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REVIEW

Nutritional and health aspects related to frying (I)

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Abstract

Current consumer requirements are directed towards improving the quality of foodstuffs expecting that certain processed foods and the ones prepared by frying will exhibit in addition to sensorial attributes nutritional qualities as well. Most of the processing and preparation methods of food are based on heat treatment, which also has less desirable effects on food such as: changing in color, taste, flavor and texture. In addition, during heat treatment by frying beside the aroma compounds formed which are very appreciated by consumers other compounds which are not desirable get also accumulated in the products; those compounds are formed by partial or total alteration of thermolabile nutrients present in food and in the frying oil. Tocopherols, essential amino acids, fatty acids present in food are degraded following hydrolysis, oxidation and polymerization reactions, etc. Therefore we are trying to review the nutritional and the risk factors associated to frying.

Keywords: food safety, food quality, frying process, oils

Introduction

A review of the literature indicates that food industry scientists and public health authorities in several countries, especially European Union member countries, are very worried and concerned in relation to potential health hazards generated by the consumption of oxidized products, which most often contain lipid polymers resulted from oils used repeatedly in frying processes.

Despite the warnings issued by nutritionists regarding the consumption of fried foods, which contain large amount of calories, cholesterol and saturated fats, they have a growing popularity; a moderate consumption of fat is a way to ensure a balanced and healthy diet. It is true that fried food have unique sensorial properties, which make them very attractive for consumers. However the changes taking place in oil due to repeated fryings are often deteriorative and makes the food that is fried an unsuitable product in terms of nutritional facts. During the frying process, which involves subjecting oils at temperatures of 170° - 200°C, water vapor are released from food following heat transfer and some volatile substances present in the product and frying oil will evaporate in the atmosphere while the rest of volatile compounds that remain in the oil are subject to changes through chemical reactions and then absorbed in the fried food [13]. Chemical reactions that occur in oil during frying process are not limited just to thermal oxidation and auto-oxidation, they are more complex [16].

Properties of fried food

Fats and oils play important functional and sensory roles in food products. They are responsible for carrying, enhancing, and releasing the flavor of other ingredients, as well as for interacting with other ingredients to develop the texture and mouth-feel characteristics of fried foods [10].

Man has enjoyed fried foods for thousands of years, the main reason being that these foods have unique and delicious sensory characteristics [27]. One of the fundamental objectives of frying is to make food more acceptable. Fat is the natural palatable agent *par excellence*. When frying food, the hot frying fat that has penetrated into it, replaces part of the water it contains, making the food considerably more palatable [28]. This absorbed fat exerts a tenderizing effect on the crust, as well as a wetting effect on the food, and thus contributes for the popularity of deep fried foods, namely, their flavor, crispness and pleasant eating characteristics [26]. The typical fried flavor is mainly due to lipid degradation products originating from frying oils [21]. Foods fried at the optimum temperature and time have golden brown color, are properly cooked, and crispy, and have optimal oil absorption. Underfried foods at lower temperature or shorter frying time than the optimum have white or slightly brown color at the edge, and have ungelatinized or partially cooked starch at the center [6].

The following scheme shows a possible mechanism for the production of 2,4-decadienal from 2-decenal [29].

