Oil Absorption, Polymer and Polar Compounds Formation During Deep-Fat Frying of French Fries in Vegetable Oils

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INTRODUCTION

Deep-fat frying is one of the most commonly used methods for the preparation and manufacture of foods. One of the fundamental objectives of frying is to make the food more acceptable. When a food is fried, part of the moisture it contains is replaced by the frying fat. The fat that has penetrated into the food makes the food more palatable.

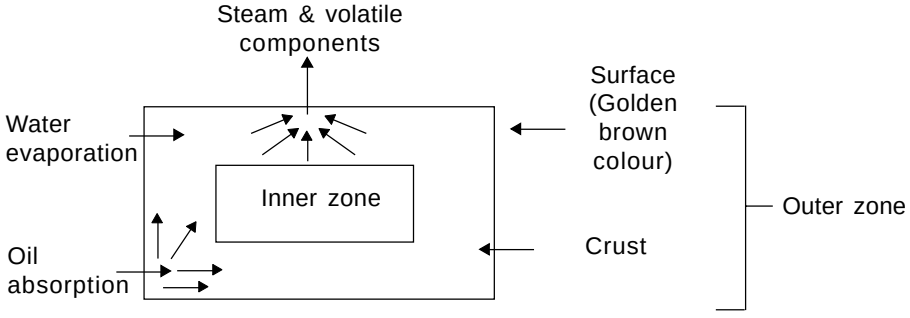
During deep-fat frying, the fat is continuously or repeatedly being exposed to temperatures of between 150°C-180°C in the presence of the substrate, air and water. Under these conditions, a complex series of reactions takes place; namely hydrolysis, oxidation, polymerization, isomerization and cyclization, resulting in the formation of both volatile and non-volatile products. These products affect sensory, functional and nutritional qualities of the frying oil or fat. Finally, as these reactions proceed, a point is reached where it is no longer possible to prepare high quality fried products and the frying oil or fat will have to be discarded from the fryer.

The result of deep-fat frying is a food with a distinctive structure consisting of outer and inner zones *(Figure 1*). According to several researchers (Robertson, 1978; Stevenson *et al.,* 1982; Gutierraz *et al.*, 1988), the surface area becomes crispy due to dehydration of the exterior parts of the food during deep-fat frying. Its formation begins when the temperature of the frying medium is close to 100°C. The surface is generally an even, golden brown colour, resulting from the browning reaction that occurs when sugars and protein present in the substrate react in the presence of heat.

The crust is an area of numerous cavities, pores and large surface area, with a moisture content of less than 3%. The void created by the loss of water is largely filled by the absorption of the frying oil or fat. This absorbed fat exerts a tenderizing effect on the crust and contributes to the flavour, aroma, lubricating and pleasant eating characteristics of the fried food. The core or the inner zone is a cooked moist interior composed solely of the food that is being fried. The texture and flavour changes occurring here are due to the effect of heat on the substrate rather than to fat absorption.

FAT ABSORPTION

The amount of frying oil or fat absorbed by a fried food depends on several factors. Among the important ones are the surface area of the food in contact with the frying medium, the moisture content or specific gravity of the food, the type of food, the ratio of the food crust to its core, the oxidative and heat stability of the oil/fat, the fryer design, whether frying is continuous or intermittent, the percentage



Source: Gutierraz *et al.* (1988).

Figure 1. Zones of fried food.

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replenishment with fresh oil, the duration of frying, the temperature of frying and the presence or absence of antioxidant.

Enormous quantities of palm oil/olein and palm shortening are now used for industrial production of snack chips, crackers, cookies, pastries, doughnut, pre-fried frozen French fries, instant noodle, fried chicken, fish fillet, meat nuggets and French fries (Masahi *et al.*, 1985; Yoon, 1991). It is thus of interest to know how much oil is absorbed by a particular fried product among the different frying oils/fats. Although fat absorbed by the fried food imparts a certain flavour and makes the food more palatable, a high oil pick-up could be a disadvantage to food processors as it will incur higher operating costs in replenishing the oil lost during the frying operation. A high fat content could also affect the shelf-life and stability of the food and may cause imbalance in the nutritive value between fats and non-fats such as carbohydrates and proteins.

