Oil Absorption During Frying of Frozen Parfried Potatoes

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ABSTRACT: A tracer method was used to assess the uptake of oil by commercial frozen parfried potatoes fried (180 °C, 150 s) in colza oil (CO) involving a short post-frying immersion in hot coconut fat (CF). CO and CF were determined directly in the crust by differential scanning calorimetry (crystallization temperature and enthalpy −42.7 °C/50 J/g and 10 °C/71 J/g, respectively). Oil uptake by the crust during frying in CO or CF was similar (average 25.3%). Potato samples transferred immediately after frying in CO to the CF bath had most of the CO absorbed replaced by CF after a 10 s post-frying, meaning that CO was readily accessible in the crust structure. Samples fried in CO and cooled for up to 60 s before transfer to hot CF showed only partial replacement of CO. Oil wetting the surface of the sample at the end of frying was estimated as 70 to 80% of the total oil uptake. Formation of the crust (frying time > 1 min) was required for oil to migrate into intercellular spaces that are dynamically formed during frying and thus accessible to CF and solvents.

Key Words: frying, oil uptake, potato, crust, kinetics, DSC, colza oil

Introduction

DEEP-FAT FRYING IS EXTENSIVELY USED IN FOOD PROCESSING both industrially and at home, and fried potato products are one of its largest applications. Frying of potato strips is based on heat transfer from the hot oil, which results in water removal and oil uptake by the piece. Since French fries contain almost 15% fat, pressure to reduce the lipid content of diets has prompted many studies on the mechanisms of fat absorption during frying. Although data are still inconclusive, it appears that longer times and lower frying temperatures lead to higher final oil contents (Saguy and others 1998).

Gathering reliable data for oil uptake during frying of potato strips is difficult. First, samples are heterogeneous due to the complex morphology of the potato tuber (Fedec and others 1977; Sayre and others 1975). Second, oil uptake is usually determined by solvent extraction (for example, Soxhlet method). Preparation for extraction involves extensive manipulation of a relatively large sample (that is, a few grams) including fine grinding to expose the oil occluded in the crust to the solvent. To circumvent this problem, microanalytical methods using differential scanning calorimetry (DSC) and radiolabeling techniques have been introduced to determine oil directly in the crust with minimal intrusion (Aguilera and Gloria 1997; Saguy and others 1997). Third, since surface wetting appears to be a major mechanism of oil retention in the product leaving the fryer, migration of oil into the crust after cooling cannot be determined by Soxhlet analysis.

There is a need to relate total oil uptake, the mechanisms of oil adhesion at the surface and oil migration to the inner structure of a potato product (Baumann and Escher 1995). Most of the oil in French fries (for example, > 90%) accumulates in a thin crust of about 1 mm thickness (Lamberg and others 1990; Keller and others 1986). Moreira and others (1997) have shown that only 20% of the oil in tortilla chips at the end of frying is present internally while 80% remains at the surface of the product; 64% percent of this surface oil is later absorbed to the interior during cooling. Ufheil and Escher (1996) added a tracer dye to the frying oil at the end of frying and found that more than 80% of the oil in potato chips was absorbed after the dye was added. Conceivably, 3 mechanisms contribute to the oil content of a finished fried potato strip: a) oil that adheres to the surface after the product cools down; b) oil that enters into the crust by suction through "pores" after removal from the fryer (Gamble and others 1987; Moreira and others 1997); and c) oil that may be occluded in the forming crust during frying.

Interestingly, formation of a crust (thickness *ca.* 1 mm) during frying of potato pieces does not lead to the rupture of cells in the crust (size approximately 150 μm),which remain largely intact but shrunken and dehydrated, with swollen starch granules pushing against the cell walls (Spiruta and Mackey 1961). Recently, Pedreshi and others (1999) using confocal laser scanning microscopy demonstrated that oil in the crust is arranged as an "egg-box" surrounding intact shrunken cells but does not penetrate into them. Dynamics of frying that include softening of the middle lamella between cells and water release from inside the product through intercellular passages leads to extensive "porosity" of the crust (Saguy and others 1998).