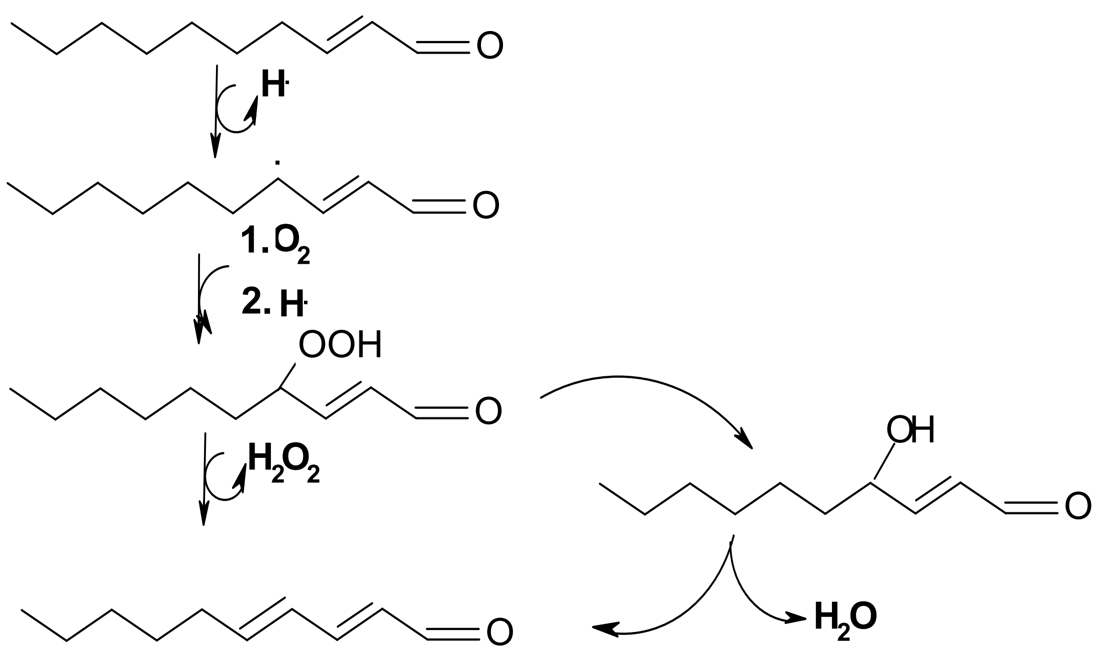

Figure 1. Proposed mechanism for formation of 2,4-dienals in heated triolein by hydroperoxidation with water/peroxide elimination reaction of 2-enals produced from decomposition of oleic hydroperoxides [29]

The volatile oxidation products of linoleic acid such as dienals, alcanals, lactones, hydrocarbons, and various cyclic compounds are the most important flavor compounds found in fried foods. The oxidation products of oleic acid are less important in contributing to the fried flavor [20].

Table 1. Contribution of fried food to the resulting fried flavor [21]

Original food component	Process occurring during frying	Typical flavor products
Sugars	Pyrolysis (Caramelization) Formation of Maillard products and their thermal decomposition	Furan derivatives Furan and pyrrole derivatives
Amino acids and proteins	Direct pyrolysis, deamination Interaction with volatile aldehydes Formation of Maillard products and Strecker degradation	Aldehydes Pyrazines Aldehydic and amine derivatives
Sulfur compounds	Pyrolysis Oxidation and pyrolysis Interaction with aldehydes	Thiols Sulfides Thiazines Trithiolanes
Lipid present in food	Oxidation and cleavage Interaction with amines Interaction with sulfur compounds	Aldehydes Pyrroles Thiols, Sulfides
Phenolics	Oxidation Pyrolysis	Aromatic derivatives
Terpenes	Oxidation Condensation and polymerization	Oxygenated products

2,4-Decadienal and 2-heptenal, which are derived directly from linoleic acid decomposition, are assumed to contribute the most to the deep-fried odor because of the high parts per million levels produced. The effect that these compounds, when produced indirectly and at low levels, have on the deep-fried flavor in foods is not fully understood, although foods fried in high-oleic oils have low intensities of deep-fried flavor [30]. The compounds may have been formed by the hydroperoxidation or hydroxylation of the allylic methylene carbon hydrogen followed by loss of hydrogen peroxide or water from 2-alkenals produced by decomposition of oleic hydroperoxides [29].Various specific components of fried substances contribute to the overall flavor (table 2). Therefore, it is possible to distinguish between flavors of different fried foods. The main chemical processes resulting in flavor substances have been reviewed by Pokorny [21].

Nutritional aspects of fried food

There is a constant concern to pinpoint the effects that the various factors involved in a thermal, industrial or culinary process have on the nutritive value of the food that is processed. When the fat penetrates the food, it may selectively modify the composition of the food, as if in a kind of chromatographic process. The changes produced depend on numerous factors, such as the composition of frying fat and of the food, the texture, size and shape of the food and the frying conditions such as temperature, duration, etc. All these factors influence the changes that occur in the nutritive value of the fried food [28]. Undesirable changes may occur concurrently with desirable modifications, one such change being the loss of nutrients, and especially vitamins, during the frying process [8].

Deep-fat frying has significant advantages over other cooking methods: the temperature within the product (aside from the crust region) is below 100 ^{0}C; the frying time is short and there is insolubility of water-soluble vitamins. Therefore, less deterioration is expected to heat-sensitive vitamins, in comparison with baking or boiling [23].

Fat intake-uptake during frying

The intake of too much saturated fat, too many calories and cholesterol from animal fats used in frying is a problem that has been already addressed by many medical and nutritional bodies. The public is now fully aware of the risks in relation to atherosclerosis and other diseases [4]. Total fat intake may influence some of the major risk factors for coronary heart disease, particularly through its impact on obesity and type II diabetes. Recent studies have shown that a high-fat meal may also impair vaso-activity and transiently impair endothelial function [15].

