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INFLUENCE OF PRESSURE AND MICROWAVE POWER ON THE DRYING-KINETICS OF EXTRUDED STARCH-BASED "HALF PRODUCTS" DURING MICROWAVE VACUUM DRYING

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Abstract: The influence of microwave power density and vacuum level on the end-product characteristics of initially cylindrical shaped pellets was investigated at microwave power densities from 2 W/g to 4 W/g and at pressure levels from 20 mbar to 190 mbar. As product characteristic the ratio of the bulk volume before and after the end-drying step was investigated. At a constant pressure of 50 mbar the drying time was reduced from 27.9 min at 2 W/g to 8.3 min at 4 W/g with a higher expansion ratio at the increased power input level. At a constant power input the pressure level had no significant influence on drying time and expansion ratio.

Keywords: third generation snacks, microwave vacuum drying, drying time, expansion ratio

INTRODUCTION

Microwave drying of foodstuffs is a quite fast dehydration method compared to drying techniques like hot-air or freeze drying. The volumetric heating achieved by the application of electromagnetic energy can also be used to expand the volume of the product, known as microwave induced puffing. This method has been used to obtain fat free puffed food products with a high nutritional value and pleasant taste (Liu et al., 2010). Puffing produces a porous and snack-like texture with the added benefit of simultaneous dehydration (Nath et al., 2007).

In literature there are basically two different kinds of microwave induced puffing known. There is the puffing of pre-structured products like fruits (Han et al., 2006; Liu et al., 2009; Zheng et al., 2012), vegetables (Figiel, 2009; Rother et al., 2009; Yan et al., 2010) and grains (Hoseney et al., 1983; Lin and Anantheswaran, 1988; Pordesimo et al., 1990; Wu and Schwartzberg, 1992; Singh and Singh, 1999; Hoke et al., 2005) or fish (Zhang et al., 2007). In this way plant or animal cells or other top-level structures act as pressure vessels and enable pressure build up inside the product enabling expansion. The other kind is microwave induced expansion of e. g. dough (Ressing et al., 2007) and extruded starch based pellets (Birch, 1989; van Lengerich et al., 1989; Lazarus, 1990; Whalen and River, 1992; Lee et al., 2000; Ernoult et al., 2002; Gimeno et al., 2004; Aguilar-Palazuelos et al., 2006; Bastos-Cardoso et al., 2007; Zhou et al., 2007; Ortiz et al., 2010; Delgado-Nieblas et al. 2011). Latter products are referred to as third generation snacks (Chinnaswamy, 1993; Huber, 2000). As no cells are present in this case, expansion is controlled by product characteristics like degree of gelatinization (Lee et al., 2000) and rheological properties (van Laarhoven et al., 1991; Ressing, 2005). Therefore material parameters like initial moisture and starch content (Liu et al., 2009; Pranabendu and Venkatesh, 2009; Therdthai and Zhou, 2009) are very important. It is likely that process parameters like applied microwave power, agitation of the product and vacuum level are of crucial influence on puffing performance, end-product quality and time required for the simultaneous dehydration.

The application of microwaves under vacuum conditions can enhance the drying kinetics and expansion behavior. This type of processing allows fast drying and expansion of products at relatively low temperatures. In this way, vitamins, taste, flavor and natural colors can be conserved (Ahrens et al., 2007). Hu et al. (2006) reported that a higher vacuum level facilitates the evaporation and volatilization of water from the materials and shortens the drying time significantly. Other authors come to the same conclusion (Kaensup et al., 2002; Jeni et al., 2010). Song et al. (2009) found that the effect of vacuum pressure on drying rate was not as significant as that of microwave power. Berteli et al. (2009) and Changrue et al. (2007) reported that drying kinetics of a granular product was not affected by the vacuum level, whereas the absorbed microwave power was higher for smaller vacuum levels.

Boischot et al. (2003) reported that higher microwave power input leads to higher expansion. This could be probably due to the linear increase of temperature in the heated matrix with microwave power, which was observed by other authors (Tong et al., 1992; Tong and Lund, 1993; Khraisheh et al., 1997).

The aim of this work was to clarify the interactive influence of microwave power density and pressure level on drying kinetics and puffing behavior. Therefore the microwave induced expansion under vacuum of starch based extruded pellets was investigated systematically under this perspective.

