innate or learned. Fat makes a diet flavorful, varied, and rich (Drewnowski A, 1992).

Fried food was noted as one of the sources related to a higher incidence of nutritionally linked cancers, especially of the breast, distal colon, prostate, pancreas, ovaries, and endometrium. It also reported that, in 1999, high fat and fried food consumption and low intake of fibers and vegetables comprised about 35% of all main causes of deaths in the USA (Weisburger JH, 2000).

Oxidized oil may comprise a health hazard as a result of the presence of peroxides, aldehydes, ketones, hydroperoxides, polymers, etc. Vitamin E in body membranes is destroyed by peroxides or subsequent free radical reaction. Similarly, polyunsaturated compounds promote oxidation, lowering the tocopherol level. Moreover, polymers formed during deep fat frying have an adverse effect on digestibility (Paul S, Mittal GS and Chinnan MS, 1997).

Dietary assessment of young NIDDM adults revealed about 50% of the subjects consumed fried foods daily in the form of samosa, kachori, manchurian, tikkis etc (Kochhar A, Agarwal V and Sachdeva R, 2010).

A study on 212 male employees of eastern railway (India) revealed that average frequency (number of days in a week) of egg, fried snacks, and Bengali sweets consumption were 5.93, 5.72, and 5.58 respectively (Ghosh A, Bose K and Chaudhuri ABD, 2003).

In India burden of CVD is great and there is evidence of a large increase in nutrition related- non communicable diseases (NR-NCDs). The absolute number of new diabetic cases in India is larger than in any other country of the world. Together, India and China comprise the majority of new cases of diabetes in the world. India's dietary pattern includes very high dairy and sugar consumption and there are marked increases in energy density of the diet, at both urban and rural levels (Popkin BM, 2002).

Diets high in total fat are associated with excess body weight. Diets for weight reduction should be limited in total calories, with $\leq 30\%$ of total calories as fat to predict a weight loss of 1 to 2 pounds per week (minus 500 to 1000 kcal/d) (Drewnowski A, and Darmon N, 2005).

2.6 FSSAI standards for edible oils

The FSSAI specifications for edible oils are given in Table 2.6. These oils should be expressed from clean and sound seeds. The oils should be clear, free from rancidity, suspended or other foreign matter, separated water, added coloring or flavoring substances, or mineral oil.

Table 2.6: FSSAI specifications for edible oils

Oils	Refractometer reading at 40°C	Saponification value	Iodine value	Polenske value Min.	Free fatty acid Max. %	Bellier test turbidity temperature °C	Unsataponifiable matter Max. %
Coconut oil	34.0-35.5	Min. 250	7.5-10	13.0	3.0	-	-
Cottonseed oil	55.6-60.2	190-198	98-112	-	1.0	-	1.5
Groundnut oil	54.0-57.1	188-196	85-99	-	3.0	39-41	1.0
Mustard oil	58.0-60.5	168-177	96-110	-	3.0	Max. 27.5	1.2
Olive oil	53.0-56.0	185-196	79-90	-	3.0		1.0
Safflower oil	62.0-64.7	186-196	135-146	-	3.0	Max. 16.0	1.0
Sesame oil	58.0-61.0	188-193	105-115	-	3.0	Max. 22.0	1.5
Soybean oil	61.7-69.5	189-195	120-141	-	1.25	-	1.5
Corn oil	56.7-62.5	187-195	103-128	-	1.0	-	1.5
Almond oil	54.0-57.0	186-195	90-109	-	-	Max. 60	3.0

According to FSSAI specifications, refined vegetable oil is a vegetable oil obtained by expression, neutralized with alkali, bleached with absorbent earth and/or activated carbon, and deodorized with steam. No other chemical agent should be used. The name of the vegetable oil from which the oil has been manufactured should be clearly specified on the label of the container. Refined oils should not contain more than 0.25% free fatty acids and 0.10% moisture by weight. The refined oils should have as light color as possible; be odorless; neutral to taste; and should have good keeping quality. Generally, refined oils are free from moisture and enzyme activity. The deterioration in refined oils is either due to rancidity or flavor reversion (VOPO, 1998).

2.7 History of fried foods

Morton ID (1998) stated "How far back in time, frying with oil goes, it is difficult to tell." However, Stier RF (2004) believed that frying is one of the oldest means for preparing food known to man. Frying supposedly had its origins in China, where foods were pre-cooked prior to roasting. Egyptian wall paintings show dough being fried in oil indicating that Europe and North Africa were using hot oil to cook foods before the time of Christ. Even the Bible has references that could be constructed as an early attempt at frying. The history of frying through the ages is shown in Table 2.7.

Table 2.7: Time line for deep-fat-frying

Year	Event
3000 BC	Chinese fry meat as prelude to roasting
1300 BC	Hebrews fry flat breads
1573	Potatoes introduced in Europe
1600-1700	French fried potatoes is created
1853	Potato chip invented in Saratoga Springs, NY by George Crum
1890's	Potato chip industry begins in US
1897	Hydrogenation of edible oils invented
1906	Commercial oil roasting of shelled peanuts by Planters
1908	J. P. Dushesues founds Leominster Potato chip company
1927-30	Cellophane begins to be used for potato chip bags
1929	Clarence Birdseye develops new commercial freezing technologies
1930-1935	National potato chip Institute warns consumers that chips are not fattening if eaten in small amounts
1938	H.W. Lay Company founds Lay's Potato Chip in Atlanta
1950	Under pan fried cookers introduced
1950-52	Fryers with external heat exchangers with oil circulation introduced; Pork rinds introduced
1953	Simplot scientists develop technique for par-frying potato slices
1961	Frito-Lay merger
1969	Potato chip controversy develops with introduction of Pringles and Chippos
1970-1975	7,000 lb. capacity fryers introduced
1973	1 st DGF Symposium-Germany proposes regulations based on oxidized fatty acids for restaurant frying oils
1979	2 nd DGF Symposium-Polar materials has index of restaurant frying oil quality
1987	Blumenthal publishes surfactant theory of frying
2000	3 rd DGF Symposium-Principle quality index should be sensory parameters of food being fried
2004	4 th DFG Symposium

Source: Stier RF (2004)

2.8 Sensory qualities of fried foods

Fats and oils play vital functional and sensory roles in food products. People enjoyed fried foods for thousands of years because of its unique and delicious sensory characteristics. One of the fundamental objectives of frying is to make food more acceptable. Fat is the natural palatable agent *par excellence* (Ghidurus M et al, 2010).

Cooking at high temperatures like frying improves the hygienic quality of the food by inactivation of pathogenic micro organisms; enhances digestibility and bio-availability of nutrient in digestive tract. Besides desirable changes some adverse changes are also involved like loss of heat and oxidation susceptible vitamins and water soluble vitamins (Bognar A, 1998).

Frying in fats brings foods to temperatures above boiling point of water and contributes to the desirable crisp or crunchy textures in fried potatoes or potato chips. Fat makes a diet flavorful, varied, and rich. It is responsible for the characteristic texture, flavor, and aroma of many foods, and largely determines the palatability of the diet. Typically, the first tasting sensation is olfactory perception through the nose or mouth of fat-soluble volatile flavor molecules. Later oral sensations involve the texture and mouth-feel of foods as they change with time, from first bite to complete mastication. Fat-related textures can change from creamy to crunchy or crisp depending on the nature of the food item (Civille GV and Liska IH, 1975).

Cooking end point of fried foods depends on cooking degree of food characterized by the sensory quality attributes namely color, shape, odor and texture. Therefore two points are essential while preparing fried foods:

- formation of attractive and typical surface browning and crust, and of aroma compounds, and
- a certain “inner” cooking degree, reflected by color, taste and texture of the food.

In addition, cooking of the product should reach to optimal degree at the end of frying period with regards to “external appearance and inner cooking degree”.

For deep frying there is only one certain point, i.e. a certain temperature of the heating medium at which both internal cooking and browning are reached at one and the same time. The inner cooking degree can be evaluated by measurement of internal temperature of food and browning can be evaluated visually during cooking; which can be classified in to 5 different classes and judged by sensory panelists by judging the degree of browning (Table 2.8) (Bognar A, 1998).

Table 2.8: Assignment of classes and descriptions when judging degree of browning during frying process

Class	Color degree of the surface
A	no browning
B	partly browning, too thin crust
C	optimal browning, golden brownish, shiny as uniform as possible due to product components
D	partly dark brown, a little bit non uniform, some brown-black parts
E	burnt, too dark brown towards the black-brown color

Source: Bognar A, 1998

The most desirable factors for acceptability of fried snack foods are golden-brown surface color, appearance and crunchy texture. The formation of a crust is helped by the presence of starch, which, if it is a constituent of the food product itself, or is added to the food in the form of bread-crumbs and/or batter, dehydrates and therefore allows a quick formation of the crust (Qualia G, Comendador J and Finotti E, 1998). Fried foods that lack these attributes are usually perceived as being of poor quality and will not appeal to the majority of consumers (Mah E and Brannan RG, 2009).

