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Two-stage frying process for high-quality sweet-potato chips

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ABSTRACT

Vacuum frying (1.33 kPa), with the aid of a de-oiling mechanism, was used to produce low-fat sweet potato chips. The kinetics of oil absorption and oil distribution in the chips (total, internal, and surface oil content) was studied so that effectiveness of the de-oiling system could be established. Product quality attributes (PQAs) such as moisture content, oil content, diameter shrinkage, and thickness expansion, as well as, color, texture, 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 final oil content of the vacuum fried chips was 60% lower than those found in traditionally fried sweet potato chip, which indicates that the de-oiling mechanism is crucial in vacuum frying processing. The rate of change in PQAs is greatly affected by temperature; however, the final values of bulk density, true density, porosity, diameter shrinkage, and thickness expansion were not affected by temperature. The structured of the chips settled faster when fried at 130–140 °C. Color b^* values was not affected by temperature by the range of temperature used in this study.

The product fried in a two-stage (TS) frying process (1 min fried at atmospheric pressure and 2 min under vacuum) had better appearance and texture compared to the ones that were only fried under vacuum or single-stage (SS) conditions. The samples were lighter and more yellow (less compact) than the chips fried under the SS process. The atmospheric frying prior to vacuum frying helped the starch to gelatinize thus producing a better product in terms of texture, oil content, and flavor. The final oil content of the TS fried chips was 15% lower than those fried by the SS process showing that the structure of the chips formed during the process affected the oil absorption during frying.

1. Introduction

Sweet potato (*Ipomoea batatas L.*) is an important food crop around the world (Wu et al., 2008). Orange-fleshed cultivars are recognized as healthy foods because of their significant content of β-carotene, phenolic acids, anthocyanin, and dietary fiber (Turner and Burri, 2001). The crop is widely cooked by deep frying and consumed in forms of French fries and chips (Farinu and Baik, 2007).

Vacuum frying is an alternative method to produce fried foods with superior product quality attributes (Da Silva and Moreira, 2008; Nunes and Moreira, 2009) and low acrylamide content (Granda and Moreira, 2005). To reduce oil absorption by the product during the process, many authors (Nunes and Moreira, 2009; Moreira et al., 2009; Pandey and Moreira, 2011; Yagua and Moreira, 2011) have used a de-oiling mechanisms after the product is fried, before the pressurization step. Pre-treatments such as blanching and/or osmotic dehydration (Krokida et al., 2001; Kim and Moreira, 2012) have also been used to reduce oil uptake during frying of fruits and vegetables.

Because of the high oil content found on the surface of chips during the pressurization step in a vacuum frying process, Moreira et al. (2009) established that a de-oiling process must be used soon after the product is fried to produce chips with reduced oil content under vacuum. They 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 was capable to remove about 80–90% the chips total oil content.

Another important aspect of vacuum frying is the pressurization speed. Mir-Bel et al. (2009) 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.

Yang et al. (2012) compared the effects of vacuum frying (30 min at 90 °C at 20 kPa) and atmospheric frying (2.5 min at 170 °C after) on the physicochemical properties and quality characteristics of deep-fat-fried yellow-fleshed and purple-fleshed sweet potatoes.

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Sweet potato slices were blanched in hot water, soaked in maltodextrin, and then frozen prior to frying. Both products were de-oiled (using a centrifuge) after frying. Vacuum-fried chips had 50% lower oil content than atmospheric-fried ones. The color of the vacuum-fried chips showed higher *L* and *b* values, with almost no difference in the texture, compared to atmospheric-fried snacks. The total carotenoid and anthocyanin contents of snacks were higher in vacuum-fried chips compared to atmospheric-fried snacks. Sensory panelists preferred the color and flavor of the vacuum-fried chips, but the texture of atmospheric-fried one due to a higher degree of crispiness.

In vacuum frying, the temperature of the chips does not reach the gelatinization temperature until most of the water is evaporated. Therefore, there is not sufficient moisture content in the product for gelatinization to occur completely. As a result, the product has a glassy texture (Ravli et al., 2012) and feels like it is uncooked. Sobukola et al. (2012) showed that a higher water boiling point temperature, during frying, in a model food (wheat starch, gluten, and water) favored the capacity of the matrix to form structure due to starch gelatinization in the presence of water and temperature, reducing the oil content of the fried products.

