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Factors that affect fat uptake during French fries production

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1. Introduction

Deep fat frying is an important, ubiquitous and highly versatile process, which has been used since antiquity to cook a wide spectrum of products. Its unique contribution to sensory characteristics, together with the relatively low cost of large-scale frying, has made fried foods the staples of the ever growing late 20th century fast food industry. Despite its considerable fat content and intensified consumers' awareness of the relationships between food, nutrition and health, frying remains a principal cooking method. Oil consumption especially saturated fat is considered a major factor increasing health risks such as coronary heart disease (CHD), cancer, diabetes and hypertension, and even linked to increased causes of deaths. Fried foods contribute a significant proportion of the total fat consumed in the Western world. Yet, aside from their high caloric value, fried foods can be nutritious and favourably compared with other cooking methods such as baking and boiling. Fried foods are popular due to their taste, distinctive flavour, aroma and crunchy texture. Misconceptions about frying extend beyond nutrition to the fundamental aspects of the process, such as the role of water and oil quality during frying. Improving oil quality, the mechanism of oil, coating, engineering considerations of residence time and design, are typical examples of frying technology that is still evolving (Saguy & Dana, 2003). Knowledge of optimal frying conditions is important to produce French fries with the lowest fat content, as well under industrial conditions as at home. This study tries to give an overview of the major factors that could affect the fat uptake during the production of French fries.

2. Background: process of deep-fat frying

The deep-fat frying process is well described according to fig. 1. Upon addition of the food to the hot oil, the surface temperature of the food rises rapidly. The water at the surface immediately starts boiling. Surrounding oil is cooled down but this is quickly compensated for by convection. If the amount of added food exceeds a critical value, however, the temperature of the oil will be significantly effected. Obviously, this critical amount is influenced by the initial temperature of the food introduced (eg. frozen/ non-frozen products).
As the boiling commences, the convection will be further intensified by the turbulent water vapour. Due to evaporation, surface drying will occur. The evaporation will also lead to shrinkage and development of surface porosity and roughness. Especially explosive evaporation can lead to the formation of large pores.
Water deep inside the food will become heated and will be cooked. As the food is fried for a longer period of time the moisture content in the crust slowly diminishes, thereby reducing the amount of steam bubbles leaving the surface. The surface temperature can rise above the boiling temperature of water. Several physicochemical changes take place (starch retrogradation, Maillard reactions). This will lead to beneficial organoleptic properties and colour of the crust. Note that for large pieces of food like French fries or meatballs the temperature of the food core will not rise above 100°C. For thin potato crisps the core temperatures will be higher.
During the frying not only water vapour but also other compounds will go from the food to the fat. This combined with long-lasting high temperatures, will lead to degradation of the frying fat (Mellema, 2003).

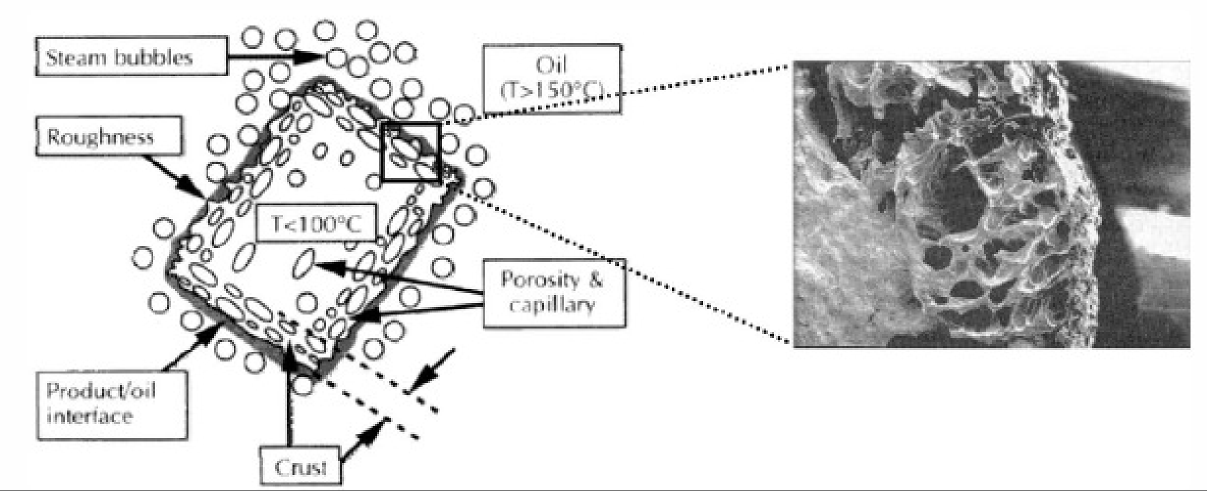

Fig 1: Schematic cross-section of a piece of food during deep fat frying (right). Scanning electron microscope image of a cross-section of the crust of a fried potato (left) (Mellema, 2003)