Frying oils degrade with continuous use. A thorough understanding of oil degradation and the effects of degraded oil on the quality of final products is

important and the quality of a fried product can be evaluated by appearance, taste and the olfaction (Qualia G, Comendador J and Finotti E, 1998). Therefore, the 3rd German Society for fat Research (DGF) recommended in 2000 symposium that sensory evaluation should be the primary determinant of quality in frying research (DGF, 2000).

2.9 Chemical changes in oil occurring during frying

Frying is a process of immersing food in hot oil with a contact among oil, air, and food at a high temperature of 160°C to 180°C. The simultaneous heat and mass transfer of oil, food, and air during deep-fat frying produces the desirable and unique quality of fried foods. Frying oil acts as a heat transfer medium and contributes to the texture and flavor of fried food and prevents sticking of food materials on to the hot surface (Choe E and Min DB, 2007; Sabhiki L and Tiwari BD, 1999).

2.9.1 Morphology of Deep-fat-frying

Deep fat frying is considered to be a moving boundary problem, where a previously nonexistent crust region develops on the food surface and increases in thickness inward during frying while the core region decreases with frying time.

According to Farkas BE, Singh RP, Rumsey TR (1996) and Blumenthal MM (1991) frying can be broken down into four stages:

2.9.1.1 Moisture transfer

The first stage, initial heating, is the period of time during which the surface of the product is heated from its initial temperature to the boiling point of water; this phase is usually short and a negligible amount of water is lost from the food. In this stage heat transfer takes place from the frying medium to the food surface, as soon as the food is immersed in the hot oil. As a result, water from outer surface of the food vaporizes and escapes into the

surrounding frying medium. This surface dehydration then forces the water in the interior of the food to move to the outer surface (Blumenthal MM, 1991).

At the food surface, the diffusing water absorbs the latent heat of vaporization from the closest layer of the oil that surrounds the food to form steam. The temperature of the food is only about 100°C, even when the temperature of the frying oil is about 180°C. Moreover, the steam formation at the surface of the food prevents the oil from getting into the interior. So, the food does not burn or char at this stage (Blumenthal MM, 1991; Farinu A and Baik OD, 2005). This suggests that the temperature of the frying oil plays only a smaller role in the thermal damage happening to food materials with high moisture content.

As the interior of the food gradually heats up, some of the lipids present in the food melt and flow out into the oil (Blumenthal MM, 1991). Small quantities of liquefied food materials also flow out of the food into the oil. These flows are collectively called leaching.

2.9.1.2 Fat/oil transfer

The next phase in the process of frying is the oil transfer. Once the diffused water escapes into the oil through the capillaries, the hot oil starts entering into the same open pores and capillaries. The rate of entry of oil into the food is a function of the viscosity and the surface tension of the oil (Blumenthal MM, 1991).

Varela G (1988) reported that the fat penetration starts only after about 60% of the moisture content evaporated in potatoes fried in olive oil. Thus, hot oil acts on the interior of the food material only for a short time, and actual time of contact of oil with the food surface is only about 10% of the total food immersion time, when the frying is done with the fresh oil (Blumenthal MM, 1991).

The amount of oil uptake is directly proportional to the amount of moisture loss. Oil adheres to the food and enters the voids left by moisture that had evaporated. The rate of oil uptake in a deep-fat fried food is initially rapid, but then slows down and approaches a linear relationship with time.

Ni H and Datla AK (1999) showed high initial transfer rate is due to the large difference of oil concentration in the surrounding oil and the initial oil concentration in the food. However, higher initial moisture content in some products (e.g., doughnuts), results in lower fat uptake probably because porosity and initial moisture content are inversely related for a doughnut batter since a batter of higher moisture content has lower leavening acid concentration, which results in less volume expansion (pore formation) and consequently, lower fat uptake during frying (Wheeler FG and Stingley DV, 1963).

Study on high fat content foods revealed that both fat absorption and fat desorption processes occur during frying. In frying beef meatballs, it was reported that fat absorption changed to fat desorption after 60 seconds of frying and at a product temperature of 45.5°C (Ateba P and Mittal GS, 1994).

2.9.1.3 Surface and crust formation

The outer zone of the fried food consists of the crust. The surface, which contributes to the initial visual impact, generally has an even, golden brown color resulting from browning or Maillard reaction.

The content of reducing sugars is related to the final color of the fried product, *i.e.* the higher content of sugars, the darker tone is expected in potato products such as french fries, potato chips and others. Moreover, potatoes high in sugar taste sweet and have a poor/soft texture after cooking. This poor texture may probably be related to the low starch levels associated with the high sugar content. Starch provides the most important contribution to the texture of processed potatoes (Miranda ML and Aguilera JM, 2006).

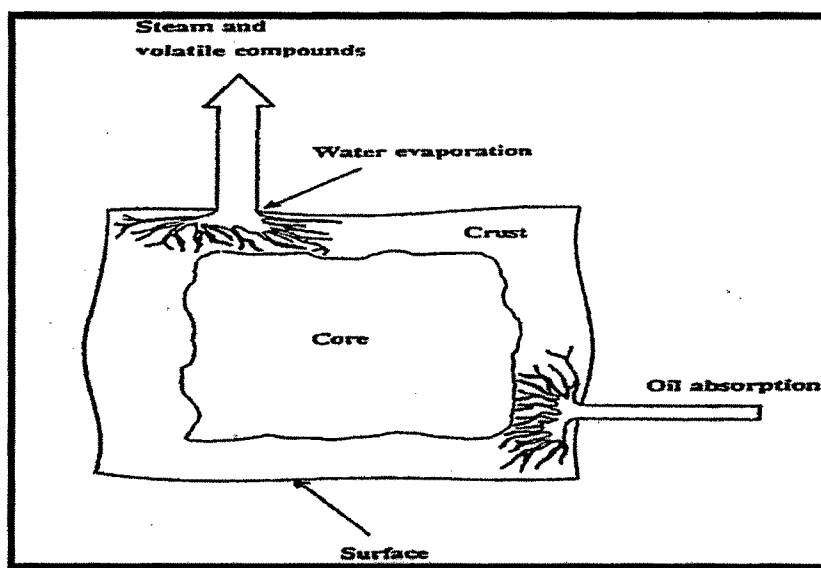
The duration and the temperature of frying, in combination with the chemical composition of the food, that influence the degree of browning, rather than the type of frying oil used (Stevenson SG, Vaisey-Genser M and Eskin NAM, 1984).

The crust formation, which is one of the most palatable characteristics of the fried food, was greatly influenced by fat penetration kinetics (Varela G, 1988). The heat from the frying medium drove the cellular or capillary water out from the food material. Guillaumin R (1988) described that leaching out of this water/dehydration cause this crust formation with numerous cavities, pores, and larger surface. The frying medium then started diffusing into the capillaries and pores in the crust. The phenomenon of crust formation can be observed for about 3 to 6 min. The majority of the oil absorbed was located in the crust and the outer zone of the fried product. The moisture content of the crust was about 2 to 3% and the oil content was 8 to 10% for french fried potatoes.

When a product is removed from the fryer, the viscosity of the oil at its surface increases due to a fall in temperature which makes oil difficult to drip off the product's surface and the bulk of the oil moves into the crust due to capillary and gravity formed as result of moisture loss. Keller C et al (1988) studied oil intrusion into fried potatoes using an oil soluble dye and found that oil penetrated no further than the surface crust layer.

2.9.1.4 Cooking of the interior

In the final phase of cooking, the moist inner zone or the core gets cooked. The core may not be observed in thin products like potato chips, due to the overlapping of crusts from both sides. The cooking of the core is mainly due to the heat penetration rather than the oil penetration or absorption (Stevenson SG, Vaisey-Genser M and Eskin NAM, 1984). Figure 2.9.1.4 shows the cross section structure of a typical fried food.



Source: Paul S, Mittal GS and Chinnan MS, 1997

Figure 2.9.1.4: Structure of the cross section of a typical fried food

2.9.2 Factors affecting oil penetration and absorption by the food

Foods high in initial fat content do not absorb oil during frying in fact; food fat is leached out into the oil. The important factors affecting oil penetration into the food products are described by Guillaumin R in 1988, as follows:

2.9.2.1 The geometrical shape of the food products

The geometrical shape, that is, the ratio of surface area of the product to its volume plays an important role in the oil penetration. For example, the French fried potato contained only 13.5% oil on an average, whereas the fried potato chip contained about 40% oil, because the surface area of potato chip was 10 to 15 times greater than that of the french fried potato for the same volume (Guillauman R, 1988).

Goni I et al (1997) reported thickness of chips is an important factor affecting the overall fat content of hot chips. Cracks and rough surfaces increase the surface area and thus increase the fat absorption. Thick-cut chips (12 mm or bigger) absorb less fat than thin cut chips. The fat content in chips decreased

with increasing cross-section at area of potato sticks, and fat is restricted to the surface of the sticks (Keller C et al, 1990).