There is a lack of information in the literature regarding to the kinetics of sweet potato chips fried under vacuum conditions, and to texture and flavor changes during vacuum frying by increasing the degree of starch gelatinization during the process. Hence, the objectives of this study were (1) to quantify the kinetics of product quality attribute (PQA) changes such as moisture content, oil content, texture, diameter shrinkage, and thickness expansion of sweet potato chips fried at different frying temperatures (120, 130, and 140 °C) under vacuum conditions; and (2) determine the degree of starch gelatinization, evaluate the microstructure, and all PQA for the single-stage (vacuum) and two-stage fried (atmosphere plus vacuum) sweet potato chips fried at 130 °C.

2. Materials and methods

2.1. Raw material

Sweet potatoes (*Ipomea batata L.*), were obtained from a local grocery store. They were stored in an environmental chamber at 10 °C and 95% relative humidity. Before frying, the potatoes were kept for 3–4 days at room temperature to allow reconditioning. We used the variety Beauregard, a popular variety characterized by a pale reddish skin with dark orange flesh.

2.2. Sample preparation

Potatoes were washed, peeled, and then sliced using a mandolin slicer (Mafter model 2000, Paris, France). The thickness of a slice was 1.6 ± 0.01 mm and measured with a thickness gage (Mitutoyo Thickness Gage, Tokio, Japan). A cylindrical metal cutter was used to cut a diameter of 5.08 ± 0.01 cm. The slices were rinsed in water to remove starch from the surface of slices and then blotted with paper towel before frying.

2.3. Single-stage or vacuum frying experiments

The experiments were performed using a vacuum fryer (Fig. 1) available at the Food Engineering Laboratory, Department of Biological and Agricultural Engineering at Texas A&M University, College Station, Texas. The frying process consisted of loading 6 potato slices (about 25 g) into the basket, closing the lid, and depressurizing the vessel. Once the pressure in the vessel reached 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. The test was performed in triplicate.

2.4. Two-stage frying experiments

A two-stage frying process was used to improve the appearance and texture of sweet potato chips. Both atmospheric and vacuum frying was done in the vacuum frying equipment. First, a basket filled with sweet potato slices was submerged into the oil under atmospheric conditions (1st-stage). As soon as the potato slices were partially cooked (1 min), the pressure was lowered to1.33 kPa (2nd-stage) and the product fried for 2 more minutes (in 0.5 min intervals). It took about 30 s for the vacuum to be reached. These times were based on preliminary experiments and produced products with the best oil content, mouth feel, color, and appearance. The products were fried at 130 °C. After frying was completed, the basket was raised and the slices were centrifuged for 40 s at 750 rpm. The vessel was pressurized after centrifuging. Fried potato slices were allowed to cool down at ambient temperature. Fresh canola oil was used in all frying experiments. The test was performed in triplicate.

2.5. Data acquisition system

The changes in temperature and pressure of the vacuum system 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 analog-to-digital conversion. A controller directly collects temperature and pressure data in the form of voltage through type-K thermocouples (Model KMQXL, Omega Engineering Inc., Stamford, CT, USA) and a pressure transducer (Model PX209-015G5V, Omega Engineering Inc., Stamford, CT, USA) placed inside the vacuum fryer. The variables measured by this system are temperature at the surface and at center of the potato chip, temperature of the vessel headspace, and pressure inside the vessel. A K-type thermocouple (0.0254 mm diameter) was used to measure changes in the slice temperature during frying (center and surface). Temperature at the chip-oil interface, *surface temperature*, was recorded during the complete frying process by means of a thermocouple placed slightly below the surface of the potato chip. Triplicate runs were performed and the average values were recorded for the center and surface temperatures. The slices were 2.66 mm thick for these experiments, because it was easier to accurately insert the thermocouple into the center of the sample than for the 1.6 mm chips.

2.6. Oil content

The Soxtec System HT extraction unit (Pertorp, Inc., Silver Spring, MD, USA) with petroleum ether as the solvent (AACC, 1986) was used to determine the oil content of the samples. The oil content was divided into three types: (1) total oil content (TOC) defined as the oil content of the product after frying without any de-oiling process; (2) internal oil content (IOC), i.e., the oil content of the chips after the de-oiling process; and the (3) surface oil content (SOC) was defined as the TOC minus the IOC. All measurements were made at least in triplicate.