3. Fat uptake

During deep-fat frying, water in the crust will evaporate and move out of the food. In order for the flow of vapour to continue, sufficient water has to be able to migrate from the core of the food to the crust and the crust has to remain permeable. The fact that the vapour leaves voids for the fat to enter later, is the reason why fat uptake is largely determined by the moisture content of the food (Mehta & Swinburn, 2001). Similarly, sections of the food with more moisture loss also show more fat uptake. Some even argue that the total volume of fat will equal the total volume of water removed (mass balance) (Pinthus et al., 1993). Indirect proof of increased evaporation resulting in more damage to the crust is given by the observation that porosity and fat uptake are inversely related to moisture content at various time-stages during deep frying (Moreira et al., 1995). Since oil can only penetrate where water has evaporated, oil penetration only occurs where the temperature has been sufficiently high, i.e. in the crust. There is abundant proof that oil hardly penetrates in the cooked core and that the microstructure of the crust is the main determining factor in oil uptake (Pinthus et al., 1995). It has been shown using calorimetry (Aguilera & Gloria, 1997), that in fried potatoes the crust contains almost 6 times as much oil as the inner part. A more detailed study was performed by Bouchon et al. (2001). They showed using infrared microspectroscopy that the oil penetration depth in potato is approximately 300-400 µm, which was very close to the evaporation front.
Besides the mass balance argument, there is another reason for oil to accumulate at the surface: the presence of hardstock or solid fat. Because the frying oil may contain a portion of fat that solidifies upon cooling. If that fat solidifies, it will be harder to drain or shake from the food. The total fat uptake is considered to be the sum of both fat penetration (through condensation or capillary mechanisms) in the crust and fat crystallization on the surface (Mellema, 2003).

The fat content in French fries according to different food composition tables is given in table 1.

Table 1: Fat content of French fries according to different food composition tables:

Source	Food	Energy (kJ)	Protein (g/100g)	Fat (g/100g)	SFA (g/100g)	MUFA (g/100g)	PUFA (g/100g)	CHO (g/100g)	Water (g/100g)
1	Frieten bereid	1435	4.1	20.9	9.1	10.8	1.0	34.6	38
2	Frites bereid gemiddeld	1256	4.5	14.3	4.6	5.4	2.5	38.3	37
2	Frites bereid met hard vet	1241	4.5	13.9	5.7	4.2	1.6	38.3	37
2	Frites bereid met vloeibaar vet	1275	4.5	14.8	3.3	6.8	3.6	38.3	37
2	Frites oven -bereid	812	3.7	6.7	2.8	1.8	1.6	29.5	55
2	Frites oven – diepvries bereid	1206	5.8	8.8	3.7	2.4	2.0	46.0	33
2	Frites voorgebakken	595	3.0	4.5	2.3	1.2	0.5	22.0	70
3	French fries frozen	979	4.3	5.0	2.0	2.0	0.8	42.0	48
4	Potato chips deepfried	1469	4.9	18.7	7.92	7.62	2.17	42.4	31.6
5	French fries fast food restaurant	1381	3.0	16.8	5.4	8.4	1.8	39.8	34
5	French fries frozen	641	2.2	5.2	2.5	1.9	0.6	22	66
6	French fries frozen, as purchased	558	2.19	3.39	0.688	2.025	0.218	23.51	69.29
6	French fries frozen oven heated	636	2.57	3.76	0.737	2.207	0.252	26.98	64.85
6	French fries Burger King	1385	3.5	17.4	4.367	11.061	1.147	40.08	36.66
6	French fries Mc Donald's	1411	3.38	17.86	3.561	8.065	4.693	41.10	39.76
6	French fries Wendy's	1336	3.89	16.23	3.201	8.518	3.728	39.44	38.81