Fat intake is a much smaller contributor to coronary heart disease than the type of fat [12]. It is evident that the fatty acid composition of a particular fat is more important that its absolute concentration regarding these diseases [22]. High intakes of saturated fats and trans fatty acids have been recognized as a risk factor for coronary heart disease [12]. The degree of saturation of fat used for deep-frying will be reflected in the fat content of the chips, and this will significantly influence the tendency to artheroscrelosis and thrombosis [15].

The study of oil uptake during the frying of foods is complex and depends significantly on the substrate to be fried [14].

The fat content increases with increasing frying time. Foods of plant origin absorb more than foods of animal origin. The highest fat uptake has been observed in fried vegetables, such as peeled eggplant, tomatoes, onion, mushrooms and flesh pineapple. White bread also absorbs a lot of fat. The fat intake of peeled potatoes was 19.4% after 70 seconds, which is higher than the fat intake of fried chicken, meat, fish or prawns. Low fat changes have been determined in frying beef, pork, lamb or sausages [21].

Frying oils and fats are absorbed by cooked food, and so become part of our diet. The uptake of absorbed oil in food ranges in percentages from 4% to 14% of the total weight, depending upon the food and the type of the frying medium [1]. Frying oil quality influences the oil uptake. The interfacial tension between frying oil and potato surface is high in fresh oil. During repeated frying the polarity of oil increases and the interfacial tension decreases. Therefore, the oil intake increases during repeated potato frying [19].

Vitamin changes during frying

Several vitamins are sensitive to higher temperatures and oxidation, but high temperatures are reached only in surface layers of fried food, where their loss is certainly very high. Total losses depend mostly on internal temperature, which usually varies between 70 and 90^{0}C. In this range, vitamin retention depends much more on the internal temperature than on the temperature of the frying oil [21].

Vitamin E

Vitamin E is lost along with the oxidation of unsaturated fatty acids during heating. Frying oil is absorbed by the food during cooking and the absorbed quantity depends on the quality of the cooking oil, which affects the net intake of vitamin E [2].

A remarkable resistance has been demonstrated for tocopherol homologues during domestic frying simulation with virgin olive oil, sunflower oil or vegetable shortening oil for eight successive frying operations. Fifty percent of Vitamin E was retained after four to five consecutive frying sessions, depending on the oil type [1].

Vegetable frying oils are an excellent source of vitamin E [5]. All vegetable oils used for frying contain vitamin E at a concentration of between 15 and 49 mg a-tocopherol equivalents/100 g. Fried foods, due to oil uptake, are enriched with considerable amounts of the vitamin. For instance, a portion of 100 g homemade French fries provides up to 50% of the RDA (Recommended Daily Allowance) of vitamin E [23].

An increase in vitamin E loss during frying was observed by Carlson and Tabacchi [5]. Vitamin E (tocopherols) from the frying oil participates in free radical reactions, thus decreasing their rate [21]. However, no significant change in the vitamin E content of the French fries during four days of commercial frying was observed, due to an increase in the fat intake of the fries that compensated for the vitamin E reduction resulting from frying the oil [5].

Simonne *et al.* [24] studied the changes in Vitamin E content of chicken nuggets and breaded shrimp during frying. After frying in soybean and corn oils, an increase in total vitamin E was noted from 4.6 mg/100 g before frying to 4.9 mg/100 g after frying in chicken nuggets and in breaded shrimp from 0.6 mg/100 g before frying to 5.1 mg/100 g after frying [24].

Vitamin A

Vitamin A active carotenes are present in plant foods. If the frying process is short, losses of beta-carotene, the most important representative of this group of pro-vitamins, are kept low. In deep fried vegetables, losses of beta-carotene were twice as high as in shallow-fried foods. Some beta-carotene could migrate into the frying oil. During the frying of cabbage, 29% of beta-carotene was destroyed [21].

The effect of processing on the carotenoid content of Thai vegetables was studied by Speek *et al.* [25]. He found average losses of vitamin A activity of 14% for boiling, 24% for frying, 29% for fermenting, 44% for sun-drying and 60% for sun-drying followed by boiling. Some carotenoids were lost in the cooking water but losses during frying were greater due to leaching into frying oil [25].

Vitamin B and C

Vitamins B_1, B_2, B_6 and C are better retained in frying than in boiling, steaming, or stewing [4].

Thiamin is one of the most important vitamins of the B group. Fortunately, thiamin losses are lower in the case of frying than when food is prepared using other methods [21]. The largest loss of thiamin occurred in boiling (70%), followed by steaming (40%), parching (35%) and frying (30%). This can be attributed to the water-soluble nature of the vitamin being leached out into the water [11].

