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Physical and thermal properties of potato chips during vacuum frying

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ABSTRACT

Vacuum frying (1.33 kPa), with the aid of a de-oiling mechanism, was used to produce low-fat potato chips.

The kinetics of oil absorption and oil distribution in the potato chips was studied so that effectiveness of the de-oiling system could be established. Non-linear regression was used to fit the experimental data to the models used to describe oil absorption in potato chips with time.

Moisture content, oil content, microstructure, diameter and thickness expansion, bulk density, true density, and porosity of chips fried at different temperatures (120, 130, and 140 °C) was performed to evaluate the effect of process temperature on the product. The convective heat transfer coefficient at the oil-chip interface was determined for the same temperature range.

The final oil content of the potato chips was 0.072 ± 0.004, 0.062 ± 0.003, and 0.059 ± 0.003 g/g solid for frying temperatures of 120, 130, and 140 °C, respectively. These values are lower (80–87% less) than those found in the not de-oiled potato chips, which indicates that the de-oiling mechanism is crucial in vacuum frying processing. A significant difference ($P < 0.05$) was observed in oil content and oil distribution within temperatures. The rate of change in product quality attributes was greatly affected by temperature; however, the final values of moisture content, bulk density, true density, porosity, diameter shrinkage, and thickness expansion were not affected by temperature.

During vacuum frying, the convective heat transfer coefficient changed considerably as frying progressed; moreover, it increased with temperature reaching a maximum between 2200 and 2650 W/m^2 K depending on frying temperature.

1. Introduction

Frying under reduced pressure (vacuum frying) is an efficient alternative method of reducing the oil content in fried foods while producing potato chips with the same texture and color of those fried in atmospheric conditions (Da Silva and Moreira, 2008; Garayo and Moreira, 2002), as well as, lower acrylamide content (Granda et al., 2004) and enhanced organoleptic and nutritional qualities (Dueik et al., 2010; Da Silva and Moreira, 2008; Shyu and Hwang, 2001).

Several studies have shown that less oil is absorbed during the vacuum frying process using different pre-treatment and de-oiling steps (Garayo and Moreira, 2002; Mariscal and Bouchon, 2008; Moreira et al., 2009). Troncoso and Pedreschi (2009) found that oil absorption at the surface increases during vacuum frying processes because of the higher heat and mass transfer rates and the existence of a pressurization step, thus increasing the final oil content compared to traditional frying for the same working temperature.

The pressurization process plays an important role in the oil absorption mechanism. It can increase or decrease oil absorption depending on the amount of surface oil and free water present in the product (Garayo and Moreira, 2002). Furthermore, Moreira et al. (2009) considered the amount of surface oil present at the moment of pressurization as a determining aspect for the final oil content of the product, and established that a de-oiling process must be used to remove surface oil under vacuum after the product is fried. They determined the internal and structural oil absorption kinetics during vacuum frying of potato chips, and found that 14% of the total oil content was located in the core (internal oil) and the remaining 86% of the oil content was surface oil. The de-oiling mechanism (centrifuging system) used in the study removed surface oil before the pressurization step and was able to reduce the total oil content in about 80–90%.

In order to understand and decrease oil absorption during the pressurization step, Mir-Bel et al. (2009) investigated the influence of various parameters of the pressurization and cooling stage on the final oil content of fried potato using different geometries, and explained that oil absorption during the cooling stage is

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Nomenclature

Parameter			
a	Chips half-thickness, m	P	Pressure, kPa
D_e	Diffusion coefficient, m^2/s	PC	Potato chip, –
HS	Frying vessel head space, –	PS	Potato's surface, –
IOC	Internal oil content, g-oil/g-solid	SOC	Surface oil content, g-oil/g-solid
L	Thickness change, %	t	time, s
M	Moisture content, g-water/g-solids	T	temperature, K
		TOC	Total oil content, g-oil/g-solid

greatly influenced not only by the difference in temperature, but also by the vacuum break conditions as the system recovers atmospheric pressure. They found that the volume of oil absorbed by the product is inversely proportional to the pressurization velocity meaning that lower velocities favors oil absorption showing an increase of 70% for potato chips compared to the oil content when the vacuum breaks abruptly.

During frying heat is transfer from the oil to the surface of the product by convection and then from the surface to the center of the product by conduction, which causes an increase in temperature until the boiling temperature is attained and water starts evaporating (Moreira et al., 1999).