(SFA= saturated fatty acids, MUFA= monounsaturated fatty acids, PUFA= polyunsaturated fatty acids, CHO= carbohydrates)
1. Nubel (1999)
2. NEVO (2006)
3. www.fineli.fi
4. www.foodcomp.dk
5. matportalen.no/matvaretabellen
6. www.nal.usda.gov/fnic/foodcomp/search/

4. Reduction of fat uptake

4.1. Modification of frying techniques

4.1.1. Properties of the potato strips

A. Moisture/Surface moisture

The properties of the potato are very important in producing French fries of good quality. Potatoes at some times of the year have a very high moisture content and produce more soggy French fries. Potatoes used for frying should be low in sugar and moisture and have a specific gravity of 1.08 or more with 1.1 preferred. Some sugar is required to provide colour and flavour, but if it is too high the sugar and fat produce bitter flavours. An increase in the density of potato tuber also leads to a decrease in fat absorption. In one study of fried potato chips, tubers with a higher density (1.103 g/cm^3) yielded chips with lower fat content (42.1%) than slices with lower density of 1.093 g/cm^3 (48.8% fat) (Ufheil & Escher, 1996).

B. Size and shape of potato strips

The thickness of the potato strips is an important factor affecting the overall fat content of French fries. Thick-cut strips (12 mm or bigger) absorb less fat than thin-cut strips. The fat content in French fries decreases with increasing cross-section area of potato sticks, and fat is restricted to the surface of the sticks. Cracks and rough surfaces increase the surface area and thus increase the fat absorption. Ideally, all potato sticks need to be cut to the same dimensions, with a fairly uniform cross section and, to a lesser extent, length to allow for uniform cooking (Blumentahl, 1991).

4.1.2. Preprocessing of French fries

In the preparation of French fries , several processes are involved. The most common sequence is cutting – blanching – drying – pre-frying – freezing/chilling – packing – thawing. Each step may be important for the final product quality. The fat uptake varies with the pre-treatment of the potato.

A. Blanching

Blanching is a processing step whereby potatoes are heated in steam or water for 2 to 3 min. This inactivates enzymes and prolongs the storage life of frozen fries. Moreover, blanching reduces the subsequent cooking time. Blanching also makes the colour more uniform after frying and it forms a layer of gelatinized starch that limits oil absorption and improves texture (Moreira, 1999).

Low temperature blanching enhances pectin methyl esterase (PME) activity and is another option proposed that affects both textural quality and oil uptake (Aguilar et al., 1999). In potatoes and most vegetables, texture depends on the presence of pectic substances, which are part of the intercellular material. PME hydrolyses the methyl ester bonds in pectin leaving free carboxylic groups that can then react with divalent ions such as calcium and magnesium, increasing firmness (Miranda & Aguilera, 2006).

B. Drying

Drying the surface of the potato strips before frying reduces the fat uptake in French fries. In the experiments of Lamberg et al. (1990) drying reduced the fat uptake by 7 to 29% (for 1 min frying) and by 15 to 40% (for 5 min frying). Drying causes a 'skin' to form on the surface of the potato strip and this reduces vapour transport through the surface layer.

C. Freezing

The method of freezing fries has an important impact on the fat content and other qualities after they are deep fried. French fries are frozen either cryogenically (rapid freezing) or mechanically (slow freezing). Cryogenically frozen chips have a lower fat content and better organoleptic qualities. Kock et al. (1995) compared the quality of fries that had been frozen by these two different methods. During cryogenic freezing the water losses were minimal compared with the water losses caused by the moving air (blast air) in mechanical freezing. Thus, cryogenically dried fries had significantly higher moisture content (73%) than the mechanically frozen fries (67%). Rapid freezing resulted in better quality fries. This can be explained by the structural damage caused by the slow freezing rate of mechanical freezing. The large ice crystals that form during the process damage the surrounding tissues. During frying, some of the moisture is removed, and more fat is absorbed into the holes left by the ice crystals. Thus, cryogenically frozen fries have a lower fat content despite starting with a higher moisture content.

4.1.3. Frying practices/procedures

A. Temperature

Very high temperatures shorten the life of the fat. Raising the temperature of the fat higher than 185°C causes the fat to break down more rapidly due to an increased rate of oxidation and polymer formation in the fat. When frying at 200°C or above, excess energy in the fat is converted into cross-links leading to case-hardening of food. This results in a brown surface forming on the food before the inside is completely cooked and immersing the food for a longer time to cook the inside properly may cause burning on the outside (Blumenthal & Stier, 1991). In some countries maximum frying temperature is set at 180°C.

