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Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato

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ABSTRACT

This objective of this study was to evaluate the kinetics of mass transfer, microstructural development, the impact of freezing method (Unfrozen, −18 °C, −82 °C and N_2) and storage (0–4 months) on the quality of finish-fried parfried-frozen potato strips. Frying parfried potato between 170 and 190 °C showed significant ($P < 0.05$) effect on fat uptake. Up to 20% fat was absorbed by the product post-frying while surface oil decreased and matrix oil increased. Freezing at −82 °C reduced the amount of oil absorbed compared to other freezing methods. Textural property of finished fried potato strip was significantly ($P < 0.05$) impacted after storage for 4 months. Color determination showed a significant ($P < 0.05$) change in the finish-fried products compared to the parfried. Scanning electron microscopy provided a visual chronicle of changes in the structure of potato during pre and post freezing and frying processes.

1. Introduction

Potato is a major root crop used for the production of various staple foods. Fried potato products account for a significant portion of potato utilization in United States with about 46.16% of production (National Potato Council, 2015; USDA, 2015). Out of these fried potato products, 69.78% are parfried and frozen (National Potato Council, 2015). Parfried frozen potato business is a multi-billion dollars market in the US, which was worth $1.23 - $1.36 billion between 2011 and 2013, and this represents a significant increase over the last decade (USDA, 2015). Parfrying potato brings convenience for the consumers with shorter finish frying time and partially cooked product, hence the continued interest and the viability of the market. And this is in spite of the health concerns related to fried foods.

Frying imparts unique characteristics to products that cannot be replicated by other processing methods. In order for parfried potato to be stable and maintain its quality along the supply chain, it is often frozen and packaged. Freezing process could significantly impact the final quality of finish-fried product. How quickly a product is frozen determines the size of ice crystals formed, and the degree of structural change that may occur. Large ice crystals are synonymous with mechanical damage, significant drip loss and structural deformation of cellular structure of many biological materials (Delgado and Sun, 2001; Singh and Heldman, 2014; Sun and Li, 2003). To date, there is no study on how freezing rate of parfried potato affects its final quality.

Optimal process design is possible when the kinetics of reaction or property change under various conditions of processing are fully understood. There has been significant work done on understanding kinetics of mass transfer during frying and post-frying period. Yagua and Moreira (2011) described the kinetics of mass transfer during vacuum frying of potato chips; Troncoso and Pedreschi (2009) presented a study on kinetics of water loss and oil uptake during frying of pretreated potato slices under vacuum and atmospheric pressure, and they used Fick's model, a form of first order kinetic equation to fit moisture loss and oil uptake data; Adedeji et al. (2009) determined the impact of microwave-precooking and frying conditions of temperature and time on kinetics of mass transfer during deep fat frying of chicken nuggets and reported that reaction rate constant and diffusivity increased with microwave power density and frying temperature. Pedreschi et al. (2008) studied the kinetics of oil absorption and distribution on the structure of potato slices during frying, considering the impact of oil temperature and blanching pretreatment. They

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Nomenclature

SO	Surface oil
MO	Matrix oil
TO	Total oil content
SOA	Space occupied by air
SOM	Space occupied by moisture
SOF	Space occupied by fat
ε	Porosity, %
ρ_b	Bulk density, g/cm^3
ρ_a	Apparent density, g/cm^3
V_{samp}	volume of the sample, cm^3
V_{cell}	volume of the cell, cm^3
V_{exp}	Volume of the expansion chamber, cm^3
P_1	Sample chamber initial pressure (psi)
P_2	Final chamber pressure (psi)
ΔE	Color difference
pf	Parfried
ff	Finish-fried
L*	Lightness
a*	Redness to green
b*	Yellowness to blueness

concluded that oil absorbed is distributed into three fractions they called structural oil (STO); penetrated surface oil (PSO), and surface oil (SO). However, nothing is known about kinetics of mass transfer after finish frying of parfried potato strips (Vauvre et al., 2014). There is a strong interest in understanding the effect of pre- and post-frying processes namely effect of freezing rate, frying conditions and cooling, and how oil is absorbed by parfried potato during finishing frying processes. Also, there is desire to know how freezing method and structural changes during finish frying impact mass transfer in stored parfried potato strips. The objectives of this study was therefore to evaluate the oil absorption kinetics, microstructural and textural changes during finish frying of parfried potato strips, and to determine the impact of freezing method on oil absorption and quality parameters of par-fried potato during finish frying after storage.

