Chemical Reactions Involved in the Deep-Fat Frying of Foods

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ABSTRACT

Deep-fat frying is one of the most commonly used procedures for the preparation and manufacture of foods in the world. During deep-fat frying, oxidative and thermal decompositions may take place with the formation of volatile and nonvolatile decomposition products, some of which in excessive amounts are harmful to human health. A limited survey of frying fats used in commercial operations indicated that some were maintained at good quality and others were overused or abused. The volatile decomposition products produced by corn oil, hydrogenated cottonseed oil, trilinolein, and triolein, under simulated commercial frying conditions, were collected, fractionated, and identified. A total of 211 compounds were identified. The nonvolatile decomposition products produced by trilinolein, triolein, and tristearin under simulated commercial frying conditions were collected and characterized. After being treated under deep-fat frying conditions at 185°C for 74 hr, trilinolein yielded 26.3% non-urea-adduct-forming esters, triolein yielded 10.8%, and tristearin also yielded 4.2%.

INTRODUCTION

Deep-fat frying is one of the most commonly used procedures for the preparation and manufacture of foods in the world. The fast food restaurants which have been growing rapidly in recent years further increase the consumption of fried foods, especially fried chicken, fish and chips, and french fries. Evidently, a major portion of the ten billion pounds of edible fats and oils consumed each year in the United States are used in fried foods. For example, an estimated 500 million pounds of fats and oils are used each year for the manufacture of potato chips and another 200 million pounds in doughnuts.

During deep-fat frying, the oil is continuously or repeatedly used at elevated temperatures in the presence of air. Under such conditions, both thermal and oxidative decomposition of the oil may take place. Such unavoidable chemical reactions cause formation of both volatile and nonvolatile decomposition products. The latter can be isolated from fats and oils which have been used for deep-fat frying as a brownish, transparent, viscous liquid (Fig. 1). They also cause foaming when moist foods are deep-fat fried in the oil (Fig. 2). The foaming is often regarded by restauranteurs and food processors as an indication that the frying oil must be discarded. However, at that time, there is already a considerable amount of decomposition products in the oil. Foods fried in such oils during the period prior to the foaming may contain a sufficient amount of decomposition products to cause adverse effects to the safety, flavor, flavor stability, color, and texture of the fried food. For example, foods fried in oils with a foaming tendency are often greasy and less crispy. In addition, such decomposition products, both volatile and nonvolatile, may effect human health.

Various symptoms of toxicity, including irritation of the digestive tract, organ enlargement, growth depression, and even death have been observed when highly abused (oxidized and heated) fats were fed to laboratory animals. Kaunitz et al. (1) autoxidized lard and cottonseed oil at 100°C for 210 hr and found growth depression, diarrhea, and rapid death when the product was fed to Albino rats. Crampton et al. (2) heated polymerized linseed oil at 275°C for 12 hr under carbon dioxide and found toxic materials which are believed to be monomeric cyclic acids. Perkins and Kummerow (3) reported significant growth depression after feeding rats corn oil that had been heated at 200°C for 48 hr while being aerated with a stream of oxygen.
elucidation of the chemical structure of such decomposition products and their possible toxicity were reviewed by Artman (4).

Furthermore, there is some evidence that highly oxidized and heated fat may have carcinogenic properties. As early as 1944, Roffo (5) suggested that heated fat might cause cancer. He found that sunflower and olive oils oxidized by heating to 250-350°C had carcinogenic potential when fed to rats. Peacock and Beck (6) reported that long term feeding of heated oil to mice raised the incidence of squamous carcinomas. Sugai et al. (7) claimed that the non-urea-adduct-forming fraction isolated from heated corn oil acted in synergism with 2-acetylaminofluorene and enhanced its carcinogenic activity. Among the volatile decomposition products, Dickens and Jones (8) reported the carcinogenic properties of some unsaturated lactones.

Results of investigations from laboratories using commercial frying fats and oils, on the other hand, generally indicated that such decomposition products have no deleterious effect upon human health. Melnick et al. (9) concluded that the oils used in the production of potato chips are free of thermal polymers and that there is no reason to question the wholesomeness of the oil being absorbed by the chip. Keane et al. (10) reported that hydrogenated cottonseed oil used in a commercial deep fryer under actual production conditions for as long as 24 days had no toxic effect on rats when fed at levels as high as 20% of the diet. Rice et al. (11) claimed that fats are not nutritionally damaged when handled by normally accepted good practice in present day food preparation.

Very recently, Billek and Guhr (12) isolated a large amount of the thermally oxidized materials from oils used commercially for production of fish-fingers which were taken at the end of a production period when the oil was usually discarded, according to the practice of this company. The oil contained only 6.5% of polymeric materials which, based upon their quality assessment work of commercial frying oil, could still be considered to be of good quality. They reported that when the thermally oxidized materials were fed to rats at 20% by weight in the diet over a period of one and a half years, growth retardation, increased weight of liver and kidney, increased SGPT and SGOT activities were observed.

It is, therefore, evident that fried foods prepared with fresh oils or fats under good food preparation practices are delicious in flavor and have no adverse effect upon human health. However, if the frying oil or fat is overused or abused in the frying process, the triglycerides may produce thermal oxidative materials harmful to human health.

SURVEY OF COMMERCIALLY USED FRYING FAT

A limited survey was conducted in 1967 with 21 sets of samples of fats and oils commercially used for deep-fat frying in restaurants, food processing plants, and institutions (13). Each set consisted of two samples: one was the fresh oil before it was used for frying; the other was the same batch of oil after it had been used for deep-fat frying until it was ready to be discarded in the batch process or until it had reached a state of equilibrium in continuous process. The results clearly demonstrated that some of the fats and oils commercially used for deep-fat frying were maintained at good quality and others were overused or abused to a higher degree of deterioration. This could be observed even visually. The sample of cottonseed oil used commercially for the manufacture of potato chips (Fig. 3, left top) was evidently not abused, while that used commercially for the manufacture of another food product (Fig. 3, left bottom) was badly damaged. The same wide range of deterioration was observed in more saturated hydrogenated shortenings. The sample collected from the dining hall of a university.

![FIG. 3. Comparison of two sets each of cottonseed oils (left) and hydrogenated shortenings (right) before and after being commercially used for deep-fat frying.](image)

![FIG. 4. Laboratory apparatus for deep-fat frying under simulated restaurant conditions.](image)

![FIG. 5. Apparatus used for treating pure triglycerides under simulated deep-fat frying conditions.](image)