Characterization of the Distribution of Oil Uptake in French Fries

Clifford S. Todd,[1]* David M. Williams,[1] and Jing Guo[2]**

[1]Analytical Sciences, The Dow Chemical Company, Midland, MI

[2]Food & Nutrition R&D, The Dow Chemical Company, Midland, MI

*CTodd2@dow.com

**Retired

Abstract: Methyl cellulose based coatings applied to food before deep-fat frying can reduce the amount of oil absorbed by the food during cooking as measured by bulk analysis techniques. However, information about the distribution of oil in the food, and how that is impacted by the coatings is lacking. A method is presented using osmium tetroxide to stain the oil and light microscopy to visualize its distribution. The method was applied to French fries and showed that the extent of oil ingress was reduced when a methyl cellulose coating was used.

Keywords: light microscopy, fat content, methyl cellulose coating, osmium staining, image analysis

Introduction

Deep-fat cooking is a common cooking technique used to quickly produce tasty and satisfying food, both in texture and flavor. Through the years concerns have grown regarding negative health consequences of fried foods. These concerns are generally associated with the addition of fat to the food during the frying process. Obesity rates in the USA and many other countries are rising, and some of the blame is directed toward the fat content of the public's diet [1]. Because of this, food producers are coming under increasing pressure to lower the fat content of their foods. For deep-fried foods this requires an understanding of the mechanisms of oil uptake during deep frying and what to do about it.

When room temperature food such as potato is submerged in hot oil, the water inside the food will boil. The resulting volume increase causes steam bubbles to leave the food, leading to the foaming and bubbling typically seen during frying. The continual escape of steam bubbles can establish small capillary channels between the interior and the food-oil interface. When the food is removed from the hot oil, the temperature in the food decreases to the point where steam still inside the food condenses back to liquid. The resulting volume decrease may lead to surface oil being drawn into the interior of the food, increasing its fat content [2].

Several variables can impact the amount of oil absorbed during frying [3]. The temperature and the length of time frying interact to impact the caloric increase during frying. At lower temperatures thorough cooking takes more time, generally leading to more oil uptake. Even assuming thorough cooking, the length of time in a hot oil bath at a given temperature is a variable controlled by the chef. Generally, cooking so long that steam bubbles diminish or cease leads to more oil uptake in the food. Controlling the temperature and time of cooking need to be balanced with their impact on the flavor and texture of the food. Surface roughness of the food and viscosity of the oil can also impact ultimate fat uptake [4,5].

Other than optimizing the frying process, an approach to reduce the amount of oil absorbed by food during deep frying is to apply a coating designed for that purpose [6,7]. Some materials form a barrier that can reduce the ability of oil to penetrate into the food. The Dow Chemical Company has developed a suite of products under the brand name WELLENCE™ Smart Fry for this purpose [8]. They contain methyl cellulose, a material with the unusual property that the viscosity of formulations *increases* with

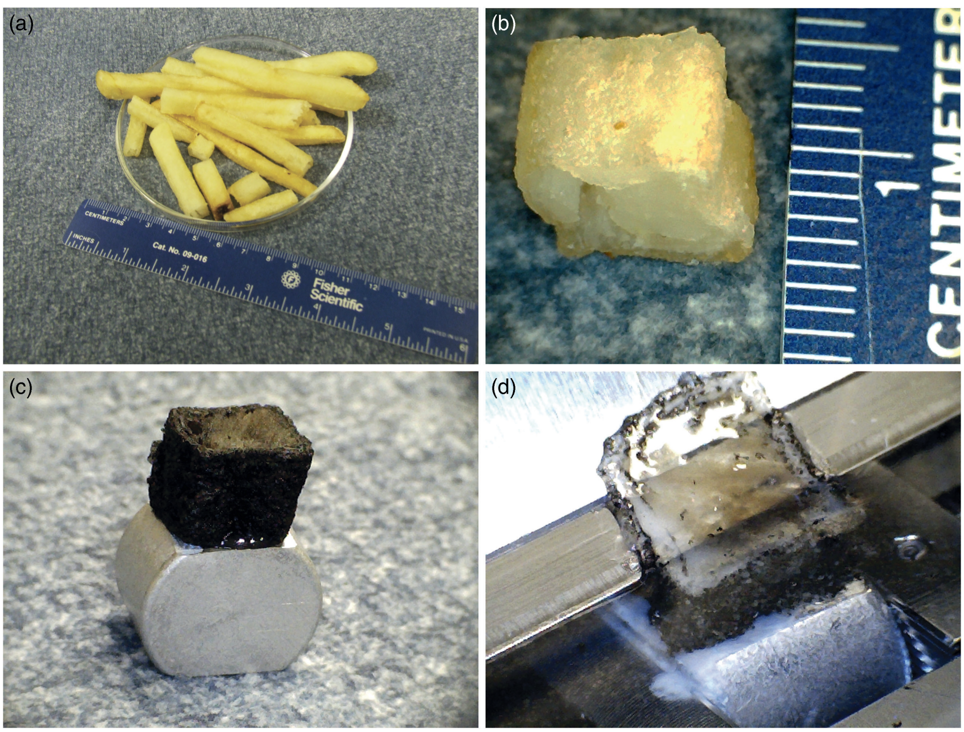

Figure 1: Sample preparation. (a) Cooked French fries. (b) Cut fry sample. (c) Osmium-stained fry glued to stub. (d) Vibrotome blade part-way through cutting a section.