2.9.2.2 Viscosity of the frying oil

Viscosity of the frying oil is an important factor determining the total volume of oil sticking to the large cavities in the crust of the food product. Higher viscosity provided a larger volume of oil on the fried food. Potatoes absorbed about 8.5% of oil when fried in fresh oil, and it increased to 15% in degraded oil due to increase in viscosity (Guillaumin R, 1988).

Study by Yamsaengsung R and Moreira RG (2002) reported higher cooling temperature results in low oil viscosity and thus low adhesion between oil and product and more of the oil runs off the surface of the product.

Frying of potato chips in soybean oil and partially hydrogenated vegetable oil for 80 h intermittently showed an increase in periodic in viscosity, influenced by frying temperature rather than frying medium (Tyagi VK and Vasishttha AK, 1996).

2.9.2.3 Specific gravity of the food

Generally, the oil absorption decreases as the specific gravity of the food increases. An increase in specific gravity of the food generally means an increase in the moisture content. Higher moisture content produces larger quantity of steam, which reduces the oil-to-food contact time (Guillauman R, 1988).

In a study by Tyagi VK and Vasishttha AK, 1996 reported *vanaspati* (partially hydrogenated vegetable oil) used for frying potato chips intermittently for 80 h had lowest specific gravity as compared to soybean oil with different levels of antioxidants, irrespective of frying temperature and duration of frying.

2.9.2.4 Type of food

Fedeli E in 1998 reported that foods are not pure chemical products; they are a mixture of chemical components classified as lipids, proteins, sugars (starch) and minor components ascribable to various chemical classes. Variability of the components of each class gives rise to many alternatives that are important for frying process. For instance lipids vary in saturation, physical characters, and chemical behavior which may act as a solubilizer of many minor components. Proteins vary in the physical and chemical characters because of their constituents amino acids; they show free reacting groups which are present in food originally or batter created during the cooking process. Starch has high degree of active centers, usually OH, CH and NH. Thus their physical and chemical characteristics vary strongly as a function of the polymerization degree that varies also during the cooking operations.

The textural properties, porosity, size, and orientation of capillary spaces, etc. are differ from one food to another. This makes the oil penetration characteristically different from food to food (Guillauman R, 1988).

Absorption of nonglyceride components such as nutraceuticals/antioxidants or other related phytochemicals also may have a selective distribution between oil and the batter coated products during deep frying, more so when the product has many other components such as starch, carbohydrates, and protein (Nasirullah and Rangaswamy BL, 2005). In study, oil absorption can be reduced by coating of whey protein isolate as a post breading dip in deep fried battered and breaded chicken patties (Mah E and Brannan RG, 2009).

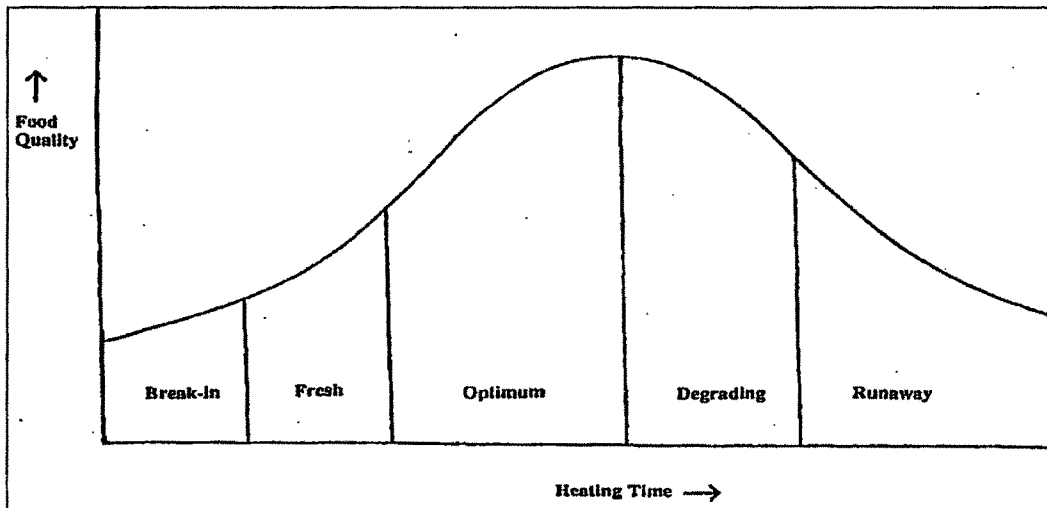
2.9.2.5 Temperature of the frying medium

Varela G (1988) established that the frying oil temperature in a range of 150 to 180°C has no significant effect on oil absorption by foods. Oil absorption decreases with a higher frying oil temperature of 180 to 200°C. However, this temperature range is not usually accepted in frying operations.

Yamsaengsung R and Moreira RG (2002) reported that the temperature, at which food is cooled after frying, has the largest effect on oil absorption and higher cooling temperatures lead to lower oil absorption, known as cooling temperature.

2.9.2.6 Time of frying

The oil absorption by the food increases with longer durations of frying. Frying oil quality curve shows the quality of the fried potato as a function of frying oil stages, as the frying operation proceeds. Frying oil quality curve is described by Blumenthal MM in 1991 is shown in Figure 2.9.2.6.



Source: Blumenthal MM, 1991

Figure 2.9.2.6: Frying oil quality curve showing the five phases that frying oil passes through during the degradation process

The changes occurring in food quality with the advancement of heating of oil are described as follows:

1. **Break-in oil-** White-colored product; raw, ungelatinized starch at the center of the fry; no cooked odor; no crisping of the surface; and little oil absorbed by the food.

2. **Fresh oil-** Slight browning at the edges of the fry; partially cooked (gelatinized) centers; crisping of the surface; and slightly more oil absorption.
3. **Optimum oil-** Golden-brown color; crisp, rigid surfaces; delicious potato and oil odors; fully cooked centers (rigid, ringing gel); and optimal oil absorption.
4. **Degrading oil-** Darkened and/or spotty surfaces; excess oil pickup; product moving toward limpness; and case-hardened surfaces.
5. **Runaway oil-** Dark, case-hardened surfaces; excessively oily product; surfaces collapsing inward; centers not fully cooked; and off-odor and flavors (burned).

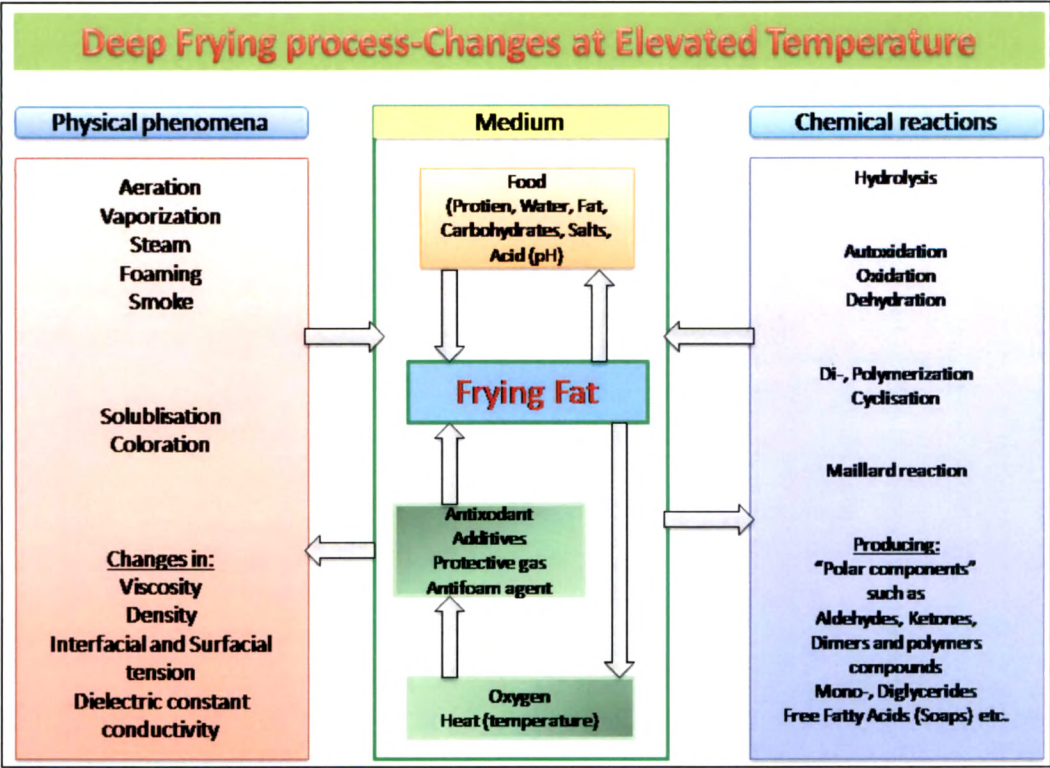
2.9.3 Chemistry of deep-fat- frying/fat degradation

Frying is the combination of prolonged heating and high temperature in the presence of moisture and oxygen causes an interrelated series of reactions takes place (Figure 2.9.3.1) and the physical and chemical changes taking place shown in Table 2.9.3.1.