Most studies of frying of potato products have been performed in restructured homogeneous materials (Pinthus and others 1995) or in potato chips (Ufheil and Escher 1996) rather than in actual commercial products such as frozen parfried (slightly prefried) potatoes (FPFP). The dye tracer method used to assess surface oil can be adopted if fried FPFP are dipped for short times into another hot oil or fat and the amount of this oil determined. Discrimination between oils in small samples of crust can be done in a fast, accurate, and simple way using DSC (Gloria and Aguilera 1998). Coconut fat (CF) has a crystallization temperature almost 50 °C higher than any commercial frying oil, so it can be used as tracer for surface oil. Two effects on oil uptake can then be evaluated: the cooling time before the transfer and the residence time in hot CF. The objectives of this work were to assess the effects of frying time, cooling time, and residence time in the tracer CO on the oil content of the crust of commercial French fries and to relate frying kinetics to mechanisms of oil uptake.

Results and Discussion

Frying kinetics in CO and CF

CO and CF had different crystallization properties that permitted discriminating their simultaneous presence in the crust of the fried product by DSC. Peak temperatures and enthalpies for CO and CF were: −42.7 °C/50 J/g and 10 °C/71 J/g, respectively. No interference from the original fat in FPFP was noticed in the thermograms as it became highly diluted in the frying medium. The temperature and enthalpy of crystallization of the original fat in FPFP were 28 °C/ 24 J/g, respectively.

First it was necessary to demonstrate that there was no difference in oil uptake by the crust when frying was performed with either lipid material, and results are shown in Fig. 1. Both frying media resulted in similar and fairly constant uptake of fatty material independent of frying time (range: CO, 21.0% to 28.2% and CF, 22.8% to 29.1%). Variation in oil contents for these and later data are probably due to the heterogeneous distribution of oil in the crust and the small sample size needed for the DSC analysis (50 to 90 mg). The ratio standard deviation/mean for all data varied between 5.0% and 27.5%. Oil contents in crusts were intermediate between those reported for potato chips (34.6%) and French fries (14.8%). Potato chips may be considered as the crust of French fries but infiltrated by oil from both sides.

For short frying times (that is, 10 s to 1 min), a "leathery" crust was formed that already contained a large amount of lipid material (range 21% to 26%). Because the thickness and structure of the crust vary with frying time, these data confirm that oil uptake is related more to wetting and adhesion to the surface of piece than to progressive migration into the crust (Ufheil and Escher 1996). If a diffusional process prevailed for oil uptake during frying, it would be expected that the oil content would increase continuously from 0 with frying time. High oil contents even for short times have been extensively reported for frying of food pieces, in accord with the wetting theory (Moreira and others 1997; Ufheil and Escher 1996).

Frying in CO and immediate transfer to CF

Displacement of CO from the crust potato pieces by CF after immediate transfer (without cooling) to the CF bath is shown in Fig. 2. A large portion of the CO in the crust was almost instantaneously replaced by CF in less than 2 s while almost complete removal of CO had been achieved after 10 s of dipping in CF. The portion of oil removed in the first 2 s was 82% of the CO present in the crust after frying. This value comes from [(25.5 − 4.64) × 100/25.5] where 25.5 is the %CO at the end of frying (Fig. 3) and 4.64 the %CO remaining after dipping in CO for 2 s (Fig. 2). This result coincides with values reported previously by Moreira and others (1997) and Ufheil and Escher (1996), and may be regarded as surface or "wetting" oil since it was rapidly washed away by CF. The remaining 18% of the oil present after frying in CO could be oil located deeper in the crust, thus, less accessible to CF and consequently slower to remove.

