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Effect of water content on the dynamic measurement of dielectric properties of food snack pellets during microwave expansion

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A B S T R A C T

The evolution of dielectric properties of starch-based food pellets with different moisture contents was measured during microwave expansion to determine the effect of water content on the expansion dynamics.

Dynamic dielectric measurements were found to be an excellent procedure to *in situ* monitor and characterize the different stages in the material transformation of food pellets during microwave expansion.

Although the maximum bulk expansion of pellets was achieved at a moisture content of approximately 8% (wet basis), comparative analysis showed that a moisture content 10–11% produced the best results considering the tradeoff between the foaming and expansion temperature. This was due to the high expansion index and an expansion temperature that was sufficiently lower than the onset temperature for pellet scorching, which provides an operating window to maximize expansion and minimize the likelihood of burning.

Dielectric measurements during microwave heating in short on/off cycles prior to pellet expansion suggested that the water was not as dielectrically bound for high moisture content pellets.

1. Introduction

Third-generation starchy snacks provide a new way to appeal to consumers by offering the possibility to finish the snack at home from an intermediate pellet form. To create a shelf-stable glassy product, food pellets are first extruded at low pressure at the die to prevent expansion, and are subsequently dried-down to the desired moisture content (Riaz, 2006), which is typically 10–13%. This process route allows storage without refrigeration, which simplifies transport and improves marketability by affording a high bulk density. The final dried product requires an expansion (puffing) step that can be accomplished by baking, hot air puffing, immersion frying in oil, or microwave heating (Moraru and Kokini, 2003; Nath et al., 2007; Osman et al., 2000).

Compared with other heating technologies, microwave expansion of snacks has been reported as more efficient, faster, and eliminates the need for additional fat (Lee et al., 2000; Moraru and Kokini, 2003). Nevertheless, pellet expansion in the domestic microwave oven is a more complicated process than traditional frying and remains a focus of investigation to overcome challenges related to condensation brought about by the cooler surrounding regions, which can cause clumping after expansion, low and uneven rates of pellet expansion, and/or burning (van der Sman and Bows, 2017).

Starchy pellets undergo several stages during microwave expansion (Boischot et al., 2003; Moraru and Kokini, 2003): (I) the absorption of energy increases the temperature of water molecules to produce superheated steam in the glassy matrix and the material undergoes a state transition from a glassy to a rubbery state, provided that the temperature exceeds the glass transition temperature (Tg); (II) pellet expansion occurs when the vapor pressure of the superheated steam is sufficient to overcome the resistance of the rubber-like matrix; (III) after expansion, if the microwave energy is turned off, the pellet cools down and reverts to a glassy state; (IV) if, however, the energy is maintained for a long enough period, the pellet experiences scorching and then burning.

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The moisture content of the food product is a critical element during the successive stages of the microwave process and influences the physical and mechanical properties of the expanded material (van der Sman and Bows, 2017). Consequently, several studies have investigated the effects of moisture content for the microwave performance of snack pellets and other related materials.

Lee et al. (2000) analyzed the effect of moisture content and gelatinization on the puffing efficiency and expansion volume of corn-starch pellets, finding an optimal expansion for half-gelatinized starch when the pellet moisture content was ~10% wet basis (wb). By studying the microwave expansion of glassy amylopectin extrudates for five different water activities, Boischot et al. (2003) concluded that a maximum expansion was achieved with moisture losses in the range 10–12% wb. Similarly, Sjöqvist and Gatenholm (2007) examined the influence of the moisture content in the expansion of high amylopectin starch extrudates for packaging applications processed by microwave energy, determining that the largest expansion was attained at moisture levels of 11.2 and 13.4% for extrudates conditioned at a relative humidity of 33% and 54%, respectively.

An important caveat to the aforementioned studies is that they were conducted using multimode domestic microwave chambers, which could result in misleading conclusions because of the uneven electric field configuration that is highly dependent on the chamber configuration, the sample location inside the chamber and the size of the workload, in addition to limited process control (e.g., inability to measure power absorbed by the sample).

Water content has a profound influence on the dielectric properties of food materials and in the glass/rubber transition. Accordingly, the measurement of the dielectric properties can provide valuable information about the water activity and consequently the heating performance of starch pellets during microwave expansion (Nelson and Datta, 2001).