Table 2.9.3.1: Effects of physical and chemical reactions during deep fat frying

Physical changes:
Increased viscosity, color and foaming
Decreased smoke-point
Chemical changes:
Increased free fatty acids, carbonyl compounds and high molecular weight products, decreased unsaturation, flavor quality and nutritive value (e.g. from essential fatty acids)

Source: Podmore J, 2002

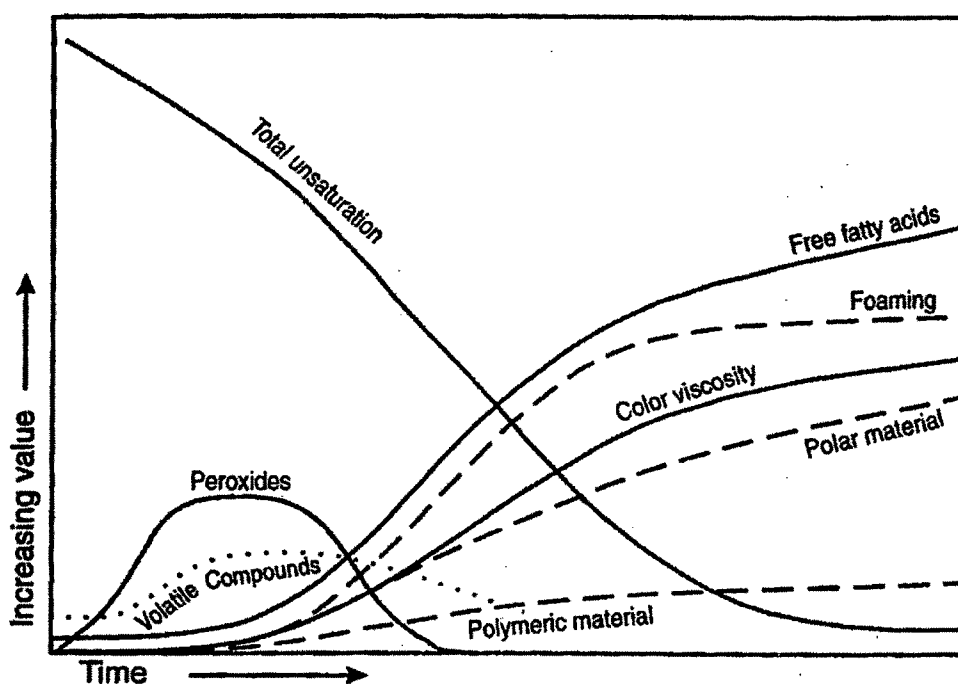


Source: Gertz C, 2000

Figure 2.9.3.1: Scheme of the influence of the deep-frying process

During frying hundreds of complex chemical reactions takes place in the oil and it gets chemically altered during frying. More than 400 different chemical compounds have been identified in deteriorated frying oils. The products of degradation can generally be divided into two main groups, namely, volatile and non-volatile products (Figure 2.9.3.2).

A portion of the volatile products escapes into the atmosphere with steam, while the rest remains in the oil and may undergo further alterations or get consumed by the fried food. Some of the volatile compounds contribute to the flavor of the fried food products. The degradation products can be detrimental to the oil and food as well as making the flavor more attractive (Choe E and Min DB, 2007; Paul S, Mittal GS, and Chinnan MS, 1997).



Source: Choe E and Min DB, 2007

Figure 2.9.3.2: Changes in volatile and nonvolatile decomposition products during the frying process

The non-volatile degradation products are shown in Table 2.9.3.2 which remains in the oil, promoting further degradation. They are responsible for the changes in the physical properties and the various analytical indices of the oil (White PJ, 1991).

Table 2.9.3.2: Volatile and nonvolatile degradation products from frying oil

Nonvolatile products	Volatile products
Monoglycerols	Hydrocarbons
Diglycerols	Ketones
Oxidised triacylglycerols	Aldehydes
Triacylglycerol dimers	Alcohols
Triacylglycerol trimers	Esters
Triacylglycerol polymers	Lactones
Free fatty acids	

Source: Lawson H, 1997

2.9.3.1 Changes during frying oil degradation

The thermal degradation of frying oil is complex, with many variables shown in Table 2.9.3.1.

Table 2.9.3.1: Factors affecting oil degradation

Oil or food factors:
❖ Unsaturation of fatty acids
❖ Type of oil
❖ Type of food
❖ Metal in oil or food
❖ Initial oil quality
❖ Degradation products in oil
❖ Antioxidants
❖ Antifoaming agents
Process factors:
❖ Oil temperature
❖ Frying time
❖ Aeration or oxygen absorption
❖ Frying equipment
❖ Continuous or intermittent heating or frying
❖ Frying rate
❖ Heat transfer
❖ Turnover rate ^a ; addition of makeup oil
❖ Filtering of oil or frying vessel/fryer cleaning

^a Turnover is the ratio of the volumetric capacity of the fryer to the rate at which fresh frying oil is added to replenish the fryer

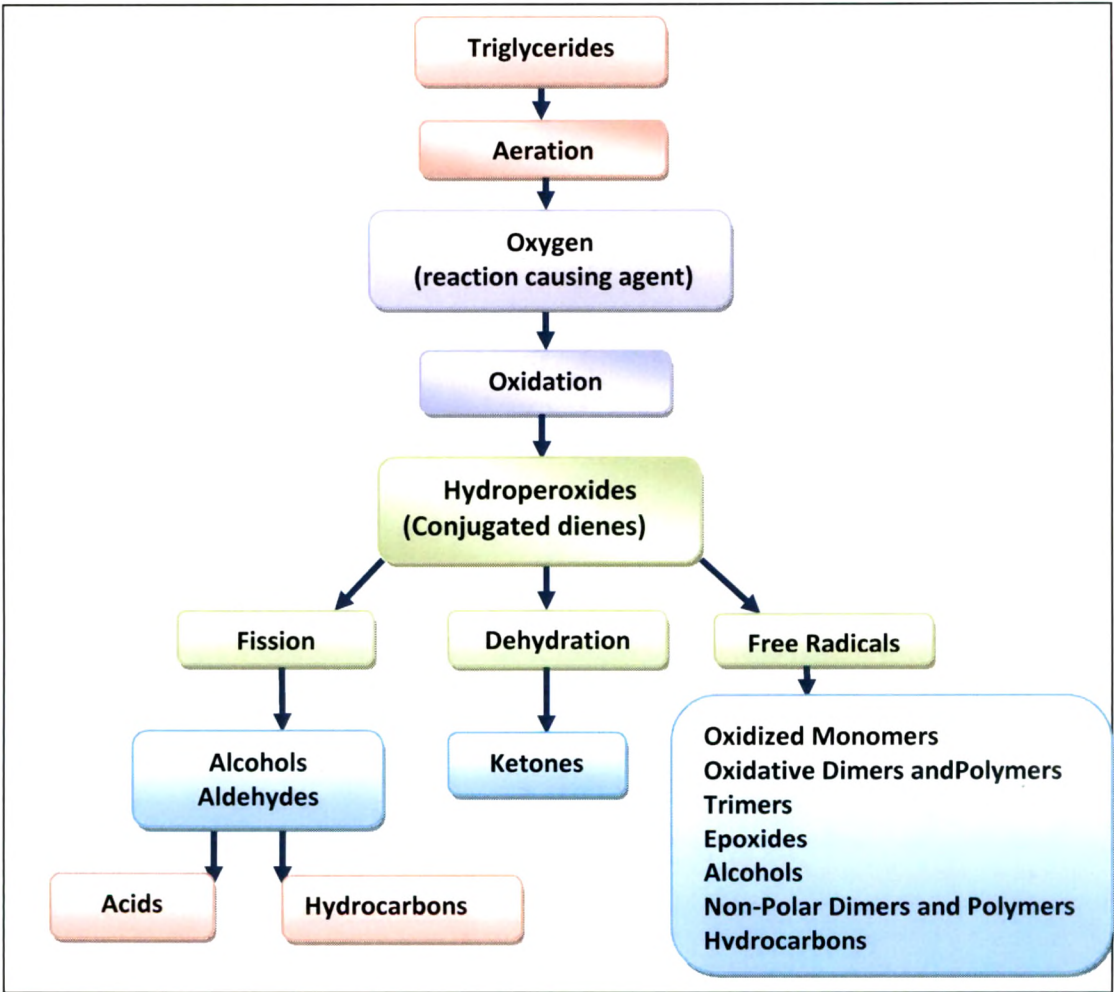
Source: Podmore J, 2002

Above given factors affect oil by: **hydrolytic alteration caused by moisture, oxidative alteration caused by oxygen, and thermal alteration caused by heat** (White PJ, 1991). These all contribute to the breakdown of fats. During frying there is an increase in saturation of fatty acids, breakdown products are formed and there are texture, color and flavor changes. Other changes include, an exchange of substances between the food and the fat with the food absorbing fat and breakdown products, proteins, and other substances released into the fat.

