Dishing the Dirt on Deep-Fat Frying

Deep-fat frying (DFF) is one of the oldest cooking methods, very well established in a wide variety of cultures worldwide. DFF involves immersing food in hot oil at temperatures of 302 degrees Fahrenheit (F) to 374 degrees F (Choe & Min, 2007). The interactions of heat and transfer of oil, food, and air give fried foods their unique culinary profile (Choe & Min, 2007). However, the story on deep-fat frying goes beyond "extra fat calories". DFF changes the quality and nutritional value of the food due to dynamic and complex biochemical reactions. The process of DFF affects the quality of the oil, which in turn affects the food. The food itself also affects the quality of the oil. The quality of the oil is important because oil degradation and by-products of DFF create potential health risks.

Deep fried foods have a distinct flavor, crunchy texture and color that set them apart. Oil gives deep fried foods that special flavor. Oil choice to complement the food is important. Fried food flavor has been described as "fruity, grassy, buttery, burnt, nutty, and fishy" (Choe & Min, 2007, p. 81). Linolenic acid of oil is mostly responsible for flavor (Choe & Min, 2007). Different qualities and quantities of fatty acids in different oils account for different flavors (Choe & Min, 2007). Oxidation of linolenic acid increases the "fishiness" and decreases the "fruity/nutty" flavor (Choe & Min, 2007). Flavor also depends on the number of fryings the oil has been through (Choe & Min, 2007).

Deep fried foods absorb the frying oil which is how the special flavor gets inside the food. During frying, moisture inside the food violently escapes as steam via bubbles seen in oil and creates microstructural defects such as cracks, open channels/capillaries, and damaging the cell walls (Dueik & Bouchon, 2011). The theory is that the escape of water vapor creates a kind of barrier that keeps most of the oil accumulation during frying at (or just below) the food's surface (Choe & Min, 2007; Dueik & Bouchon, 2011). It is during the cooling process that more oil gets absorbed into the food's interior (Choe & Min, 2007; Dueik & Bouchon, 2011). For example, oil uptake in tortilla chips occur within the first 20 seconds of cooling (Dueik & Bouchon, 2011). Moreira et al. (as cited in Dueik & Bouchon, 2011) theorized that oil absorption works like capillary action. Although the oil absorption methods are not well known, yet, the use of dyes in oils confirms the process does take place during cooling (Dueik & Bouchon, 2011). Variables influencing the amount of oil absorbed into the food are type of food, frying time, oil selection, moisture of food, and battering/breading/coating of food prior to frying (Choe & Min, 2007).

Deep fried foods have a crunchy textural quality as well. In the deep frying process stage 1, the surface of the food is heated (Dueik & Bouchon, 2011). Stage 2 marks the sudden, volatile loss of water from the food and the start of crust formation (Dueik & Bouchon, 2011). The food loses most of its moisture content in stage 3, which is also the longest stage. Crust formation is the result from altering the food's structure at the cellular level on the outer layers (as opposed to the core) of the food--rapid dehydration, breakdown and release of cellular material, structural damage from high heat, starch gelatinization, protein denaturation, breakdown of cellular adhesion, water evaporation, and oil uptake (Dueik & Bouchon, 2011). Different foods have different composition and therefore, the crust varies with the food.

Unique flavor and crunch are distinctive features of deep-fried foods. A large part of the appeal is the color and when properly fried, ranges from orange-brown to golden-brown (Choe & Min, 2007; Del Carmen Flores-Álvarez, Molina-Hernández, Hernández-Raya, & Sosa-Morales, 2012). The coloration is due in large part to the complex non-enzymatic "browning" Maillard reaction (MR) involving sugars and certain amino acids (Choe & Min, 2007; Delgado-Andrade, 2014; Vinci, Mestdagh, Van Poucke, Van Peteghem, & De Meulenaer, 2012). Under heat (especially the high heat of DFF) the sugars break down and their carbonyl group (carbon double-bonded to oxygen) start to bind to the amino groups forming new compounds (Amadori compounds) which are known as Maillard reaction products (MRPs) or advanced glycation end-products (AGEs) which are formed from the oxidation and dehydration of Amadori compounds (Foodsciencetv, 2011, Delgado-Andrade, 2014; Toda, Heilmann, Ilchmann, & Vieths, 2014).

Advanced glycation end-products (AGEs) from the MR have been associated with diabetes (renal issues, diabetic nephropathy, glomerular hypertrophy, and mesangial damage), weight gain, neurological disorders (Alzheimer's and Parkinson's disease), sarcopenia, bone/cartilage pathology (rheumatoid arthritis, impaired bone remodelling, and less structurally robust bones), immune response as some AGEs act as immune epitopes, and cardiovascular disease complications (aterial stiffening, myocardial anomalies, plaque build-up in arteries, contribution to endothelial dysfunction) (Delgado-Andrade, 2014; Toda et al., 2014).