On the other hand, if French fries are cooked at lower temperature, or the 'boiling action' on the surface ceases due to a lower heat input, the crust does not form on the surface. This allows extra fat to penetrate into the core of the French fries. About 40% more fat is absorbed when the fat temperature is 10°C lower than the recommended cooking temperature of 180°C to 185°C (Mehta & Swinburn, 2001).

B. Number of fryings

An increased number of fryings degrades the frying fat, thus affecting the fat absorption. In one study, sets of 500g of potatoes were fried discontinuously 15 times in 3 litres of sunflower oil without the addition of fresh fat. The fat content of the fried potatoes increased significantly with the number of fryings from 26.7 to 29.5 %. According to Blumenthal (1991), the more altered the fat is, the higher the content of polar compounds, the higher the surfactant production, and the higher the fat content of the food. However, Sebedio et al. (1990) described no significant differences between the 1st and the 30th frying operation in either peanut or soybean fat.

C. Mixed frying

When fat-containing food such as chicken, sausages, and other meat products are fried, some of the fat from these foods is extracted during cooking and replaced with the cooking fat. This exchange of components, including fat and salt, changes the composition of the frying fat during the cooking process. Moreover, this extracted fat is in a natural unrefined state that is more unstable and causes darkening of the fat. Potatoes fried in this fat are of reduced quality. Therefore it is preferable to use a separate fryer for the cooking of French fries and the same fat should not be used for frying of different foods. In addition, enclosing such foods in batter tends to reduce the contamination of the frying fat by the food being cooked (Mehta & Swinburn, 2001).

4.2. Modification of frying medium

The medium in which frying takes place is usually a triglyceride oil. The use of triglycerides with polyunsaturated fatty acids is desired from a health point of view. Even though it may influence key quality factors of the fried food like texture and appearance (Brinkmann, 2000), it is a widely accepted view that the balance of fatty acids does not significantly influence fat uptake (Bognar, 1998).

A minor positive correlation between oil uptake and oxidative degradation of the frying fat has been identified (Dobarganes et al., 2000). The reason for this is probably a combination of decreased oil/air surface tension and increased oil viscosity. Respectively, these are affected by the formation of polar and polymer compounds (see also above section 4.1.3.B Number of fryings).

Would it be possible to affect the oil viscosity sufficiently to obtain a reduced fat uptake? Even though theory predicts that the viscosity of hot oil affects oil uptake, it will not be easy to control this parameter. A high oil viscosity, or a steeply increasing oil viscosity upon cooling will decrease oil uptake because oil flow is hampered especially in the small pores. However the same will lead to less easy drainage or shaking of the oil from the food after it is taken out of the frying oil. In principle the total amount of oil adhering to the food determines the maximum amount of oil that can enter the pores. This suggests that easy drainage can be beneficial (Mellema, 2003).

No food-grade techniques are available yet that alter the wetting/surface tension characteristics sufficiently to obtain a significant reduction in fat uptake over the whole timescale of using a specific batch of frying fat. There seems, however, some potential in delaying the degradation. Up to now the positive correlation between oil degradation and uptake has not been exploited for the development of frying fats with claimed reduced fat uptake. The reason for this is probably that the effect of antioxidants like ascorbyl palmitate, phytosterols, tocopherols, tocotrienols and avenasterols on fat uptake is too small. Most antioxidants will break down quickly because of the high temperatures involved and the presence of a diverse range of chemicals (also formed in reaction with the fried foods) (Mellama, 2003).

4.3. Coatings and batters

Since the properties of the surface of the food are most important for fat uptake, the application of a coating is a promising route. This coating can be thin and invisible or thick like a batter.

As previously mentioned, one of the most often mentioned parameters for reducing fat uptake at the level of the food composition is the moisture content. In principle only the outer layer of the food needs to have low moisture content, which can also be achieved by applying a low-moisture level coating. Hydrophilic biopolymers can be used as water binders in a coating to reduce water loss from the coat. Most commercial biopolymer coating that are claimed to act like this to reduce fat uptake, are polysaccharide coatings. For instance corn zein and gellan gum coatings have been claimed to reduce fat diffusivity. Some coatings are claimed to be ‘more firm’, thereby reducing evaporation (damage). Often the increase in firmness is brought about by thermogelling action or crosslinking. The resulting high gel strength leads to less evaporation damage and hence to a lower water diffusivity (Mellema, 2003).

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