2.9.3.1.1 Oxidation

Oil oxidation is inevitable it involves release of moisture, elevated temperature and exposure of oil to atmospheric oxygen during frying favor oxidation of the frying medium. Figure 2.9.3.1.1 shows a schematic diagram of oxidative alterations. Oxidation may be auto oxidation or thermal oxidation.

- i) **Auto oxidation:** The reaction of the atmospheric oxygen with fat molecules at room temperature is known as auto oxidation.
- ii) **Thermal oxidation:** The process taking place when oil is heated at high temperature in presence of oxygen is termed as thermal oxidation.



Source: Paul S, Mittal GS and Chinnan MS, 1997

Figure 2.9.3.1.1: An overview of fat aging

Oxidation can be described as comprising three sub-processes, which produce a variety of decomposition compounds known as: **primary, secondary and tertiary oxidation**.

Primary oxidation caused by the reaction of oxygen with oil at high temperatures, leading to formation of hydroperoxides bound to a double bond of an unsaturated fatty acid. The first degradation is the '*fission*', which produces smaller molecules which cross-link together to form monomers and dimers (alcohols, aldehydes, acids, and hydrocarbons). High temperature accelerates oxidation. **Peroxide value** is a simple common test to determine the quality of fresh oil, but quite insignificant for frying processes, since peroxides are volatile at high temperatures. Peroxide value indicates oxidation reactions occurring after frying and characterizes the sampling rather than the oil quality during the process (Dana D and Saguy S, 2001).

Secondary oxidation, fission of hydroperoxides at high temperatures leads to the second degradation known as '*dehydration*'. This forms secondary oxidation products like alcohols, carbonyls and acids. Unsaturated aldehydes can undergo auto oxidation giving rise to dialdehydes such as malondialdehyde (MDA). A common method for measuring aldehyde concentration is the **p-anisidine value**, which enables colorimetric determination of aldehyde concentration. It also provides a criterion that could be correlated with the organoleptic quality of the fried product (Kock Wai TN, 2007). Decomposition of fatty acids from triglycerides results in the formation of small and large molecules. Small molecules are generally volatile and large are generally non-volatile decomposition products. Volatile decomposition products are responsible for the unique and characteristic taste of fried products (Dana D and Saguy S, 2001).

Tertiary oxidation also known as third degradation or '*free radical formation*', which produces oxidized monomers, oxidative dimers and polymers, trimers, epoxides, alcohols, hydrocarbons, non-polar dimers, and polymers

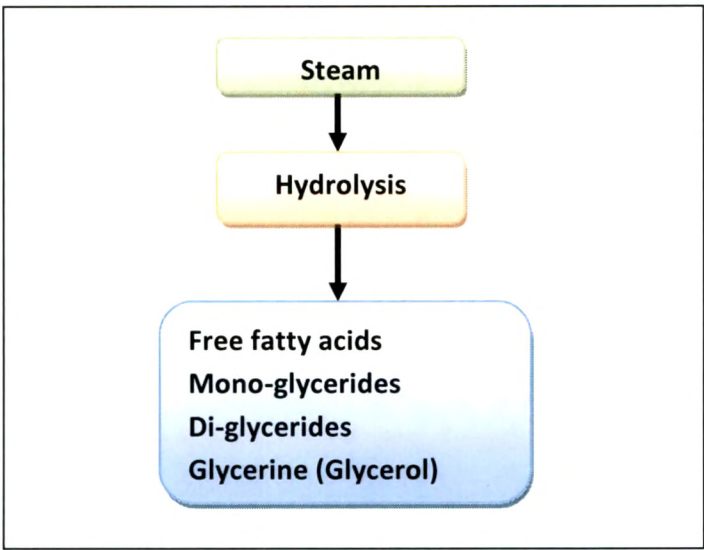
which are harmful to human health (Stevenson SG, Vaisey-Genser M and Eskin NAM, 1984). This process increases oil viscosity, the color turns darker and brown layers appear on the surface. Most of the decomposition products are formed by the free radical chain reactions. The rate of these reactions increases with higher concentrations of oxygen and free radicals (Gere A, 1983). Polymerization is **abundant mainly in oils rich in free unsaturated fatty acids, such as soybean oil** (Dana D and Saguy IS, 2001).

Blumenthal MM (1991) reported the basic theory of frying that materials which affect the heat transfer at the oil-food interface act to reduce the surface tension between the two immiscible materials and are referred as surfactants. Only a small amount of oxygen is introduced into the oil at low concentrations of surfactants. As the interfacial tension is high at low concentrations of surfactants, the steam bubbles readily break and form a blanket of steam over the oil surface, reducing the contact of atmospheric oxygen with the oil. At moderate surfactant concentrations, oxygenation forms a number of chemicals. They include oxidized fatty acids, which produce good heat transfer properties in the oil and desirable volatile compounds. However, at high concentrations of surfactant materials, oil degradation dynamics and kinetics are forced to form short-chain fatty acids because of the high availability of oxygen. Flammable ketones and ethers are formed at this stage.

As oil degrades the specific gravity increases, heat capacity, and surface tension decrease and contact time between the oil and the food increases causing changes in heat transfer. Volatile and non-volatile decomposition products are formed, free fatty acid content increases, iodine value decreases, fat darkens, strong flavors develop, the smoke point is lowered and there is increased foaming and viscosity (Saguy IS and Pinthus EJ, 1995; Blumenthal MM, 1991). It is suggested that potentially harmful compounds may be formed in the food (Whero F and Birch J, 1997).

2.9.3.1.2 *Hydrolysis*

De-esterification reaction leads to cleavage of bonds between glycerol and fatty acids. When food is fried in heated oil, the moisture forms steam, which evaporates with bubbling action and gradually subsides as the food are fried. Water, steam, and oxygen initiate the chemical reactions in the frying oil and food. Water, a weak nucleophile, attacks the ester linkage of triacylglycerols, and produces di- and monoacylglycerols, glycerol, and free fatty acids. Free fatty acids contents in frying oil increases with the number of frying (Figure 2.9.3.1.2). Thermal hydrolysis takes place mainly within the oil phase rather than water-oil interface (Lascaray L, 1949). Hydrolysis is more preferable in oil with short and unsaturated fatty acids than oil with long and saturated fatty acids because short and unsaturated fatty acids are more soluble in water than long and saturated fatty acids. Water from foods is easily accessible to short-chain fats and oils for hydrolysis (Nawar WW, 1969).



Source: Paul S, Mittal GS and Chinnan MS, 1997

Figure 2.9.3.1.2: Schematic diagram of hydrolysis

Large amount of water hydrolyze the oil rapidly than steam. Large contact between the oil and the aqueous phase of food increases hydrolysis of oil. The amount of free fatty acids formed is directly proportional to the amount of

steam released by the food into the fat (Lawson H, 1997; Dana D, Blumenthal MM and Saguy IS, 2003).

In a study by Houhoula DP, Oreopoulou V and Tzia C (2002) reported that mono- and diacylglycerols in cottonseed oil during frying of potato chips at 155°C to 195°C increased initially and then reached a plateau. Further, study by Romero A, Cuesta C and Sanchez-Muniz FJ (1998) revealed frequent replacement of frying oil with fresh oil slows down the hydrolysis of frying oil.

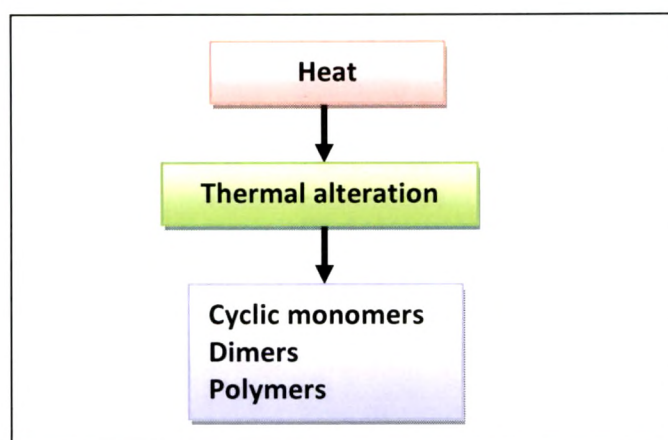
Frega N, Mozzon M and Lecker G (1999) reported that free fatty acids and their oxidized compounds produce off-flavor and make the oil less acceptable for deep-fat-frying. Di- and monoacylglycerols, glycerol, and free fatty acids accelerate the further hydrolysis reaction of oil. Glycerol evaporates at 150°C and the remaining glycerol in oil promotes the production of free fatty acids by hydrolysis (Naz S et al, 2005).

