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Frying

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Frying

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Introduction
The snack industry (which includes many fried vegetable products) is an important part of the food industry worldwide, mainly in Europe and the USA, with sales around the world of almost $374 billion annually, increasing by approximately 2% year-on-year (Pedreschi et al., 2018). The current changes in eating habits and the short time people allocate to eating have produced substantial changes in both the frequency and the type of regular meals, which has left a gap for the creation of new snacks with different sensory, nutritional and technological characteristics. Frying, a very old unit operation (Zeb, 2019), is increasingly used worldwide in fast food outlets and at home, which has led to concerns about its health implications (Pedreschi et al., 2018).

Frying is a food unit operation in which the liquid transferring heat is hydrophobic, yet becomes part of the food. Deep-fat frying consists of immersion of food pieces in hot vegetable oil. It is a rather complex process, comprising simultaneous heat and mass transfer with chemical reactions and textural changes taking place. The intense heat and mass transfer achieved during deep frying have led to innovative applications for food materials. As a result of frying, the piece of food emerges sterile and dry at the surface, with increased shelf-life. The high temperatures of frying (e.g., >120 °C) eliminate microorganisms from the food, favouring its microbiological safety (Pedreschi, 2012).

Deep-fat frying also involves significant microstructural changes. Most of the desirable characteristics of fried foods are derived from the formation of a composite structure: a dry, porous, crispy and oily outer layer (crust) and a moist cooked interior (core) are formed during the process in the case of fried potato strips (Bouchon et al., 2001). The high temperatures of frying oils typically lead to a desirable surface colour; the heating of sugars causes a complex group of reactions leading to browning development, which defines the colour of the final product. Additionally, toxic compounds (like acrylamide) may be formed during this process, in particular as a result of Maillard reactions. Moreover, some heat-induced toxicants that can be formed during frying include ethyl-carbamate, furan, heterocyclic amines, 5-hydroxymethylfurfural (HMF), polycyclic aromatic hydrocarbons and nitroso-amines (Murkovich et al., 2018).

The characteristics of fried products depend not only on the frying conditions but also on the type of oils and foods used during the process (Aguilera and Gloria-Hernandez, 1997). Immersing frying or deep-frying is a common multi-functional unit operation for fast frying, texturing and cooking of foods. For decades, consumers have desired fried foods because of their unique combination of flavour, colour and texture (Saguy and Dana, 2003).

Oil Uptake
Over the last two decades, reducing the oil content of fried products has had great appeal. The consumer trend is towards healthier and less greasy products (Ziaiiifar et al., 2010). The majority of fried foods initially contain low levels of fat. The mechanism of oil uptake has been studied primarily to understand the phenomenon and to develop the know-how and means to reduce the final oil content (Dana and Saguy, 2006). However, in spite of all these efforts, fried food products still possess significant amounts of fat, exceeding 30% in some cases (Table 53.1). The oil content in each fried product will depend on the frying conditions, and principally on the original microstructure of the raw material and the changes that it undergoes during deep-fat frying (Pedreschi, 2012).

Oil uptake is mainly a surface phenomenon, as confirmed by many experimental observations (Baumann and Escher, 1995). Both the oil content and the moisture content are critical parameters that determine the quality and stability of fried products (Pedreschi and Moyano, 2006). The final oil and moisture content of the fried food will depend on its microstructure, chemical composition, geometrical shapes and process conditions (Saguy and Dana, 2003). Moisture content is an important property in fried food product quality. It is desirable that the moisture and oil content in fried foods are expressed on a dry basis (free of oil), since both the oil and the water content of the sample being fried change during the process (Moreira et al., 1999).

These issues have prompted a search for technologies that reduce the absorption of oil, preserve the nutritional value of raw materials, and mitigate the formation of potentially toxic compounds such as acrylamide, furan and HMF while keeping the desirable eating quality of fried products (Medeiros et al., 2012; Pedreschi et al., 2018). Frying involves heat transfer by convection (from the hot oil at 160 to 190 °C) and conduction (to
Chemical, Physical and Microstructural Changes

During frying, chemical, physical and microstructural transformations of raw food material tissue are also induced (vegetable or animal). These changes are responsible for the final attractive sensorial attributes of fried products (Pedreschi, 2012). The study and modelling of the kinetics of the changes in some important physical properties in potatoes during frying have been reported (Moyano and Pedreschi, 2006; Pedreschi et al., 2005; Pedreschi and Moyano, 2005; Pedreschi et al., 2001). However, in parallel with the development of colour, texture and flavour of the food pieces being fried, excessive heating in frying can produce (according to the chemical composition of the raw material) undesirable reactions and the formation of potentially toxic compounds such as acrylamide, furan and HMF, among others. As said, due to Maillard reactions, fried products develop not only attractive sensory attributes, such as odour and colour, but also some undesirable toxic contaminants such as acrylamide and HMF, which are potential human carcinogens. The high temperatures favour reactions between some substances naturally present in the raw food (e.g., reducing sugars and asparagine), inducing the formation of some toxic compounds such as acrylamide and furan, and in this way, negatively affect the chemical safety of some starchy fried foods (Pedreschi, 2012; Murkovich et al., 2018).

During atmospheric frying, fats and oils can reach much higher temperatures than water at normal atmospheric pressure. Therefore, the food sample is cooked quickly and acquires the desirable and attractive sensorial attributes. If the frying time is too long, the surface of the food could even be carbonized, while some sugars are chemically modified. On the other hand, in vacuum frying, the food is heated under reduced pressure in a closed system that lowers the boiling points of frying oil and the moisture in the food (Garayo and Moreira, 2002). Mariotti et al. (2018) showed that vacuum frying is an effective technology for furan and acrylamide mitigation in potato chips, since it reduces the content of both contaminants and preserves the quality attributes of fried snacks. Vacuum-fried potato chips showed reductions of about 81%, 58% and 28% of furan, acrylamide and oil content, respectively, when compared with their atmospheric counterparts. Vacuum frying can be considered as a promising technology to produce healthier potato chips.