Studies in the literature have reported dielectric properties values for similar materials as a function of the moisture content level. For example, Ling et al. (2015) used an open-ended coaxial-line probe to obtain the (off-line) dielectric properties dependencies of pistachio kernels with regards to radio frequency energy, temperature and moisture content. They found that the loss factor increased with increasing temperature and moisture. Bansal et al. (2015) employed a coaxial probe placed at the bottom of a sample holder to obtain the dielectric properties of corn flour for different moisture contents ranging from 8.8% to 22.7% wb, which again showed a clear correlation of both parameters. Finally, Kraus et al. (2013) used a cylindrical cavity and the cavity perturbation method (CPM) to calculate the dielectric properties of starch-based food materials for different moisture values at room temperature, also reporting a direct correlation between dielectric properties and the moisture content of the samples.

A better understanding of the mechanisms involved during microwave expansion requires the development of fast measurement devices that can provide *in situ* information in the short time period that the expansion process takes place. This knowledge could be used to improve the palatability and texture of snack foods in addition to providing a framework for the development of new products. We recently described a new procedure capable of measuring, for the first time, the *in situ* evolution of dielectric properties and other process-related variables along the different stages of the microwave expansion of starch-based materials (Gutiérrez et al., 2017). This method enabled us to analyze the dynamics of the expansion process and its relationship with process parameters such as the expansion time and the expansion index (EI) during the rapid process of expansion. The procedure was based on the work described in Catalá-Civera et al. (2015), where a microwave cavity with two orthogonal modes was employed for simultaneous heating and measuring without interferences.

The aim of present study was to extend the previous results in Gutiérrez et al. (2017) by directly analyzing the effect of the moisture content of starch-based food pellets during microwave expansion by *in situ* dynamic measurement of dielectric properties. The findings from this work may increase our understanding of the kinetics and processing conditions of the expansion process to further improve the overall properties of these types of snacks finished by microwave heating.

2. Materials and methods

2.1. Food pellets

An intermediate half-product pellet for commercially available snack foods was used as the test material (identical to that used in Gutiérrez et al., 2017). During the production process, these pellets (primarily based on potato flakes) leave the extruder at 35% moisture and are hot air-dried to ~12% moisture in a humidity-controlled environment in preparation for later finish drying in the commercial production process. Although not formulated for microwave heating, the pellets show favorable expansion in a domestic microwave oven. The pellets used in this study were cylindrical in shape and were approximately 30 mm in length and 3 mm in diameter. When fully expanded, the finished product is approximately 50–60 mm in length and 6 mm in diameter.

The pellets were conditioned at three different levels of relative humidity in order to achieve three different moisture content levels (MC) in the range of 8%, 11% and 15% MC (hereinafter, MC refers to wet basis). The initial moisture content of the pellet was calculated by heating 60 g of product in a convection oven (Heraeus WU 6100) for 72 h and measuring the weight loss. The initial moisture obtained was 10.31%.

For the additional moisture level measurements, fragments of pellets were placed inside a desiccator containing a saturated solution of potassium acetate (791733 Fluka) and potassium chloride (P9541 Sigma), for six weeks, to allow the pellets to reach a state of equilibrium. The samples were weighed before and after this conditioning period and the final moisture content of the samples was obtained from the difference in weight. The moisture content achieved was 7.91% and 15.67% MC.

Prior to microwave heating, the conditioned pellets were equilibrated to room temperature. The pellets presented a circular cross-section (~3 mm in diameter) and were cut into small pieces of 10 mm in length with flat sides, to allow the vertical placement into the reactor.

2.2. Experimental set-up

Microwave expansion of one single pellet placed inside a quartz tube was conducted in the dual-mode microwave cavity as described in Catalá-Civera et al. (2015), where simultaneous microwave heating and dielectric properties measurements are feasible without interference.

The cavity was conditioned for the specific application of microwave expansion of pellets as described in Gutierrez et al. (2017) by installing a venturi-based suction system at the top of the cavity to prevent water condensation in the quartz tube during expansion. To avoid interferences of the temperature measurements caused by the pellet volume change during microwave expansion, the temperature was measured at the surface of the pellet with an infrared camera (Optris PI 160, Optris, Berlin, Germany) from the top of the cavity. A video camera (MU9PC-MH, Ximea, Münster, Germany), placed at the side of the microwave cavity (see Fig. 1), recorded the