Determination of free fatty acids (FFA or acid value) concentration is often used as a criterion for oil quality during frying and some countries are implementing it as an upper measure for oil acceptability for frying. Japan Ministry of Health and Welfare recommended 2.5mg/g acid value as the upper limit in frying oil.

2.9.3.1.3 *Polymerization*

At elevated temperatures, when the oxygen supply is rather limited, the main reactions lead to polymerization rather than oxidation (Figure 2.9.3.1.3). Due to oxidation and thermal alteration, products undergo polymerization forming gums and resins. Polymerization results in brown residues near the heating elements. Polymers formed in deep-fat frying are rich in oxygen. Thermal changes lead to the formation of cyclic monomers, dimers and polymers in a non-radical mechanism. Dimers and polymers are large molecules with a molecular weight range of 692 to 1600 daltons. Polymerized triglyceride formation is proportional to the temperature, frying time and less

dependent on fatty acid composition. Saturated fatty acids are more stable than unsaturated counterparts but at temperatures over 150°C they decompose to carboxylic acids and a large variety of aldehydes, ketones, and other carbons (Gertz C, Klostermann S and Kochhar SP, 2000).



Source: Paul S, Mittal GS and Chinnan MS, 1997

Figure 2.9.3.1.3: Schematic diagram of thermal alterations

The linoleic acid (polyunsaturated) present in fat is conjugated by heat. It may then cyclise within itself or another molecule containing a double bond to form a six member cyclic compound. The double bond of cyclohexane ring reacts with conjugated linoleate to form a trimer (Diels O and Alder K, 1928).

Formation of polymers during frying in oil bring some changes like increase in viscosity, density, development of dark color, decrease in iodine value and surface tension and an increased foaming tendency of oil (White PJ, 1991).

2.9.3.2: Interrelation of Hydrolytic, Oxidative and Thermal alterations

The hydrolytic, oxidative, and thermal alterations are interrelated as well as superimposed. For an instance, both oxidative, non-oxidative dimers and polymers are formed at high temperature of frying. Both hydrolysis and oxidation of double bonds result in free fatty acids formation in the frying oil. Furthermore, volatile compounds such as ketones, aldehydes, alcohols etc. resulting from oxidation are volatilized and liberated into the atmosphere by

steam that is responsible for the hydrolysis. As a result of oxidative and thermal alterations polymers are formed and cause foaming, consequently the steam bubbles are trapped longer in the oil to accelerate hydrolysis. Formation of steam plays an important role in reducing oxidative alterations by forming a blanket over the oil surface (Blumenthal MM, 1991).

Nawar WW (2000) reported that food can leach fat during frying, resulting in different mixture stability compared to the original frying oil. The presence of food crumbs and batter residues contributes to color changes.

2.9.3.3 Polar and non-polar fractions of deteriorated oil

The non-polar fraction mainly consists of all the unaltered triglycerides. Very small amounts of trimers and non-polar dimers also contribute to this fraction (Lumely ID, 1988).

Polar fractions are collectively known as all the degradation products other than non-polar fraction. They are also called '**total polar materials**' or '**total polar artifacts**'. All the polar materials refer to polar material present in oil, as well as those due to contamination from food materials. Leaching of fat from meat products and other present compounds in oil are also responsible for degradation of frying oil together with formation of polar materials (Paul S, Mittal GS and Chinnan MS, 1997).

In terms polar compounds quality of used frying fats and oils was studied by Dobarganes MC and Marquez-Ruiz G (1998) from three different frying sectors: domestic use, restaurants and fried-food outlets and industrial frying. The finding of the study is shown in Table 2.9.3.3.1.

Table 2.9.3.3.1: Polar compounds (PC) in used frying fats from different sources

	Discontinuous Fryers		Continuous fryers
	Domestic use	Restaurants and fried food outlets	
Number of samples	72	190	82
Polar compound range (wt %)	10.5-42.1	3.1-61.4	4.2-27.3
Number of samples with PC >25%	24	69	3

Source: Dobarganes MC and Marquez-Ruiz G, 1998

Paul S, Mittal GS and Chinnan MS (1997) classified polar fraction according to their molecular weights and relative polarities into polymers and decomposition products listed in Table 2.9.3.3.2. **Polymers** refer to the group of all the degradation products with molecular weight higher than that of triglycerides. **Decomposition products** refer to the group of all the degradation products with molecular weights less than that of triglycerides.

Table 2.9.3.3.2: Classification of degradation products

Major fractions of chemical degradation	Components forming the Fractions
Polymers (low polarity)	Highly polymerized materials Trimers Dimers
Triglycerides (neutral)	Triglycerides
Decomposition products (high polarity)	Diglycerides Monoglycerides Free fatty acids Cyclic monomers Non-cyclic monomers Volatile compounds

Source: Paul S, Mittal GS and Chinnan MS, 1997

2.9.3.4 Trans isomers

Edible fats and oils vary in their triglyceride makeup, relative degree and forms of unsaturation (*cis* and *trans*), weight-average molecular weight, and overall fatty acid composition/distribution, and these complex determinants define the physico-chemical properties of the lipid system. For stability and functionality reasons, oils are often hydrogenated and converted into fats, this increase the concentration of *trans* isomers (Voort ven de FR, Sedman J and Ismail AA, 1997).

Chemically, *trans* fat refers to a lipid molecule, that contains one or more double bonds in *trans* configuration. A double bond may exhibit one of two possible configurations; *trans* or *cis*. In *trans* configuration, the carbon chain extends from opposite sides of the double bonds, rendering a straighter molecule, whereas in *cis* configuration, the carbon chain extends from the side of the double bond, rendering a bent molecule (Mudgil D, Barak S and Khatkar BS, 2010).

Fatty acids found in foods can be saturated (no double bonds), monounsaturated (one double bond) or polyunsaturated (more than one double bond). The double bonds provide rigidity to the molecule and result in specific molecular configurations. Naturally occurring fatty acids in foods usually have the *cis* configuration, i.e. the hydrogen atoms with respect to the double bond are on the same side of the molecule (Figure 2.9.3.4).

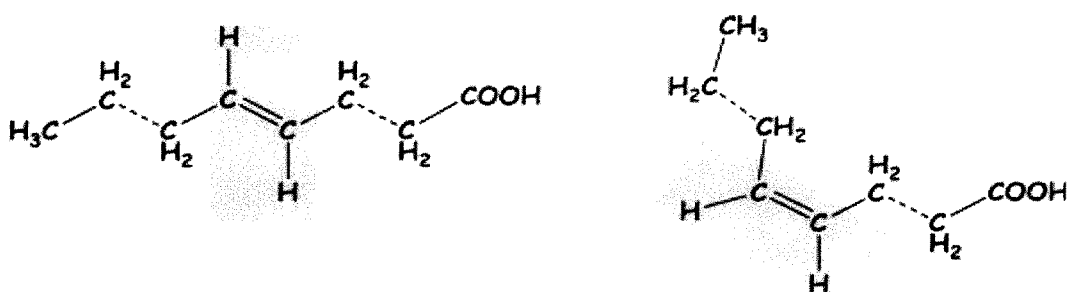


Figure 2.9.3.4: *Trans* (left) and *cis* (right) geometrical configuration

Two double bonds may be “methylene interrupted” (MI) meaning separated by a methylene (-CH₂-) group, or “non-methylene interrupted” (NMI), i.e. separated by several methylene groups, or “conjugated”, means separated by only a single carbon-carbon bond. Among fatty acids with conjugated bonds, conjugated isomers of linoleic acid called conjugated linoleic acids (CLA). Theoretically, these could include 14 positional isomers from Δ 2,4- to Δ 15,17-18:2, and each having either a *c,c*, *c,t*, *t,c*, or *t,t* configuration, for a total of 56 isomers (Ledoux M, Juaneda P and Sebedio JL, 2007).

The consumption of deep-fried foods, hydrogenated fats and baked food items are major sources of *trans* fats. In developed countries like Europe and North America, average population *trans* fatty acid (TFA) consumption has varied between 2 and 4% energy (%E), or between 5 and 10g/day in an average 2000 kcal/day diet. Estimation by food frequency questionnaires of average per capita TFA intake in North America was 3-4g/day. However, TFA concentration in human milk was 10g/day. In Australia, per capita estimates ranged from 3 to 8g/day. However, population consumption estimates in traditional diets of Asian countries was much low, 0.6g/day in Korea and 0.1-0.3g/day in Japan (Craig-Schmidt MC, 2006).

In Western European countries, mean per capita TFA intake in men was lowest in Greece, Italy, Portugal, and Spain (1.2-2.1 g/day); intermediated in Finland, Germany, France, the United Kingdom, Denmark, and Sweden (2.4-3g/day) and in Belgium, Norway, and the Netherlands (4.4-4.8g/day); and highest in Iceland (6.7g/day) (Hulshof KF et al, 1999; van Poppel G, 1998).