MATERIALS AND METHODS

Raw material

As a typical ingredient for snack products, wheat flour type 405 was purchased from the BÄKO Mittelbaden e.G. (Karlsruhe, Germany). Sucrose was added at 11.6 % d.b. to enhance the expansion.

Extrusion

The starch-based pellets called 'half products' used in this study were prepared using a co-rotating twin-screw extruder (model ZSK 26 Mc, Coperion Werner & Pfleiderer GmbH, Stuttgart, Germany, L/D = 29, 7 sections) equipped with a die with 3 mm diameter. For pellet production the dry ingredients were fed into the first extruder section from a feeder (Brabender DDW-DDSR 40) with a gravimetric balance at a feeding rate of 8 kg/h. Water was added directly into the second extruder barrel and mixed with the dry ingredients inside the extruder. At the end of section 7 the hot melt leaves the extruder through the die. To avoid expansion at the die, product cooling was enhanced by a degassing opening at section 6. The screw speed was kept constant at 180 1/min. Samples were collected at stable extruder conditions (constant torque, stable temperature and pressure readings).

Sample handling

The extruded melt was cut into 40 cm long ropes and placed on baking paper, cooled down and dried for half an hour at environmental conditions. This was necessary to reduce the stickiness of the surface. Then the ropes were packed in plastic bags and stored over night in a fridge at 8 °C to allow for water equilibration. The cooled ropes had a diameter of about 4 mm. They were sliced by a self constructed cutting device into cylinders of 10 mm length.

Microwave vacuum drying

Prior to expansion, the pellets were equilibrated to room temperature in a closed vessel. The pellets were expanded in a processing drum rotating at 8 rpm. After every rotation the direction of the rotation was changed. This ensures a 3 dimensional mixing of the pellets which enables homogeneous microwave power absorption and thereby even drying and expansion of the pellets.

For all experiments the initial weight of each bulk was 200 g and the initial water content of the pellets was 39 %. During the whole process, every two seconds product surface temperature (IR-Sensor), pressure, incident and backward microwave power were read and stored on a computer.

To investigate the influence of microwave power density on drying time and expansion behavior power densities of 2 W/g, 3 W/g and 4 W/g per initial weight of the pellets were applied. The power density is calculated as the ratio of incident microwave power to the initial mass of one bulk of pellets. The pressure in the cavity was set to a constant value of 50 mbar.

The influence of the pressure in the cavity was investigated at a constant microwave power density of 3 W/g. The pressure was set to 20 mbar, 50 mbar, 100 mbar and 190 mbar.

The power input was ceased automatically by the drying processor when the surface temperature of the pellets exceeded 120 °C. When this temperature was reached, the pellets were sufficient dry and the expansion process was completed. Drying times were calculated as the time necessary to reach a water content of 10 %. At this water content the a_w-value of the end-product is below 0.45 (data not shown) which ensures a stable product with extended shelf life. All drying respectively puffing experiments were conducted in triplicate.

Pellet characterization

The moisture content of the pellets was determined by drying approximately 10 g of the samples at 90 °C in an oven until steady state of weight was reached (at least 24 h).

To quantify the gain in volume during the microwave induced expansion, a bulk volume expansion index (EI) is defined as:

$$EI = \frac{V_f}{V_i} . \qquad (1)$$

In this equation V_i is the initial volume of a bulk of 200 g of pellets and V_f is the final bulk volume after expansion. Volumes were measured with a graduated measuring cylinder of 500 ml total volume.

RESULTS AND DISCUSSION

As shown in figure 1, the required drying time at a constant pressure of 50 mbar in the cavity to decrease the initial water content to 10 % decreases with increasing microwave power density. At 2 W/g microwave power density the drying and expansion of the pellets takes about 28.1 min, at 3 W/g about 18.25 min and at 4 W/g the process time is reduced to 8.5 min. These findings are basically supported by several authors (Hu et al., 2006; Heredia et al., 2007;

Figiel, 2009; Jeni et al., 2010). Besides this, an increase of absorbed microwave power at higher microwave power densities can be observed. At 2 W/g microwave power density the mean absorbed power is about 1.27 W/g, at 3 W/g and 4 W/g this value is increased to 1.73 W/g and 2.21 W/g respectively. This phenomenon is also described by Figiel (2009) and Dixit et al. (2011).