Extension of the frying period results in a decrease of the rate of water release, an alteration in mechanism (for example, presence of fewer and larger bubbles from localized spots on the crust as time increases), and possibly changes in the crust structure and the dynamics of fat impregnation. Frying in CO for 240 s instead of 150 s before immediate transfer and immersion in CF resulted in similar trends in CO and CF contents, suggesting that prolonging the frying period does not affect the exchange of frying media (Fig. 2). To further corroborate these results an extra sample fried in CO for 360 s (29.8% CO content at the end of frying) and subjected to immediate transfer presented a residual CO of 2.06% after 30 s immersion in CF (data not shown).

Pedreschi and others (1999) using confocal laser scanning microscopy have demonstrated that oil in the crust of fried potato pieces is located in intercellular spaces as an "egg-box" and not in the interior of cells, which stay intact and oil-free. The exchange of CO and CF presented in Fig. 2 substantiate the dynamic aspect of the oil infiltration process during frying in which intercellular passages are constantly being formed as steam is released in the form of bubbles when pressure builds up in the interior of the forming crust (Saguy and others 1998). Ufheil and Escher (1996) working on potato chips also found that immersion of 5 s was enough for dyed oil added at the end of frying to completely substitute the frying oil in which potato slices had been fried for approximately 115 s.

Frying in CO followed by cooling and then transfer to CF

It was assumed that the longer the cooling or transfer time between the end of frying in CO and immersion of the piece in CF, the deeper would surface CO penetrate into the crust, thus re-

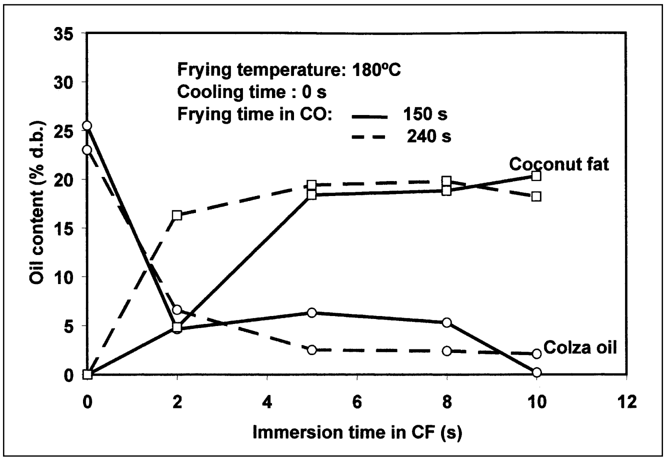

Fig. 2—Effect of residence time in hot coconut fat (□) on oil exchange in the crust of fried frozen parfried potatoes fried in colza oil (○). Immediate transfer from CO into CF (0 cooling time)

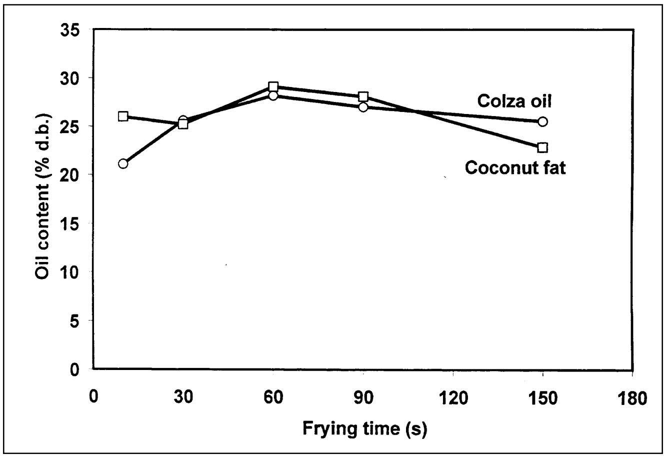

Fig. 1—Kinetics of colza oil (○) and coconut fat (□) uptake during frying of frozen parfried potatoes at 180 °C