Studies on TFA consumption in developing countries revealed that use of partially hydrogenated vegetable oil (PHVO) in Iran was extensive for household cooking in rural and less educated regions (overall average TFA intake was 12.4g/day; ~4.2%E). Similarly in India, PHVO use for cooking in form of *vanaspati* is popular in various regions (Mozaffarian D et al, 2007; Ghafoorunssia G, 2008).

Review by Teegala SM, Willet WC and Mozaffarian D (2009) compiled TFA consumption effects on numerous adverse risk factors responsible for chronic disease, systemic inflammation, endothelial dysfunction insulin resistance and adiposity shown in Table 2.9.3.4.

Table 2.9.3.4: Adverse effects of dietary trans fatty acids on risk factors for chronic disease

Risk factor	Evidence for effects of dietary trans fat
Inflammation	Increased tumor necrosis factor activity, interleukin-6, C-reactive protein
Endothelial dysfunction	Increased plasma E selection, soluble intercellular adhesion molecule-1, soluble vascular cell adhesion molecule-1 Decreased brachial artery flow mediated dilation
Blood lipids and lipoproteins	Increased total/HDL-cholesterol ratio, total cholesterol, LDL-cholesterol, apolipoprotein B, triglycerides, lipoprotein (a) Decreased HDL-cholesterol, ApoA1, LDL particle size
Insulin resistance and diabetes	Increased insulin resistance in animal experiments No significant effects on glucose-insulin markers in short-term trials among lean, healthy individuals Association with incident (new-onset) type 2 diabetes
Weight gain and obesity	Increase in weight gain due to increased visceral fat

Source: Teegala SM, Willet WC and Mozaffarian D, 2009

2.9.4 Characteristics of oils for frying

Food oils and fats enter into three major areas of food preparation: a) food processing plants, b) food service kitchens, and c) the home. Therefore the performance characteristics of oils and fats in these three areas are of prime concern (Lawson H, 1997). The inherent stability of different vegetable oils used for frying purpose is provided in Table 2.9.4.

Table 2.9.4: Inherent stability of oils use in frying

Rating	Fat and oil source	Inherent* oxidation stability	PUFA oxidizability#	Calculated Iodine value
Worst	Safflower oil	8.0	78.5	146.1
	Sunflower oil	7.1	69.1	135.3
	Soybean oil	7.1	66.9	133.0
	Corn oil	6.5	62.0	128.4
	Cottonseed oil	5.8	55.8	112.6
	Canola oil	4.5	38.6	113.0
	Peanut oil	3.7	32.0	97.1
	High oleic sunflower oil	1.7	9.0	85.6
	Olive oil	1.6	7.7	82.4
	High oleic safflower oil	1.6	7.4	83.3
	Palm oil	1.5	10.9	52.4
	Palm kernel oil	0.4	2.3	17.2
	Coconut oil	0.2	1.6	8.1
Best	Milk fat	0.7	4.0	34.0

*Inherent stability calculated from decimal fraction of fatty acids multiplied by reaction rates with oxygen, assuming rate for oleic acid as 1, linoleic acid as 10 and linolenic acid as 25.

PUFA oxidizability is the sum of PUFA times the active methylene group (% C18:2 X 1) + (% C18:3 X 2), etc.

Source: Jana AH et al, 2011

Coconut and Palm kernel oil: The lauric oils (Coconut, Palm kernel) stand apart in the world of oils and fats. Lauric fatty acid rich oils are unsatisfactory as frying oil since they contain large proportion of lauric acids and other fatty acids with fewer than 14 carbon atoms. These fatty acids are quite volatile and can cause excessive smoke development during frying. These are very oxidative stable and have a melting point slightly above ambient temperature. These two lauric oils differ slightly from one another in that coconut oil is richer in the C6:0 to C10:0 acid and Palm kernel oil is richer in unsaturated C18 acids (Pantzaris TP and Basiron Y, 2002). Coconut oil is used as frying medium where there is local preference i.e. Southern India or if the flavor attributes of coconut oil are desirable e.g. for banana chips.

Palm oil: It is widely produced semi-solid oil and does not pose problem of smoke during frying as does Palm kernel oil. It has the advantage of being low in PUFA (10%) and low Iodine value (IV) and consequently has good heat and oxidative stability. It has high (~42.5%) oleic acid content. Its high proportion of saturated fatty acids (SFAs) may be disadvantageous from nutritional point of view and may result in solidification in pipes and during storage. Palm oil has too high a melting point to give the right appearance on cold served foods or snacks (Pantzaris TP, 1999). Palm oil and its fractions are accepted as frying oils for food products such as snack chips, crackers, cookies, pastries, doughnuts, fries and instant noodles. Frying, being a thermal process, results in rapid deterioration of oil (Wai Lin S, 2002).

Soybean or Rapeseed oil: They have high IV and low level of SFAs. They are fully fluid even at low ambient temperatures. These liquid oils have a poor oxidative stability due to the presence of linolenic acid (6-10%). Linolenic acid oxidizes 100 times faster than oleic acid (Nawar WW, 1993). Therefore, rapeseed oil is blended with other more stable oils or is partially hydrogenated. Both soybean and rapeseed oils are often used where storage of the fried food is not necessary. Use of soybean oil for frying showed poor oxidative stability than palm oil, canola oil sunflower oil and palm olein (Machado ER et al, 2007; Abdulkarim SM et al, 2008).

Groundnut oil: It was considered to be a premium frying oil. Its popularity has declined due to its cost and the worry of public regarding peanut allergy and aflatoxin problems (Pattee HE, 2005). It is sufficiently fluid at ambient temperature. But in cold winter weather, it might solidify in pipes and drums. The low IV and near zero level of linolenic acid makes it an admirable oil. The most unsaturated component is linoleic acid which ranges from 15-43%. It has high (~ 46.7%) oleic acid content. Groundnut oil is susceptible to oxidation. However, absence of linolenic acid in groundnut oil provides it with greater oxidative stability compared to other specialty vegetable oils (Podmore J,

2002). Good acceptability of products fried in GNO makes it popular in western region of India (Gupta A and Sheth M, 2011).

Rice bran oil: It is increasingly popular as frying oil due to its high smoke point and stability. High oryzanol Rice Bran Oil (RBO) and refined bleached and deodorized RBO used for french fried potatoes showed an enhancement in stability with increasing oryzanol content. RBO contains sterol esters called γ -oryzanol, which are claimed to have several health benefits. It is also rich in sterol γ -5 avenosterol—a sterol having antioxidant action at frying temperatures. RBO contain highest tocopherol content (1800ppm) than palmolein (840ppm) and sesame oil (604ppm) (Archana U and Premakumari S, 2005). Unrefined RBO contains 2-20% FFA, depending on the quality of bran. Because of its high FFA and color, it is difficult to refine RBO without reducing the amount of oryzanol (Abidi SL and Rennick KA, 2003).

Study by Valsalan A, Siddhu A and Sundararaj P in 2004 reported, when various products were fried RBO underwent less oxidative deterioration as compared to GNO.

Olive oil: Olive oil is considered to be a premium frying oil, having low concentration of linoleic and linolenic acids and low levels of SFAs. Long shelf life of olive oil is also due to combination of various phenolic antioxidants inherent in olive oil. It is very flavor stable oil because of high oleic acid content (~ 80%). Frying performance of olive oil is linked to its relatively low melting point that which makes it easy to store at low temperatures. It drains from the fried food readily with no danger of solidification of frying oil leading to excess fat on fried foods (Cicerale S et al, 2009).

Sesame seed oil: It is a specialist commodity. It has approximately equal amount of both oleic and linoleic acids and very low linolenic acid content. It contains powerful antioxidants viz., 800 mg/kg of tocopherol as mainly γ -tocopherol. The compounds sesamol, sesamin and sesamol all give antioxidant properties. It has a high potential for heat stability, but it is

considered as an allergen (Hwang LS, 2005). Study by Archana U and Premakumari S (2005) stated that sesame oil: palmolein blend (70:30) was more stable than other blends ricebran oil: sesame oil, ricebran oil: palmolein when stored for 3 months. However, apparent changes were observed in all the blends after potato chips frying.

Cottonseed oil: It contains moderately high amount of SFAs namely 21-26% palmitic, together with up to 4% of longer chain saturated acids. It contains oleic and linoleic acids at levels of 17 and 56% respectively; linolenic acid is less than 1%. It is more stable compared to other liquid oils and could replace lard as the preferred fat for baking and frying (O'Brien RD et al, 2005).

Corn oil: It is considered to be superior frying oil when compared with canola and soybean oils. High sterol content could impart a lower viscosity and thus favor better drainage from the fried food. Corn oil's desirable properties include its mild nutty flavor, high levels of unsaturated fatty acids, low levels of saturated fatty acids, very low levels of linolenic acid, and stability during frying (Moreau RA, 2005).