One particular reaction involving carbonyls and the amino acid asparagines produces acrylamide (Choe & Min, 2007; Vinci et al., 2012). Acrylamide (AA) is carcinogenic to humans (Dueik & Bouchon, 2011). Potato products (e.g. French fries and chips have highest recorded AA concentrations) are especially prone to this biochemical pathway due to asparagine's abundance in potatoes (Dueik & Bouchon, 2011). Hydroxymethylfurfural (HMF), a MRP, is found in processed bakery goods like fried dough, biscuits, box cereals, bread, processed fruits, and carbohydrate-rich foods (Dueik & Bouchon, 2011). HMF is toxic to living cells (cytoxic), damages genetic information (genotoxic), alters genetic expression (mutagenic), and carcinogenic (Dueik & Bouchon, 2011). DFF fish and meat may create carcinogenic heterocyclic amines (HAs) via MR that have been shown to cause cancer in rats, mice, and primates (Dueik & Bouchon, 2011). The concentration of HAs increase with cooking time and temperature Dueik & Bouchon, 2011). The International Agency for Research on Cancer (IARC) considers HAs to possibly be harmful just as a precaution (Dueik & Bouchon, 2011).

Deep-fried food undergoes a lot of changes and becomes less nutritious during the DFF process. The other side to consider is the role of oil, the heat transfer medium, and its degradation resulting from thermal stress, interacting with air, moisture, food particles, and the fryer (contact with metal and atomic level exchange). Oil under such thermal stress undergoes oxidation, isomerization, polymerization, and hydrolysis (Del Carmen Flores-Álvarez et al., 2012). Hydrolysis results from exposing oil to moisture (from food), steam, and air (Choe & Min, 2007; Dobarganes & Márquez-Ruiz, 2013). Triacylglycerols (TAG, or triglycerides, simple lipid found in animal and plant based fats/oils with one glycerol molecule linked to 3 fatty acids) are broken down into di- and mono- acylglycerols, glycerol, and free fatty acids which increase with repeated use of the same frying oil (Choe & Min, 2007; Dueik & Bouchon, 2011). The amount of free fatty acids in the oil is an indicator of oil quality and repeated use (Choe & Min, 2007). These diacylglycerols, monoacylglycerols, glycerol, and fatty acids are less stable than their parent TAG.

Thermal oxidation of oil occurs when hydrogen is lost "in the presence of heat, light, and trace metals" and forms hydroperoxydes (Dueik & Bouchon, 2011, p. 418). The free fatty acids and oxidized compounds give "old oil" that bad off-flavor (when you know the oil has not been changed recently) (Choe & Min, 2007). Highly oxidized and heated fats may undergo an array of reactions resulting in hydroperoxides and 4-hydroxy-2-trans-nonenal (HNE) from linoleic acid oxidation (Dueik & Bouchon, 2011). HNE is potentially carcinogenic as it has been shown to possess cytogenic and mutagenic qualities (Dueik & Bouchon, 2011).

Further oxidation can cause formation of aldehydes or ketones, and the oil cooling/reheating cycle opens up even more reactive pathways (Del Carmen Flores-Álvarez et al., 2012). These structural alterations darkens the oil's color, increases viscosity, and decreases the smoke point (Duiek & Bouchon, 2011). Two other compounds may be formed as linolenic and linoleic acids degrade, 4-hydroxy-2-trans-hexenal (HHE) and 4-hydroxy-2-trans-octenal (HOE) (Dueik & Bouchon, 2011). HHE and HOE negatively affect proteins, necleic acids (DNA, RNA) and have been linked to atherosclerosis, Alzheimer's and liver diseases (Dueik & Bouchon, 2011).

Repeated usage of frying oil can also cause formation of trans-fats. Del Carmen Flores-Álvarez et al. (2012) study on the effects of deep-frying fish nuggets and French fries on oil degradation found that after 12 days of frying, the trans-fatty linoelaidic acid was found present in the oil.

Vitamin E, a natural antioxidant present in vegetable oils, is made up of tocopherols (Toc, with alpha, beta, gamma variants) (Andrikopoulos, Dedoussis, Falirea, Kalogeropoulos, & Hatzinikola, 2002). The oxidation of fatty acids during DFF, destroys Toc (Andrikopoulos et al., 2002). Phenolic compounds are also natural antioxidants present in vegetable oils especially olive oil. These beneficial properties of olive oil, are also destroyed in high heat via oxidation of fatty acids and other subsequent chain reactions (Andrikopoulos et al., 2002; Foster, Williamson, & Lunn, 2009).

During deep-fat frying, both oil and food become much less nutritious due to many dynamic, complex biochemical reactions which vary depending on environmental factors. The by-products from the DFF process are often unexpected and less than desirable. The "bad" quality of DFF and deep-fried foods is much more than a few extra calories gained. The long-term exposure risks still are not clearly known, and there is still much to learn including occupational health hazards from exposure to air particles and steam/vapor from DFF.

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