Several authors have studied the convection heat transfer coefficient, h, between the oil and the surface of the product using direct and indirect measurement methods. Costa et al. (2001) compared the lumped capacitance method (LCM) with a direct method during frying of French fries and potato chips, the latter method is based in an energy balance assuming that the total heat transferred by convection is used for heating the potato and water evaporation. They found that the heat transfer coefficient determined in frying were up to two times greater than those obtained in the absence of vapor bubbling; also, the h calculated from the direct method, maximum of 600 W/m^2 K for French fries at 140 °C, are higher than those calculated with the LCM, maximum of 440 W/m^2 K for the same conditions.

A procedure for determination of convective heat transfer coefficient for canola oil during the boiling phase of frying of potato cylinders was developed by Hubbard and Farkas (1999); they measured the drying rate of the material, surface area, oil temperature, and surface temperature of the product, and then calculated the heat transfer coefficient (300–1100 W/m^2 K) using an energy balance on the cylinder, assuming no heat gradient on the core of the potato.

Using the previous approach, Budzaki and Seruga (2004) determined the convective heat transfer coefficient of potato dough balls during deep fat-frying in soybean oil, which ranged from 94.22 to 774.88 W/m^2 K, and evaluated the influence of oil temperature (160–190 °C), water migration and surface temperature. Erdogdu and Dejmek (2010) also used Hubbard and Farkas' (1999) method to estimate the h value during high pressure (200 kPa) frying of potato slabs in canola oil at 170 °C; pressure frying was found to lead to higher heat transfer coefficient values.

Although there is literature concerning the feasibility and advantages of the vacuum frying process, and some studies in quality attributes of the final product, research on vacuum frying is at the initial stages since the process has not been fully understood. There is a need to understand and characterize the transport processes that occur during vacuum frying, as well as to determine physical and thermal properties that can be used to develop a mathematical model of the process, in order to optimize its application and to predict quality changes. Hence, the objectives of this study were (1) to characterize product quality attributes such as oil content, pore size distribution, shrinkage, and expansion of potato chips during vacuum frying at different frying temperatures; and (2) to measure physical and thermal properties including bulk density, solid density, porosity, and heat transfer coefficient at different frying temperatures.

2. Materials and methods

2.1. Raw material

Potatoes were provided by Frito-Lay North America, Inc. (Plano, Texas). After harvest, potatoes were stored in a refrigerator at 10 °C and 95% relative humidity; they were left at room temperature for 3–4 days to allow reconditioning (specific gravity 1.09 ± 0.1) and to lower the reducing sugar content before processing.

2.2. Sample preparation

Potatoes were peeled and then sliced using a mandolin slicer (Matfer model 2000, France) to a thickness of 1.6 mm, measured with a thickness gage (Mitutoyo Thickness Gage, Japan), and cut to a diameter of 5.08 cm using a cylindrical metal cutter. The potato slices were rinsed in distilled water to eliminate starch material on the surface and then blotted with paper towels before each experiment. The samples were placed in aluminum foil to avoid any moisture loss before further processing.

2.3. Vacuum frying experiments

The experiments were performed using a vacuum fryer (Fig. 1a) available at the Food Engineering Laboratory, Department of Biological and Agricultural Engineering at Texas A&M University, College Station, Texas. The frying process consists of loading 6 potato slices (about 25 g) into the basket, closing the lid, and depressurizing the vessel. Once the pressure in the vessel reaches 1.33 kPa, the basket was submerged into the oil. When the chips were fried, the basket was raised, and the centrifuging system was applied for 40 s at a speed of 750 rpm (63 g units). This setup was based on previous studies (Moreira et al., 2009). Then, the vessel was pressurized and the potato chips were allowed to cool down at ambient temperature before storing then in polyethylene bags inside of a desiccator for further examination. This procedure was used for three different oil temperatures, 120, 130, and 140 °C. Fresh canola oil (Crisco, Ohio, USA) was used in all experiments.

For the kinetic studies, the samples were collected at different frying times (0, 20, 40 60, 80, 100, 120, 180, 200,240, 300, and 360s) and all the product quality attributes were evaluated as described below.

2.4. Data acquisition system

The changes in temperature and pressure of the vacuum system (Fig. 1 b) were recorded, to assure optimum performance during frying, using a data acquisition system (model OMB DAQ 54 Omega Engineering Inc., Stamford, CT, USA), that works on the principle of