A study which has been carried out by MPOB, investigated lipid absorption by a fried product, *i.e*. French fries, during batch or intermittent laboratory deep-fat frying in palm oil and palm olein versus soyabean and hydrogenated soyabean oils. This study was conducted with less than 10% replenishment of the fresh oils compared to 20%- 25% under normal practices and without shaking of finished food in the air. Hence, the results could differ from other studies. The polar and polymer contents and fatty acid compositions of fat extracted from the French fries as well as of oil collected from the fryers, were also assessed.

In the present investigation, frozen French fries were intermittently fried for 8 hr a day over five consecutive days at 180°C for 4 min in palm oil, palm olein, soyabean and partially hydrogenated soyabean oils respectively. Oil pick-up as well as polymer and polar compound formation were studied.

FRESH FRYING OILS

The characteristics of the fresh frying oils used in the experiment and their fatty acid compositions are shown in *Tables 1* and *2*. As can be seen, of the four frying oils, soyabean oil has a very low resistance to oxidation (8 hr), as measured by the Rancimat. Its short induction period means it is not suitable to be used in deep-fat frying operations in fast-food chains, food manufacturing plants *etc.* where for economic, technical and nutritional reasons, a frying fat/oil needs to be stable for many hours, batches or days before being discarded from the fryer.

Under the French Food Law and Regulations (Firestone *et al.,* 1991), a fat/oil is considered unfit to be used as a deep-fat frying medium if it contains 2% or more linolenic acid (C18:3). Soyabean oil and most soft oils are normally hydrogenated to reduce the level of linolenic and linoleic acids in order to improve their oxidative and heat stabilities and to eliminate fishy odours associated with linolenic acid.

Hydrogenation of the soyabean oil reduces its linolenic acid content from about 9% to around 0.1% and increases its induction period by seven-fold to more than 58 hr. However, some 70% of the natural tocopherol is lost and about 41% of *trans* fatty acids are formed in comparison with the original oil. In Canada, the *trans* fatty acids are considered as equivalent to saturated fatty acids. According to Enig (1989), most *trans* fatty acids in hardened oils/fats have a straight chain structure much like saturated fatty acids and a typical hydrogenated commercial fat/oil in America contains as much as 42% *trans* fatty acids and 20% saturated fatty acids.

TABLE 1. CHARACTERISTICS OF FRESH FRYING OILS

Parameter	Palm oil	Palm olein	Soyabean oil	Hydrogenated soyabean oil
Colour (Lovibond, 5 1/4" cell)	2.2R 50 Y	1.9R 60Y	1.0R 16Y	1.0R 15Y
Free fatty acids (wt%)	0.06	0.04	0.03	0.02
Peroxide value (meq kg^{-1})	4.08	1.49	4.00	0.93
Anisidine value	2.96	1.89	2.28	2.92
Totox value	12.32	4.87	10.20	4.78
Slip melting point (°C)	37.0	20.0	-	35.8
Iodine value	52.0	56.1	135.1	73.9
Total tocopherol (ppm)	597	810	929	285
Induction period (Rancimat, hr, 100°C)	41.1	46.2	8.10	58.4
Polymer compounds (wt%)	0.62	0.47	0.84	1.04
Polar compounds (wt%)	7.96	7.84	5.89	5.20
Dielectric constant	0	0	0	0
Smoke point (°C)	214	216	217	219

TABLE 2. FATTY ACID COMPOSITION OF FRESH FRYING OILS (%)