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Table 1: Batter coating formulation

Ingredient	Brand	Amount (wt%)
Corn Starch	HYLON VII corn starch	10.3
Rice Flour	Ener-G gluten-free white rice flour	13.0
Salt	Morton's iodized	0.8
Methyl cellulose	WELLENCE™ SmartFry 900	1.0
Water	Tap water at 4°C	75.0

increased temperature. Therefore it can be applied as a thin, low-viscosity batter that, when heated, forms a gel [9]. The gelled formulation inhibits oil entering the food, reducing fat uptake generally by more than 30% [10,11]. The batter can even have the added benefit of reducing some of the water loss from the food, leading to a moister product. Batters can also decrease heat transfer coefficients, which have also been correlated to decreased fat uptake [12]. Whether incorporated into batters currently used on the food, or applied as a thin topcoat over an existing breading or directly onto unbattered food, these coatings do not negatively impact flavor or texture profiles of fried food.

The impact of fat reduction strategies can be measured by bulk analysis techniques such as Soxhlet extraction. However, information about the spatial distribution of oil within the fried foods is harder to come by. Nuclear magnetic resonance imaging [13] and X-ray imaging using radiolabeled ^{14}C palmitic acid [14] have been applied to visualize the fat distribution across cross sections of French fries. However, these techniques are not readily available, moreover they are slow and expensive. Confocal microscopy has been applied, using fluorescence-labeled oil to visualize its location at the pore and cellular level [15]; the special oil required for this method negates the ability to apply it to commercially available fried food. The purpose of our investigation was to develop a practical method (relatively fast and readily available) to characterize the distribution of oil across entire pieces of fried food.

Materials and Methods

Materials. Russet potatoes and salt were purchased from a local market in Midland, MI. Rice flour was purchased from Ener-G; corn starch was purchased from National Starch. WELLENCE™ Smart Fry 900 was acquired from Dow Chemical.

Preparation of potato strips. Potatoes were hand-peeled, with both ends cut off. Those potatoes were cut into strips with the cross section of 3/8 inch × 3/8 inch, and uniform pieces were chosen for experiments. The strips were rinsed with water and then blanched in water at 85°C for 7 min. After blanching, the potato strips were immersed in 0.2% citric acid solution at 95°C for 1 min. Then, all pieces were drained and dried in a conventional oven until ~10% weight loss was achieved.

Batter coating. Batters were prepared by dry blending rice flour, corn starch, WELLENCE™ Smart Fry, and salt in a mixing bowl (Kitchen Aid) with a wire whisk attachment according to Table 1. Water was then added to the dry ingredients, and the mixture was blended at medium to high speed for about 30 seconds. The mixture from the side of the mixing bowl was scraped down and blended for another 30 seconds, after which the mixture was blended for an additional 8 minutes at a lower speed (slow to medium-slow). The batter was then transferred to a mixing bowl and mixed with 200 g of room-temperature prepared potato strips for about 15 seconds using a spatula. Batter-coated potato strips were placed onto a wire rack, turning 1–2 times to enable excess batter to drain.