2. Materials and methods

2.1. Materials

Fresh potato (cv. Russelt) was purchased from a local store in Montreal, Canada, and it was kept at refrigeration temperature (8 °C) before use.

2.2. Parfrying, freezing, storage and frying

Raw potatoes were peeled under running tap water, washed and cut using a kitchen square cutter (8 × 8 mm), and then blanched at 85 °C for 6 min in a 0.5% aqueous solution of $CaCl_2$. The samples were drained before further use. They were then parfried in canola oil at 180 °C for 60 s, allowed to drain and cool before freezing. Weighed, blanched and parfried potato were poured into Ziploc bags and frozen at −18 and −82 °C for 6 h and 2 h, respectively. The freezing duration was based on preliminary study to ascertain how long it will take to freeze the warmest point in the sample to −18 °C. For cryogenic freezing, samples were gently placed on a wire mesh on top of liquid nitrogen in a closed container for about 5 min, after which they were allowed to equilibrate at the temperature of −18 °C for about 2 h. The control comprised of blanched unfrozen sample. Frozen samples were CO_2 packed in Ziploc bags prior to storage for up to 4 months at −18 °C for of storage time study. To study the influence of freezing methods, all the 4 treatments were finish-fried in a pre-heated canola oil for 150 s at 180 °C, and drained.

In order to study the effect of frying temperature and time, parfried and frozen (freezing was done at −18 °C for 24 h as an example of freezing method) potato samples were finish-fried frozen in a kitchen deep-fat fryer (T-FAL, Model 6197, Scarborough, ON, Canada) at three temperatures, namely 170, 180 and 190 °C in freshly preheated (for 2 h) canola oil. A ratio of sample to oil of 0.04 was used. Samples were obtained at 30 s intervals up till 180 s of frying for analyses. Finish-fried samples were drained by shaken them 50 times in the frying basket and they were subsequently placed on absorbent paper towel for 10 min before they were evaluated for other attributes.

2.3. Fat content

Three different fractions of fat content in the samples were studied namely: surface oil (SO), matrix oil (MO), and total oil content (TO). SO is defined as the oil fraction which adhered to the product surface and did not penetrate the potato microstructure during frying, while MO is defined as the oil fraction which are naturally present or penetrated the potato microstructure during frying. SO was determined following the methodology described by Pedreschi et al. (2008) with modifications. During a frying time that ranged from 0 to 150 s, about 75 g of fried potato samples were taken out every 30 s and immersed in a 140 ml glass extraction vessel containing 100 ml petroleum ether for about 3 s at ambient condition. The mass of oil extracted from the sample surface was determined by vaporizing the solvent in a solvent extractor. SO content was computed on dry weight basis by dividing the mass of oil extracted from the surface by the mass of dry matter including the SO extracted from the fried potato. To measure MO, the fried sample, which had been immersed in petroleum ether for SO measurement, was freeze-dried in a Freeze dryer (Thermo Savant Modulyod-115, NY, USA) for 36 h, it then was ground with a pestle and mortar, after which it was placed in a thimble for oil extraction in a VELP SER 148 (Velp Scientifica, Usmate, Italy) extraction unit using petroleum ether as solvent. The matrix oil content was determined on dry weight basis also by dividing the mass of extracted matrix oil by the mass of dry matter including all the oil (SO and MO) extracted (AOAC, 1991). TO was calculated by the summation of SO and MO divided by the total mass of sample.

2.4. Apparent density

Apparent volume of the samples was determined using a Pycnometer according to the method described by Adedeji and Ngadi (2011). Apparent volume (this is the volume of the sample including closed pores but excluding the open pores) of the weighed fried potato were measured into a Helium Pycnometer (Model 1305 Multivolume, Micromeritics Instrument Corporation, Norcross, GA). Each sample was placed in the 35 cm^3 sample cell of the Pycnometer and was subjected to cyclic action of purging by pressurizing and depressurizing with helium gas prior to analysis in order to expel all the air and vapor trapped in the pores and crevices. The analysis was conducted at ambient temperature with pressure of up to 135 kPa (19.5 psi). The systems valves were closed initially to allow equilibration to atmospheric pressure. Then the valve that leads to the sample chamber was opened to allow helium gas to enter up to 19.5 ± 0.2 psi (135 ± 1.37 kPa) and the valve was closed for between 15 and 30 s to allow the gas to penetrate the