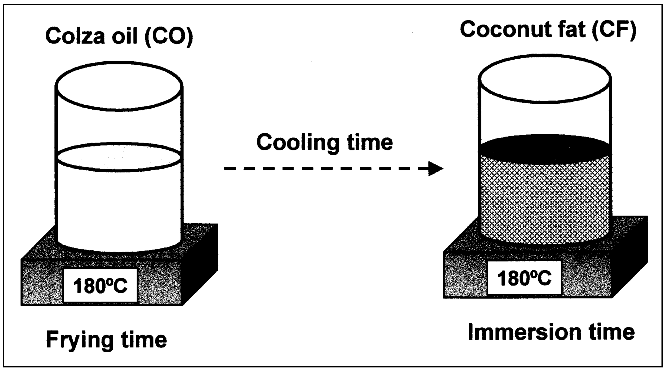

Fig. 3—Experimental setup to study frying of frozen parfried potatoes in colza oil, after-frying cooling, and immersion into coconut fat

tarding its later removal by CF. Infiltration of surface oil during cooling is due to condensing steam in intercellular spaces, which produces a vacuum (Gamble and others 1987). Cooling (or holding) at room temperature (24.3 °C) resulted in a concomitant drop in surface temperature (Fig. 4). The IR thermometer is more precise than thermocouples to measure surface temperature of the fried potato piece, but it has a short lag period of approximately 2 to 3 s, enough for the temperature to drop almost 20 °C (initial measured temperature = 160 °C). The initial fast drop in temperature from approximately 180 to 100 °C was largely the result of evaporative cooling of moisture transported through the crust rather than of convection from the surrounding ambient air, a mechanism that predominates for longer cooling times (for example, > 15 s). Results of the effect of cooling time on the exchange of CO and CF are shown in Fig. 5. A standard dipping time in CF of 5 s was chosen because this period was enough to wash away a major portion of CO in the crust (see Fig. 2). The amount of CO remaining in the piece after immersion in CF increased from 6.3% for 0 cooling time to 12.8% at 20 s and remained fairly constant thereafter. During cooling, CO is pulled into the crust as long as superheated steam cools down (to saturated steam) and condenses producing a vacuum. After 15 s cooling time, the outer surface temperature of the crust (which is what the IR thermometer measures) had dropped below the boiling point of water at atmospheric pressure (100 °C). Probably, it takes longer for the temperature inside the crust to fall below 100 °C, thus the period during which CO infiltrates the crust exceeds 15 s. It can only be surmised at this point that after 20 s of cooling, the whole crust is below 100 °C, and the suction pressure had vanished.

Oil removal by hexane

There was interest in determining what proportion of CO would a good solvent for oil (hexane) remove from a hot fried potato strip. Residual oil content of potato strips fried in CO at 180 °C for 150 s and transferred immediately into hexane at different temperatures is shown in Table 1. Since strips were introduced into hexane while hot steam bubbles were released from the surface, the final temperature of hexane changed as disclosed in Table 1. Values of residual CO after hexane extraction were almost constant (average 7.2%) and higher than those for immediate transfer into CF shown in Fig. 2. Between 67% and 77.4% of the CO was removed by hexane independent of the extraction temperature, suggesting that this portion was readily accessible to the solvent.

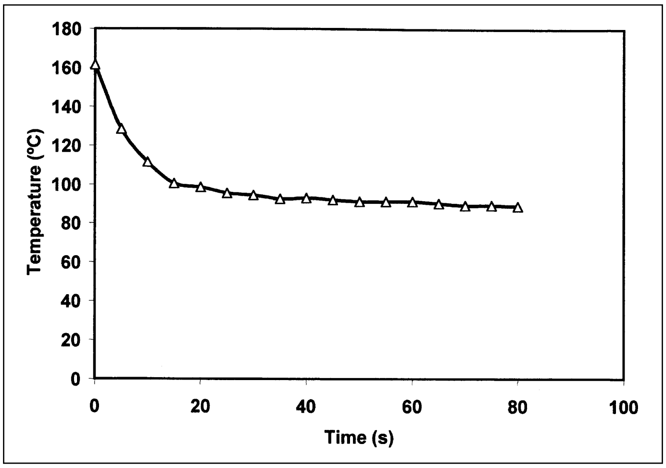

Fig. 4—Temperature in the crust of fried frozen parfried potatoes after removing from the colza oil (180 °C, 150 s). Temperature of ambient air = 24.3 °C