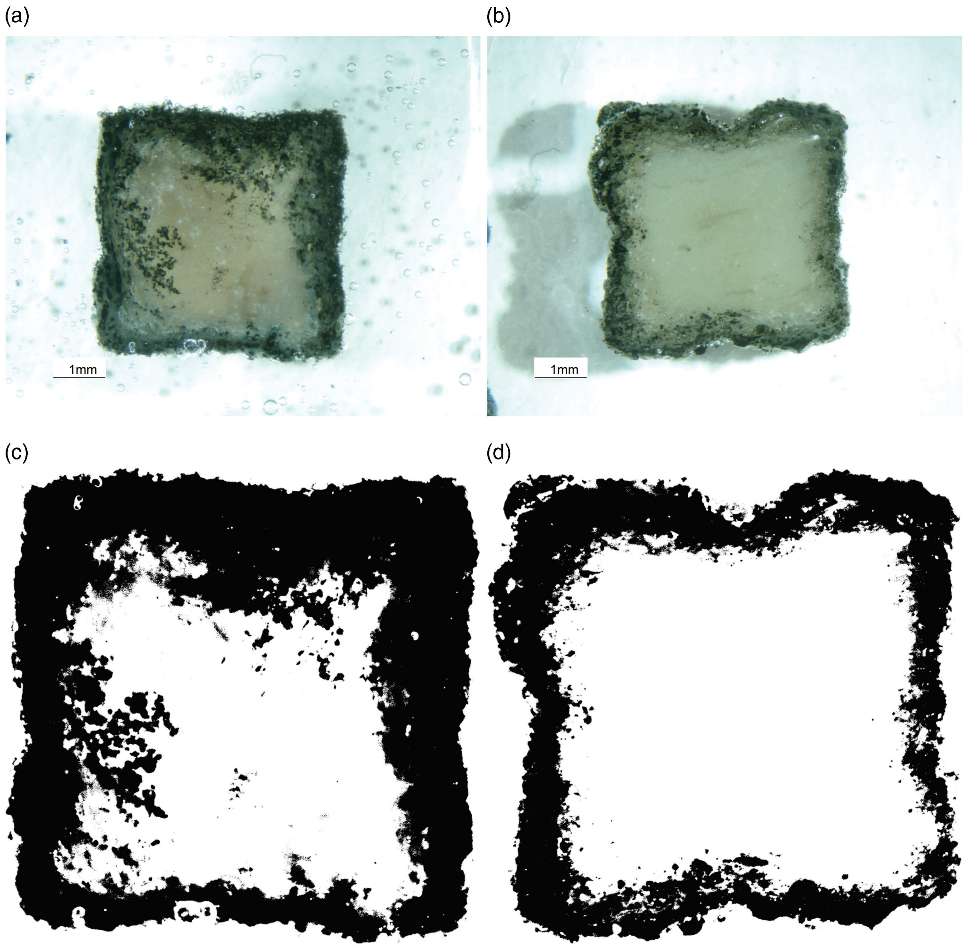

Figure 2: Depth of oil uptake. (a) Image of stained uncoated fry. (b) Image of stained coated fry. (c) Binary threshold image of uncoated fry. (d) Binary threshold image of coated fry.

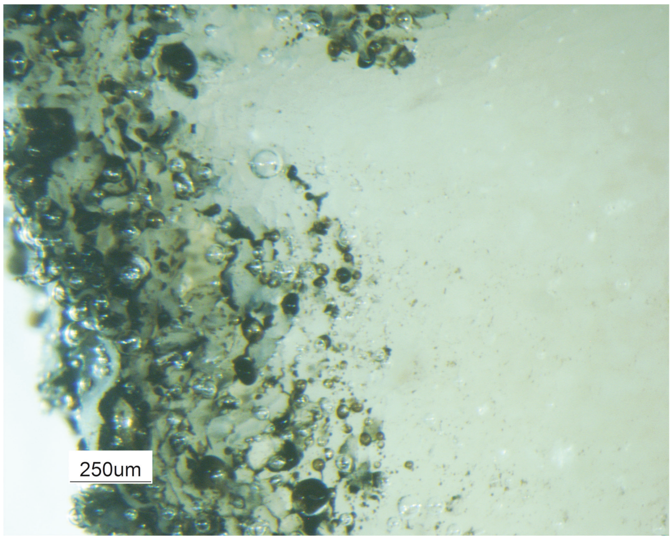

Figure 3: Higher-magnification image of the methyl cellulose coated sample.

Frying. A commercial deep-fat fryer was used. Prior to the frying experiments, the fryer was preheated to ~375 °F (190 °C). Batter-coated potato strips were placed in a basket and submerged to par-fry for 30 seconds. The frying basket was shaken a couple times after about 15–20 seconds. The basket was removed from the oil and shaken to drain away excess oil from the fries. The par-fried potatoes were then transferred to a blast freezer for 10 minutes, after which they were covered with plastic wrap or aluminum foil. Once fries had been frozen overnight, the fries were placed into a frying basket and finish-fried for about 2 minutes at ~365 °F (185 °C). The frying basket was removed from the oil and shaken to remove excess oil. The fries were frozen again prior to bulk oil analysis and microscopy. The cooking temperature and time were carefully controlled so that comparison between coated and uncoated fries was valid.

Oil Content. Oil content of French fries was determined on dried samples using Soxhlet extraction method (AOAC, 2003.65).