Fatty acid	Palm oil	Palm olein	Soyabean oil	Hydrogenated soyabean oil
Lauric (C12:0)	0.2	0.3	0.1	0.2
Myristic (C14:0)	1.0	1.0	0.1	0.5
Palmitic (C16:0)	43.4	39.7	10.8	11.9
Palmitoleic (C16:1)	0.2	0.1	0.1	0.1
Stearic (C18:0)	4.4	4.2	3.7	7.5
Cis-oleic (C18:1c)	39.3	41.5	19.5	27.0
Trans-oleic (C18:1t)	Trace	Trace	Trace	39.8
Cis-linoleic (C18:2c)	9.8	11.3	54.4	1.8
Trans-linoleic (C18:2t)	Trace	Trace	Trace	1.1
Linolenic (C18:3)	0.2	0.2	9.0	0.1
Arachidic (C20:0)	0.4	0.4	0.3	Trace
Total *trans*	-	-	-	40.9
Others	0.7	0.9	0.6	9.9

Palm oil and palm olein are balanced fats containing about 50:50 saturated to unsaturated fatty acids *(Table 2)*, the same ratio as found in human milk. They have marginal amounts of linolenic acids and about 10% linoleic acid (the essential fatty acid required by our body). They have a long induction period of more than 40 hr *(Table 1)*, low levels of polymer compound (< 1%) and a high smoke point of over 200°C. These properties, coupled with their competitive price and consistent supply, palm oil/olein and palm shortening have over the last 20 years or so been a popular choice for food manufacturers in many countries, replacing (either totally or partially) traditional frying oils such as lard, tallow, peanut or cottonseed oil (Masahi *et al.,* 1985; Razali and Nor Aini, 1992).

FRENCH FRIES

The initial fat content of the pre-fried frozen French fries before frying was found to be around 5% while their moisture content varied between 64%-66%. After frying, some 32%-35% of the moisture was retained in the French fries. *Table 3* shows the fatty acid composition of the oil extracted from the frozen French fry potatoes. The presence of 12% *trans* oleic acid means that the oil has been partially hydrogenated and may have been blended with palm oil as indicated by the high content of palmitic acid of 32%. Pre-fried frozen French fries imported by Malaysia from the western countries usually are pre-fried either in palm oil, animal fat or blend of palm oil with partially hydrogenated oil or hydrogenated soyabean oil.

The amount of oil picked up by the French fries during five days of frying is shown in *Table 4*. Starting with a fat content of roughly 5%, the oil absorbed by the French fries during the first two days of frying (equivalent to 16 hr and 28 batches) appeared to be similar for all oils with a narrow range of roughly 13%-14%.

Following an extended frying over five days, French fries fried in the soyabean oil contained a higher percentage (between 19%-21%) of oil than French fries fried in the other three oils. The soyabean oil contained a high proportion of linoleic acid (54%) and a substantial amount of linolenic acid (9%). These acids are extremely vulnerable to oxidation and also undergo thermal degradation to form polar and polymer compounds resulting in increased viscosity of the frying oil. According to Alim and Morton (1974), viscosity controls the amount of oil that coats a fried product and increases the oil absorption by the fried product. During five days of frying *(Tables 5a* and *5b)* higher proportions of

TABLE 3. FATTY ACID COMPOSITION OF OIL EXTRACTED FROM PRE-FRIED FROZEN FRENCH FRIES POTATOES BEFORE FRYING

Fatty acid	Percentage
Lauric (C12:0)	0.6
Myristic (C14:0)	0.9
Palmitic (C16:0)	32.0
Palmitoleic (C16:1)	0.1
Stearic (C18:0)	7.8
Trans-oleic (C18:1t)	12.0
Cis-oleic (C18:1c)	37.4
Trans-linoleic (C18:2t)	0.1
Cis-linoleic (C18:2c)	5.6
Linolenic (C18:3)	0.2
Arachidic (C20:0)	0.4
Others	2.7

TABLE 4. OIL ABSORPTION IN FRENCH FRIES (FF) DURING FIVE DAYS OF FRYING (%)