Table 1—Extraction of oil from potato strips transferred directly after frying in colza oil into hexane

Temperature of[a] hexane (°C)	Presence of bubbles	% residual colza oil	% initial oil extracted
25/33.5	Only during first 30 s	6.5	75.9
47/55	Few from localized spots	6.1	77.4
69/69	Many from several spots	8.9	67.0

[a] Initial and final temperature of hexane

Kinetics of surface or "wetting" and structural oil uptake

To estimate the partition of CO between the surface and the crust as a function of frying time (from 30 to 150 s), a post-frying treatment consisting of immediate transfer of the sample to CF and a 5 s immersion period was selected. From data in Fig. 2, exposure of a fried piece to CF for 5 s was enough to wash away a major portion of CO in the crust, leaving behind some CO that was more difficult to remove. The CO remaining in the crust after immersion in CF was supposed to be located inside the crust and was arbitrarily named "structural oil." CF picked up by the crust during immersion was assumed to have replaced CO in the surface of the piece at the end of the frying time and was called "surface oil." Total oil at any time was equal to structural oil plus surface oil.

Initially (frying time < 60 s) no crust was formed, and the outer portion of the piece was a thin, soft, and leathery skin that was difficult to separate from the mealy interior. As shown in Fig. 6,

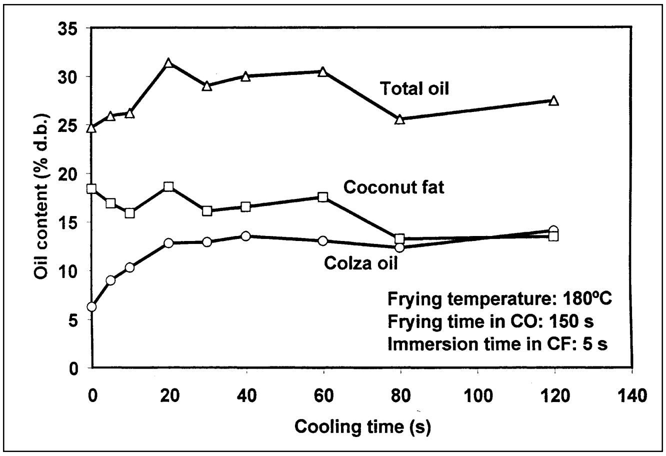

Fig. 5—Effect of post-frying cooling time on oil exchange in the crust of frozen parfried potatoes fried in colza oil. Colza oil (○). Coconut fat (□)

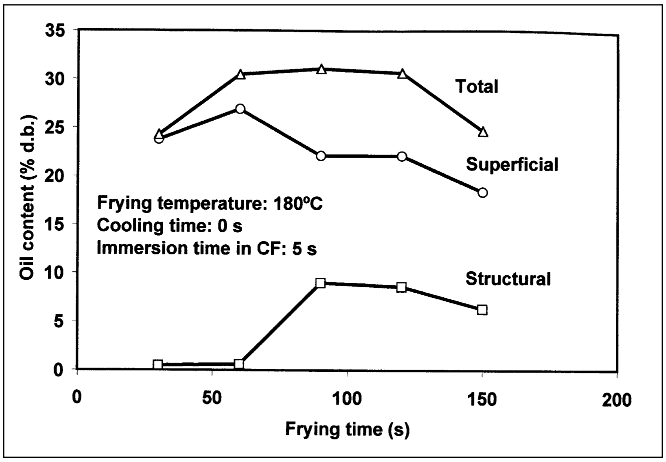

Fig. 6—Structural (□), surface (○), and total oil (△) during frying of frozen parfried potatoes at 180 °C

during this period, most of the CO was washed away during the short immersion in CF, suggesting that it was surface oil. After 90 s frying time, a thicker dehydrated crust was formed, which contained 26% to 29% of the total oil as structural oil. Crust formation—involving gelatinization of starch, softening of middle lamellae, dehydration and shrinkage of cells—provides the passages for oil migration into intercellular spaces (Pedreschi and others 1999).