Corn, Partially hydrogenated soybean, Sunflower oils: These oils are used for frying snack food and for french fries. New developments in trans-free frying oils, rich in oleic acid and low in PUFA and SFA are producing oils with good stability (Cuesta C, Romero A and Sanchez-Muniz FJ, 2001; Barrera-Arellano D, Ruiz-Mendez MV and Velasco J, 2002).

2.10 Regulation of frying fats and oils in various nations

Oils used for frying have to be discarded after certain duration of use because of the harmful effects of the degradation products forming and accumulating in the oil. *Ab initio*, taste evaluation of the food products was considered the most important factor in the quality measurement. However, taste of the food product is not a function of the quality of the frying oil alone but of many other factors also. Moreover, the taste evaluation performed is unreliable for

routine quality control testing because of its subjective nature. Thus there is a need for quantitative methods to evaluate the oil degradation in various oils.

In 1973, the German Society for Fat Research made the first attempt to define what "deteriorated fat" is. Definition given by German Society is described it as: *"a used frying fat is deteriorated if, without doubt, odor and taste are unacceptable; the concentration of petroleum ether insoluble oxidized fatty acids is 0.7% or higher and the smoke point is lower than 170°C; or if the concentration of petroleum ether insoluble oxidized fatty acids is 1% or higher"* (Fritsch CW, 1981).

Firestone D (1993) presented an overview of the laws, regulations, recommendations, and guidelines followed by a number of nations are listed below:

Belgium

In 1988, Belgium implemented laws forbidding the use of deteriorated frying oils. According to the law, frying oils should be discarded if any of the following criteria is not satisfied:

- a) Frying fats should not be heated to 180°C.
- b) Free fatty acid content should not be more than 2.5% by mass.
- c) Dimeric and polymeric triglycerides should not be more than 10% by mass.
- d) Polar compounds content should not be more than 25% by mass.
- e) Viscosity should not be greater than 37 mPa-s at 50°C for frying fats and 27 mPa-s at 50°C for frying oils.
- f) Smoke point should be above 170°C.

The Netherlands

The Netherlands follows the practice of regular inspection against the use of deteriorated frying fats and oils. According to the practice, frying fat must be discarded if any of the following conditions are not satisfied:

- a) The oil must be satisfactory in the organoleptic evaluations by food inspectors.

- b) The acid value should not exceed 4.5.
- c) The polymeric triglycerides should not exceed 16% by mass.

France

In 1986, France regulation specifies that the fats and oils containing more than 25% by mass of polar compounds are deteriorated frying fats and oils therefore they are unfit for human consumption.

Spain

According to the Spain regulation 1989, frying fat should be discarded if any of the following conditions are not satisfied:

- a) Frying fats and oils must be organoleptically acceptable.
- b) The polar compounds should not exceed 25 % by mass, as determined by the IUPAC method #2.507.
- c) Frying fats must not alter the quality of fried food.
- d) Frying fat must not be sold for subsequent use in preparing other food products after it has been used in frying operations.

Austria

According to the recommendations given by Austria in 1990, frying oils should be discarded if any of the following conditions are not satisfied:

- a) Frying fats should be organoleptically acceptable.
- b) Frying fats should be acceptable in appearance (dark color, foaming) or should not contain high levels of carbonaceous residue.
- c) Acid value should not be greater than 2.5.
- d) Smoke point should be under 170°C.
- e) Polar compounds should not be more than 27% by mass.
- f) Oxidized fatty acids insoluble in petroleum ether above 1%.
- g) Frying fat should not be heated above 180°C.

Germany

The definition of deteriorated frying fats and oils published by the German Society for Fat Research, following their two symposia in 1973 and 1979 were accepted as recommendations to prevent the use of deteriorated frying fats in Germany. Even though there is no specific law or regulation in Germany in this regard, it is noteworthy that these recommendations were established after numerous reports of gastrointestinal distress (Firestone D, Stier RF and Blumenthal MM, 1991). Based on recommendations, the German health authorities succeeded in bringing some cases to the court, resulting in a considerable improvement in the average quality of frying oils in Germany (Billek G, Guhr G, and Waibel J, 1978).

Finland

Finland follows general regulations for monitoring the use of degraded frying oil. Frying oils are considered harmful if any of the following conditions are not satisfied:

- a) Oils should be organoleptically acceptable.
- b) Fritest should not be greater than 2.
- c) Acid value should not be greater than 2.
- d) Smoke point should be below 180°C.
- e) Decrease in iodine value compared with that of the unused oil should not be greater than 16 (Firestone D, Stier RF and Blumenthal MM, 1991).

The U.S.

The Food and Drug Administration (FDA) of the U.S. has not any specific laws or regulations against the use of deteriorated frying oils. However, certain guidelines for the use and discarding of frying oils in processing plants producing fried meat products are followed by the U.S. Department of

Agriculture (USDA). During Manufacturing Processes Inspection (MPI) Regulations published by the USDA is given below for meat products.

- a) Length of time fats and oils may be used for deep-fat frying varies with temperature, quantity of new fat added daily, and fat treatment during use.
- b) Suitability of these fats for further use can be determined from degree of foaming during use or from color, odor, and flavor. Excessive foaming, darkened color, and objectionable odor or flavor are evidence of unsuitability and require fat rejection.
- c) Fat or oil should be discarded when it foams over the vessel's side during cooking, or when its color becomes almost black as viewed through a colorless glass container.
- d) Serviceable life of fat can be extended by holding frying temperature below 400°F (204°C), daily replacing one third or more, filtering as needed, and cleaning the system at least weekly. Adding an antifoam agent (methyl-polysiloxane) to new fat is helpful to delay the degradation process.

Canada

Canadian 'Food and Drugs Act and Regulations' deals with the fats and oils. It covers only the specifications for the initial quality of the frying fats and oils only. No existing law or regulation in Canada against the use of deteriorated frying fats (FDAR, 2012).

Other Nations

Scandinavian countries had no specific laws and regulations for frying fats and oils, only certain general regulations are enforced. Norway and Denmark follow the methods of organoleptic evaluations, acid value, color, smoke

point, free fatty acids, peroxide value, etc. to determine the quality of frying oils (Firestone D, Stier RF and Blumenthal MM, 1991).

Swedish National Food Administration has published guidelines for deep fat frying listed below:

- a) Change oil before it starts smoking or foaming.
- b) Strain the fat for at least once a day.
- c) Frying temperature should be 160-180°C.
- d) Use that are specially intended for frying.
- e) Avoid salting or seasoning the fried food over the fryer.
- f) Lower the temperature when not frying and protect from light.
- g) Use separate fryers for plant based and animal based foods.

Sweden accepts organoleptic evaluation, Fritest, peroxide value, free fatty acids, foam formation, etc. to determine the quality of degrading frying oil.

Israel has no specific regulations against the use of deteriorated frying fats. However, guidelines by the Swedish National Food Administration are followed by the inspectors of the Israeli Food Control Administration.

Japan has no formal laws and regulations, but they have guidelines to discard the fat when the smoke point is below 170°C, acid value is greater than 2.5, or carbonyl value is more than 50.

Switzerland also has no specific laws and regulations for frying fats. However, Fritest is commonly used by the food inspectors to check the quality of frying oils on routine inspections.

2.11 Food safety status in Indian institutes and catering outlets

Rapid industrialization and changing life styles, have led to the development of large scale catering services, which prepare and distribute food to the public. There has been a marked increase in the consumption of food outside

home. Greater numbers of people eat meals prepared in the restaurants, canteens, fast food outlets and street foods.

Nowadays popularity of commercially ready-made foods is widespread all over the world and deep-fried products are most admired by consumers among them (Totani N, Ohno C and Yamaguchi A, 2006). Oil deterioration during deep frying may pose hazards due to reactions such as oxidation, polymerization, and hydrolysis. These reactions results in formation of harmful components such as *trans* fatty acids, highly oxidized or polymerized constituents of fatty acids and acrylamide.

Safety of food is an inherent component of food quality. Food safety implies absence of biological contaminants, adulterants, naturally occurring toxins or any other substance beyond safety limits and that make injurious to health on an acute or chronic basis. Food quality can be considered as a complex characteristic of food that determines its value or acceptability to the consumers (CAC/GL21-2003). In addition, safety of oils used for deep-frying is a vital criterion in the selection of frying fats and oils for the catering industry, unlike in the home where the frying fats are normally used once or twice and then discarded (Gertz C, Klostermann S and Kochhar SP, 2000).

Oxidized oil causes deterioration in taste, flavor, odor, color, texture, and appearance, and a decrease in the nutritional value of the fried foods. Use of such oils/consumption of such foods can induce food poisoning. Thus this indicates that there is a direct relationship between the quality of the food being produced and the oil in which it is being fried (Gotoh N and Wada S, 2006).

Application of Hazard Analysis Critical Control Point (HACCP) and training to personnel on safe frying practices showed an improved safety when sunflower oil was used for frying process (Soriano JM, Molto JC and Manes J, 2002). Another study on HACCP of frying ensures production of safe potato chips and french fries by controlling the critical limits so that potential