Days of frying (x 8 hr)	FF in palm oil		FF in palm olein		FF in soyabean oil		FF in hydrogenated soyabean oil	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
0	5.14	5.16	5.19	5.19	5.17	5.19	5.21	5.19
1	13.41	14.15	13.22	13.87	13.45	14.32	13.74	14.10
2	13.94	14.40	13.64	14.45	13.88	14.56	13.62	14.38
3	14.58	15.39	14.40	15.63	15.67	17.19	14.45	16.00
4	15.77	17.01	14.99	16.64	17.00	19.15	15.97	16.89
5	16.83	18.67	17.02	18.37	19.41	21.22	17.14	18.82

Notes:
Day 0 = initial fat content of the frozen French potatoes.
Results are means of two replicates.

TABLE 5a. POLYMERIC COMPOUNDS IN FRYING OILS AND FRENCH FRIES (FF) DURING FIVE DAYS OF FRYING (%)

Days of frying (x 8 hr)	Palm oil		Palm olein		Soyabean oil		Hydrogenated soyabean oil	
	Oil	FF	Oil	FF	Oil	FF	Oil	FF
0	0.62	-	0.47	-	0.84	-	1.04	-
1	2.35	2.78	2.12	2.44	3.24	3.87	2.68	3.00
3	3.60	3.45	3.81	3.63	6.55	6.41	4.22	4.18
5	5.14	5.56	4.96	5.11	8.29	8.32	6.17	5.95

TABLE 5b. POLAR COMPOUNDS IN FRYING OILS AND FRENCH FRIES (FF) DURING FIVE DAYS OF FRYING (%)

Days of frying (x 8 hr)	Palm oil		Palm olein		Soyabean oil		Hydrogenated Soyabean oil	
	Oil	FF	Oil	FF	Oil	FF	Oil	FF
0	7.96	-	7.84	-	5.11	-	5.85	-
1	16.57	17.30	15.85	17.14	18.00	18.98	16.60	17.72
3	24.18	23.70	24.39	24.12	29.93	28.89	25.54	25.49
5	30.00	29.55	30.21	30.96	37.40	36.77	30.33	30.85

polar and polymer compounds were formed in the soyabean oil and as a result the French fries picked-up more of the polar and polymer compounds when fried in that oil, thus accounting for the higher percentage of oil absorbed.

The percentage of oil absorbed by the French fries each day varied partly because of variation in the initial moisture content of each batch of the pre-fried frozen French fries. Also, it was difficult to obtain a truly homogenous surface area to volume ratio from batch to batch. The presence of 5% fat in the frozen French fries before frying also contributed to higher oil pick-up. The actual fat pick-up by the French fries may have been reduced if shaking of the French fries had been carried out.

Shaking of the French fries in the air was said to be more effective (Greenfield *et al*., 1984) in removing excess fat absorbed by the French fries than draining on an absorbent paper.

The changes in fatty acid composition of oil absorbed by the French fries as well as in the frying oils are shown in *Table 6*. Generally, the fatty acid profiles of each frying oil and the French fries fried in the oil were similar. As a consequence of deep-fat frying, *trans*-fatty acids were also formed. However, their levels in the non-hydrogenated oils and in the French fries were too low and would not really increase human intake of *trans* fatty acids as much as from the consumption of the French fries cooked in hydrogenated soyabean oil.

CONCLUSION

The oil absorption by the French fries fried in palm oil, palm olein and partially hydrogenated soyabean oil was approximately the same under the conditions studied. During five days of frying, the oil pick-up by the French fries increased in more or less the same proportion as the increase of polar and polymeric compounds in the three frying oils.