Riboflavin is another important vitamin of the B group, and is often deficient in human diet. Riboflavin was better retained when frying chicken meat than thiamin was, when frying dark meat. Riboflavin losses in frying calves liver and swine liver were 42.5 and 43.5%, respectively [21]. The losses during the boiling of potatoes, vegetable, meat and fish occur mainly because of leaching. The increase in riboflavin content during frying is significant. This is caused probably by the generation of riboflavin from riboflavin precursors during frying [3].

Niacin is relatively stable. Still 45% losses have been reported in frying pork muscle, beef and chicken meat. In peanuts, niacin content increased during frying [21].

Vitamin C (expressed as ascorbic acid) retention in green vegetables under different cooking methods such as boiling, microwave cooking and stir-frying has been studied by Eheart and Gott [7]. Stir-frying resulted in a better retention of vitamin C than cooking with a lot of water or using a microwave [8].

Table 2. Vitamin C retention of broccoli and green beans cooked using four methods [8]

Cooking Method	Vitamin C % retention in broccoli	Vitamin C % retention in green beans
Stir-frying	76.6	57.5
Microwave	56.8	58.9
Much water	44.8	59.6
Little water	72.2	76.0

The cooking of potatoes under different conditions shows less vitamin C loss for deep frying (5-35 %) a deep frying followed by boiling (30%) and stewing (76%) [3].

Mineral component changes during frying

Mineral components show great changes during cooking operations, such as boiling, because of their solubility in water. Their changes are almost negligible during frying, as they are soluble only in trace amounts in frying oil. Due to water loss, the weight of fried food decreases during frying. Most mineral components are non-volatile, therefore the content of minerals, on wet weight, would be expected to rise. There occurs, however, another process at the same time, i.e., the uptake of frying oil. The weight of fried material increases, and if the metal content is expressed on a dry weight basis, a moderate decrease of mineral content would be found [21].

Mineral losses in deep fried foods vary from 1% in potatoes to 26% in beef, being significantly lower than in boiled foods of the same type. The mineral losses in breaded meat and fish vary after deep-frying from 2% and 8% and are significantly lower than in deep fried meat and fish fillet without coating. The breadcrumbs seem to absorbe the minerals solved in the gravy of meat [3]. Gall *et al.* [9] reported no changes in the mineral composition of mackerel fatty fish after baking or frying. In the case of low fat fish, grouper and red snapper, small losses of major minerals of up to 20% during baking were found but losses after frying were very limited: slight losses in Na, K and Mg were recorded, although Zn, Cu, Fe and Mn did not vary in any case.

Frying influence on mineral metabolism

The influence of the consumption of olive oil, sun-flower oil and palm-olein, unused and used in frying, on the bioavailability of magnesium, calcium and phosphorus in growing rats has been studied by Perez-Granados *et al.* [17]. The type of oil consumed did not influence the bioavailability of magnesium, but the three oils used in frying enhanced magnesium absorption and urinary magnesium without affecting the body retention of this mineral. Calcium absorption efficiency increased in animals consuming both forms of sunflower oil (unused and used in frying), but no effect of the amount absorbed on calcium retention, urinary calcium, serum calcium or carcass calcium was observed. The intake of oils used in frying did not induce any significant changes in Ca bioavailability [17, 18].

Protein changes during frying

If the food is fried without any additional ingredients, as is normally the case, frying does not change the digestibility of the protein. When reducing substances are added to the food that is fried, for instance, carbohydrates (meatballs and fishballs which contain flour), protein digestibility is lowered slightly, albeit significantly [28].

Bognar [3] investigated the effects of certain cooking methods on the protein content of selected foods. The retention of protein in the investigated cooked food varied from 90% in boiled meat and 96% to 100% in deep fried potatoes, meat and fish. The results obtained by Bognar [3] were in concordance with the results of Gall [9] and Varela *et al.* [28]; frying did not change the digestibility of protein.

Table 3. Protein digestibility coefficient of raw and fried foods [28]

State	Hake	Beef	Pork	Swordfish	Meat balls	Fish balls
Raw	0.92	0.93	0.92	0.94	0.90	0.92
Fried	0.91	0.93	0.92	0.96	0.88	0.89

Carbohydrate changes during frying

The change in carbohydrate content during frying has been investigated in potatoes, potato products and breaded meat and fish. The results showed that the retention of carbohydrates varied from 95% to 100%, depending on the kind of food, indicating that the frying method has no influence [3]. In comparison with raw samples, the backing of frozen French fries has no effect on starch composition, while deep-frying significantly increases the percentage of resistant starch. This is partially attributed to the formation of amylose –lipid complexes. Although frying decreases the amount of digestible starch in potato, the dietary fibre content is increased. Dietary fibres are playing an important role in the prevention of diseases such as colonic cancer, cardiovascular disease and diabetes [8].

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