According to the food microstructure, geometrical shape and frying process conditions, two principal kinds of fried products could be formed after frying (Pedreschi, 2012; Pedreschi et al., 2001). In the case of fried potatoes, there are: (a) thin fried slices (chips), characterized by having a dehydrated and crispy region where oil is located and some toxic compounds such as acrylamide could be distributed inside it; and (b) a composite structure formed by two regions, such as an external dehydrated and crispy region, where oil is located and where some toxic compounds such as acrylamide could be distributed, and a humid and cooked core free of oil and acrylamide, and other toxic compounds formed in the surface, which could not migrate into the core.

Microstructural changes in the core are similar to those occurring during the cooking of potatoes (Bouchon and Aguilera, 2001). Starch granules undergo gelatinization when the temperature is higher than 60 °C, being swollen rapidly by intracellular water, occupying the whole interior of the cell. The middle lamellae that cement cells disintegrate within a narrow temperature range (60–80 °C), and cells separate, giving a so-called

### TABLE 53.1

Typical Mean Water and Oil Content of Some Fried Foods

<table>
<thead>
<tr>
<th>Product</th>
<th>Mean water content (%)</th>
<th>Mean oil content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato chips</td>
<td>2.5</td>
<td>34.6</td>
</tr>
<tr>
<td>Corn chips</td>
<td>1.0</td>
<td>33.4</td>
</tr>
<tr>
<td>Tortilla chips</td>
<td>1.8</td>
<td>26.2</td>
</tr>
<tr>
<td>Doughnuts (plain)</td>
<td>20.8</td>
<td>22.9</td>
</tr>
<tr>
<td>Onion rings</td>
<td>28.5</td>
<td>18.7</td>
</tr>
<tr>
<td>Chicken breast-breaded</td>
<td>45.7</td>
<td>18.1</td>
</tr>
<tr>
<td>Fish fillet-battered or breaded</td>
<td>53.6</td>
<td>12.9</td>
</tr>
<tr>
<td>French fries/par-fried</td>
<td>39.5/37.9</td>
<td>14.8/7.6</td>
</tr>
</tbody>
</table>

Source: Reprinted from Saguy and Dana (2003) with kind permission of Elsevier.
mealy texture. In addition, proteins may denature. A summary of these microstructural changes appears in Figure 53.1.

On the other hand, the crust is the result of several alterations that mainly occur at the cellular and sub-cellular level, starting from the outermost layers of the food, where the temperature exceeds 100 °C. These chemical and physical changes include: physical damage produced when the product is cut and a rough surface is formed with release of intracellular material; starch gelatinization and subsequent dehydration; protein denaturation; breakdown of the cellular adhesion; water evaporation and rapid dehydration of cells located in the forming crust; oil uptake; and acrylamide formation. These changes give rise to the development of a composite structure formed of two parts: (i) a crispy, porous and oily outer layer or crust and (ii) an inner core with a moist cooked interior, where the lamella media solubilizes and starch gelatinizes. Bouchon et al. (2003) explained that three different oil fractions can be identified as a consequence of the different absorption mechanisms in fried potato cylinders: (i) structural oil (STO), which represents the oil absorbed during frying; (ii) penetrated surface oil (PSO), which represents the oil sucked into the food during cooling after removal from the fryer; and (iii) surface oil (SO), which is the oil that remains on the surface (Figure 53.1). These authors showed that a small amount of oil penetrates during frying, because most of the oil was picked up at the end of the process, suggesting that oil uptake and water removal are not synchronous phenomena. These findings have been confirmed by Pedreschi et al. (2008) and Durán et al. (2007).

Frying induces significant microstructural changes that can be understood by using different modern visualization techniques. In the case of potato tissue, most revealing has been a video microscopy study of in situ frying of potato cells showing that the starch granules swell rapidly at a temperature of 65–75 °C (Deslandes et al., 2019), which is well below the temperature used for frying. Steam bubbles leave the interior of the cells through pores in the cell walls (probably through plasmodesmata) and find their way to the product/oil interface through many intercellular passages. Swollen starch granules remained as a compact mass pressing on the outer cell wall before becoming dehydrated at higher temperatures (Bouchon and Aguilera, 2001). Cells heated in oil to 180 °C remained largely intact and decreased marginally in surface area without any evidence of oil in their interior (Aguilera et al., 2001).

Confocal laser scanning microscopy (CLSM), a non-invasive technique that produces optical sections at increasing depths in the specimen, demonstrated that oil is located in an “egg-box” arrangement surrounding intact potato cells. By using CLSM, Pedreschi and Aguilera (2002) described the absorption of oil in potato chips as seeming to wrap the surface of the parenchyma cells of potatoes like an egg box (Figure 53.2).

Conclusions

Deep-fat frying is a complex process comprising simultaneous heat and mass transfer, with chemical reactions and textural changes taking place. Deep-fat frying processes can take place at atmospheric pressure (conventional frying) or at pressures below atmospheric (vacuum frying). Additionally, deep-fat frying involves significant microstructural changes. The food piece in contact with hot oil heats up, water is lost and oil content increases; reactions between reducing sugars and amino acids lead to browning and changes of texture, with softening at the beginning of frying, and hardening of the external layers of food.
with longer frying time. As a result, frying is often selected as a method for developing unique flavours and improving texture in processed foods that enhance their overall palatability.

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REFERENCES