TABLE 6. CHANGES IN FATTY ACID COMPOSITION OF FOUR FRYING OILS AND FRENCH FRIES (FF) DURING FIVE DAYS OF FRYING (%)

a. Palm oil (PO)

Fatty acid	Palm oil				French fries			
	PO^0 initial	PO^1	PO^3	PO^5	FF^0 initial	FF^1	FF^3	FF^5
16:0	43.4	44.9	46.8	48.0	32.0	42.3	44.9	45.7
18:0	4.4	4.6	5.0	5.1	7.8	4.9	5.4	5.5
18:1c	39.3	38.6	37.7	37.4	37.4	39.1	38.0	37.9
18:1t	Tr	0.3	0.7	1	12.0	0.6	0.9	1.0
18:2c	9.8	8.4	6.4	5.9	5.6	9.5	8.4	7.1
18:2t	Tr	0.4	0.2	0.2	0.1	0.4	0.3	0.3
18:3	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.2
Others	2.5	2.6	2.8	2.2	4.9	2.9	1.9	2.3

b. Palm olein (POo)

Fatty acid	Palm oil				French fries			
	POo^0 initial	POO^1	PO^3	PO^5	FF^0 initial	FF^1	FF^3	FF^5
16:0	39.7	41	43.0	43.7	32.0	39.3	40.6	42.5
18:0	4.2	4.5	4.9	5.0	7.8	4.6	5.1	5.3
18:1c	41.5	41.2	40.8	40.3	37.4	41.9	41.2	41
18:1t	Tr	0.31	0.8	1.0	12.0	0.4	1.1	1.1
18:2c	11.3	10.0	8.0	7.4	5.6	11.0	9.0	8.6
18:2t	Tr	0.3	0.2	0.2	0.1	0.4	0.3	0.3
18:3	0.2	0.2	0.1	0.1	0.2	0.3	0.3	0.2
Others	2.6	2.5	2.2	2.2	4.9	2.1	2.4	2.0

c. Soyabean oil (SBO)

Fatty acid	Soyabean oil				French fries			
	SBO^0 initial	SBO^1	SBO^3	SBO^5	FF^0 initial	FF^1	FF^3	FF^5
16:0	10.8	11.7	13.2	13.4	32.0	12.9	13.1	13.8
18:0	3.7	3.9	4.3	4.4	7.8	3.9	4.3	4.5
18:1c	19.6	20.6	21.8	22.0	37.4	21.1	21.7	22.3
18:1t	Tr	0.4	0.8	1.3	12.0	0.8	1.6	1.7
18:2c	54.4	52.4	50.7	49.8	5.6	50.7	48.3	47.3
18: 2t	Tr	0.3	0.5	0.3	0.1	0.5	0.5	0.5
18:3	9.0	8.4	7.5	6.8	0.2	7.5	7.2	6.8
Others	2.3	2.1	2.6	1.9	4.9	2.6	3.3	3.0

d. Partially hydrogenated soyabean oil (PHSBO)

Fatty acid	PHSBO				French fries			
	$PHSBO^0$ initial	$PHSBO^1$	$PHSBO^3$	$PHSBO^5$	FF^0 initial	FF^1	FF^3	FF^5
16:0	11.9	12.6	14.0	14.7	32.0	12.8	14.4	15.3
18:0	7.5	7.5	7.6	7.8	7.8	6.9	7.5	7.7
18:1c	27.0	28.3	30.9	30.9	37.4	20.5	20.8	21.2
18:1t	39.8	37.8	35.4	34.3	12.0	42.8	42.0	38.0
18:2c	1.8	1.8	1.2	1.1	5.6	3.8	2.2	1.7
18:2t	1.1	1.1	0.8	0.8	0.1	2.2	2.0	1.8
18:3	0.1	0.1	0.1	Tr	0.2	0.5	Tr	Tr
Others	11.8	12.1	11.1	11.1	4.9	10.5	11.1	14.3

However, during five days of frying, French fries fried in soyabean oil generally absorbed more fat in comparison to French fries cooked in the other three oils. The difference in the fat absorption was partly due to the higher polar and polymeric compounds formed in the soyabean oil and subsequent higher absorption by the French fries.

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