Surface oil after 90 s of frying was 71% to74% of the total oil, a result that coincides with data from hexane extraction and that has been reported by other authors (Moreira and others 1997; Ufheil and Escher 1996). Independent of where oil is located, it appears that the total oil content of potato strips remains constant between 30 and 150 s of frying time (as shown also in Fig. 1).

Conclusions

1. The tracer method using immersion of fried FPFP in CF in conjunction with DSC to quantify CO and CF in the crust was highly satisfactory to generate data of oil uptake.

2. CO in fried FPFP was readily removed by CF, supporting the idea that oil in fried products is located in accessible intercellular spaces (Pedreschi and others 1999).

3. Cooling for up to 20 s before transfer of the piece to the CF bath increased the amount of CO that was not readily removed by CF.

4. Structural oil, that is, oil that migrates into the crust during frying, was present only after a crust was formed (frying time > 1 min). At the end of frying, roughly 25% of the total oil in the crust was structural oil, and 75% was surface oil.

Materials and Methods

Materials

Frying was performed in low-erucic acid colza oil (CO) purchased at a local supermarket (Migros, Lausanne, Switzerland), recommended for finish frying at home at 180 to 190 °C during 150 s (2.5 min). Post-frying was done in coconut fat (CF) obtained from Morgia AG (Lyss, Switzerland). Commercial frozen parfried potatoes were purchased from Findus (Switzerland) and contained 7% pre-frying fat.

CO/CF frying experiments

Frying experiments attempted to assess the uptake of CO and CF by FPFP during frying and the effect of dipping time in CF after immediate or delayed transfer from the CO. Approximately 300 mL of CO and CF previously heated for 1 h were kept at 180 ± 2 °C in separate glass beakers held over hot plates and the temperature controlled by individual contact thermometers connected to the power source. Fig. 3 shows the experimental setup used in the study. It allowed control of 3 variables: the frying time in CO, the holding or cooling time during transfer from the CO bath to the CF bath, and the residence time in CF. Two pieces of FPFP of similar size (approximately 5.0 cm in length, square cross-section 0.64 cm^2, and weight 4.5 to 4.9 g per strip) were used per run, and standard frying conditions were 180 °C and 150 s. After withdrawal from the fryer, samples were left to cool down for about 30 s. The crust was removed by sectioning with a clean razor blade and carefully scraping off the remnants of mealy material from the inner surface (Aguilera and Gloria 1997).

In the tracer studies, FPFP were fried first in CO for 150 or 240 s, rapidly transferred into hot CF, and kept immersed for times up to 10 s. Alternatively, to assess the effect of cooling time, fried samples removed from CO were held at room temperature (24.3 °C) for varying times (up to 120 s) before immersing in CF for 5 s. Lastly, partition of oil between the surface and the interior of the crust was determined for different frying times in CO (0 to 150 s) followed by immediate transfer and a constant dipping period in CF of 5 s. Oil content of the crust are averages of triplicates.

Extraction with n-hexane

Samples of FPFP fried in CO under standard frying conditions were immediately transferred into 100 mL of extra-pure n-hexane (Merck, Darmstadt, Germany) in a round-bottom flask with a water-cooled reflux condenser. Extraction proceeded under agitation at 25, 47, and 69 °C (boiling) for 5 min. Crusts were separated and analyzed for oil by DSC. Data are average of triplicates.

Determination of oil in the crust by DSC

CO, CF and oil lipid material in the crust of fried potato products were analyzed by differential scanning calorimetry in a Mettler DSC 820 (Mettler Instrument AG, Volkestwil, Switzerland) as described by Aguilera and Gloria (1997). Oil contents are expressed on a dry matter basis.

Temperature variation in the surface

The drop in surface temperature of fried FPFP after removal from the CO and held at room temperature (24.3 °C) was measured in triplicate with an infrared (IR) thermometer Tasco THI-500 (Osaka, Japan).

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