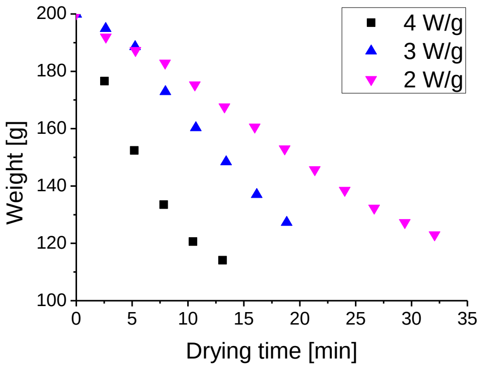

Fig. 1. Drying times required to reduce the initial water content below 10 % at microwave power densities of 2 W/g, 3 W/g and 4 W/g at a constant pressure of 50 mbar.

As shown in figure 2, the required drying time to reduce the initial water content below 10 % is nearly independent of the applied pressure in the cavity. At 20 mbar the drying and expansion of the pellets takes about 21.25 min, at 50 and 100 mbar about 18.25 min and at 190 mbar pressure 16.5 min. These findings are in accordance to findings of Changrue et al. (2007), Berteli et al. (2009) and Song et al. (2009).

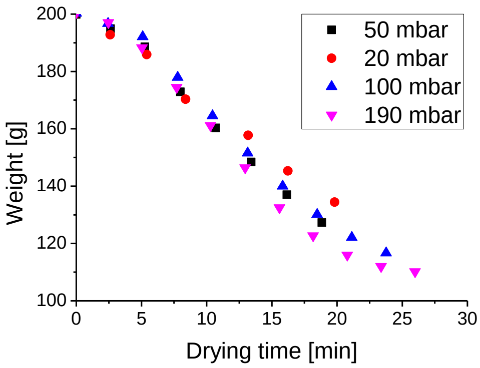

Fig. 2. Drying times required to reduce the initial water content below 10 % at pressure levels of 20, 50, 100 and 190 mbar at a constant microwave power density of 3 W/g.

Also the mean absorbed power by the pellets is almost independent of the applied pressure and varies around 1.76 W/g +- 0.03 W/g for all pressure levels.

The influence of microwave power density and vacuum level on the bulk volume expansion index EI of the pellets is shown in figure 3.

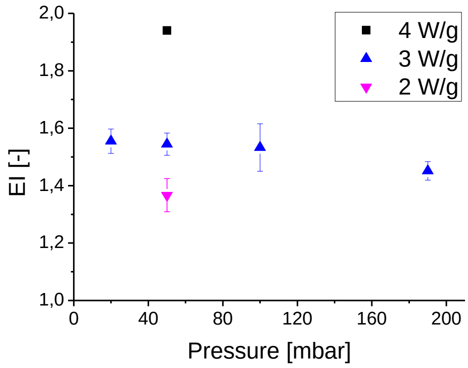

Fig. 3. Influence of microwave power density and pressure on bulk volume expansion index EI of the pellets.

At 3 W/g microwave power density the EI is approximately 1.5 and independent of the vacuum level. Only a slight decrease of the EI at 190 mbar is visible. Basically the pressure determines the temperature of the pellets as long as free water for evaporation is available. At the beginning of the expansion the a_w-value of the pellets is close to 1, which means that lots of free water is available. As higher the pressure as higher is the temperature at the surface of the product which leads to an increase of stickiness of the pellets. At 190 mbar the pellets tend to stick together and thereby form aggregates of several pellets. During the microwave application they melt together to one big pellet which suppresses the expansion. This results in a decrease of EI.

As figure 3 also reveals, the EI is strongly influenced by the microwave power density. At 2 W/g the EI is less than 1.4. This value increases to over 1.9 by application of 4 W/g. This is in accordance to findings of Boischot et al. (2003). At higher microwave power densities the temperature inside the pellets increases faster and the product can expand as long as the surface is still flexible enough and not dried in the meantime.

CONCLUSIONS

Microwave power density has the most significant effect on drying time and puffing characteristics during the microwave induced expansion under vacuum of starch based extruded pellets. An increase of microwave power density leads to a decrease of required drying time, an increase of the bulk volume expansion index and an increased microwave power absorption. The vacuum level has only minor effect on puffing and drying characteristics. Only if the pressure level allows for product temperatures which lead to significant stickiness of the product the expansion is reduced and processing rarely makes sense.

NOMENCLATURE

EI	bulk volume expansion index	[-]
a_w	water activity	[-]

V	volume	[ml]

Subscripts

i	initial
f	final

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