Microscopy. An osmium tetroxide staining method was adapted [16]. Cross sections measuring approximately 4–5 mm thick of the uncoated-cooked and coated-cooked French fries (Figure 1a and 1b) were placed in 1% aqueous osmium tetroxide for five minutes, then rinsed in running tap water for 20 minutes. The staining "fixed" or stabilized the oil. Each sample was then mounted on sample stubs using a cyanoacrylate adhesive (Figure 1c) and sectioned to 150-250 μm thickness using a Series 1000 Vibratome vibrating microtome (Figure 1d). The Vibratome sample trough was filled with distilled water to facilitate sectioning and easy removal of the cut sections. The cut sections were transferred to glass slides and imaged using a Wild M-5 photomicroscope equipped with indirect reflected illumination. An Oil Red O staining method was found to work well [16].

Image Analysis. ImageJ software was used to convert color images to black-and-white, to apply thresholds, and to measure the resulting amount of stained area.

Results

Cooking oils typically contain unsaturated fats, meaning they contain carbon-carbon double bonds. Osmium tetroxide preferentially binds to material with carbon-carbon double bonds, imparting a dark color in visible light. In contrast, the main components of potato are water, carbohydrates, and proteins, which do not contain C-C double bonds. Therefore, the amount and distribution of oil in a French fry can be visualized by the dark staining. Figure 2a shows a cross section through an uncoated French fry showing the distribution of oil. The depth of penetration of oil from the sample exterior is variable, generally about half to one millimeter. Figure 2b shows oil distribution across a sample that had a thin WELLENCE™ Smart Fry coating formulated to reduce oil absorption. The depth and intensity of stained material decreased as a result of the coating. Higher magnification images provide more detailed information about the oil distribution in the fries (Figure 3).

A semi-quantitative characterization of oil reduction can be measured from these images using image analysis. A threshold of the images from zero to 110/256 is shown in Figures 2c and 2d (zero is black and 256 is white), and the area of stained potato was measured. Then the interior of the binary image was filled in, and the area of the entire fry was measured. Results indicate that the uncoated fry cross section was about 57% stained, whereas the coated fry was about 36% stained, representing a 37% decrease in oil uptake. The exact amount of stained area in these images is a function of the threshold chosen, graphically shown in Figure 4. A higher threshold results in a larger fraction of the fry highlighted for both the coated and uncoated sample. The ratio of stained area for the coated sample to the stained area of the uncoated sample represents the reduction in oil uptake attributable to the coating. This ratio is also impacted by the threshold chosen. Reduction in stained oil area between 35% and 50% resulted from reasonable choices of threshold (Figure 4). These image analysis results are roughly consistent with the

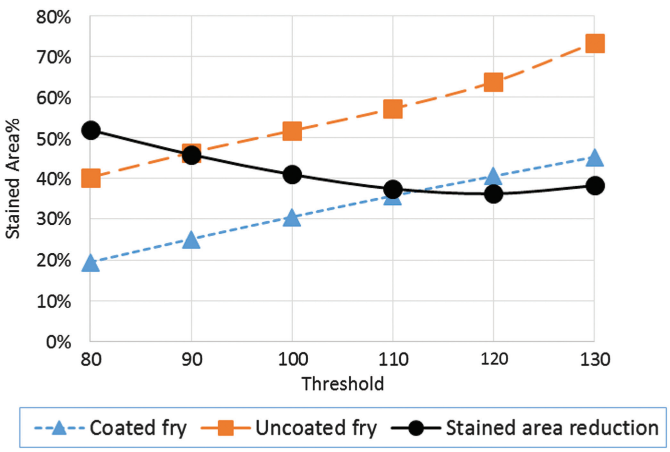

Figure 4: Area stained in cross section as a function of threshold chosen for image analysis. Also shown is the reduction in stained area attributable to the methyl cellulose coating.

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reduction in oil content measured by bulk analysis. Soxhlet extraction indicated that the uncoated French fries contained 11.8 wt% oil; whereas, the coated fries contained 8.0 wt%, representing a 32% decrease in oil absorption during frying due to the coating. The microscopy image analysis method is not meant to replace or be an alternative to bulk analysis methods such as Soxhlet extraction. Bulk analysis methods are more representative of the sample as a whole. The microscopy method, however, provides insight into the distribution of oil within the sample and the depth of penetration of oil from the sample surface, information not available from bulk techniques.

Conclusion

Using osmium staining, thick-section cross-sectioning, and light microscope imaging, qualitative differences in oil distribution in deep-fried food are readily discernible at adequate resolution. The method was used on French fries with and without a methyl cellulose coating applied before frying. Results showed that the coated fries displayed a substantial decrease in the penetration of oil into the food. This is consistent with bulk oil analysis techniques that show a substantial decrease in overall fat content of French fries when methyl cellulose coatings are applied before frying. The microscopy method described here met the goals of our efforts in that it is quick and easy to accomplish using materials and equipment readily available in microscopy and biology laboratories.

Acknowledgments

Keegan Yaroch prepared the batter, coated and fried the potatoes, and performed the bulk oil analysis.

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