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Some recent advances in microstructural modification and monitoring of foods during drying: A review

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ABSTRACT

A number of changes food undergoes during drying are related, one way or another, to changes in its microstructure. An ability to modify the microstructure of a food material is therefore highly desirable as this would allow a food processor to either produce a product with the desired characteristics or prepare a product in a way that facilitates further processing. Microstructural modification can be achieved in a number of ways, including the use of appropriate drying techniques and conditions, with or without sample pretreatment. In this review, the use of selected pretreatment methods and drying technologies to create various microstructures is explored and discussed. Selected examples of microstructural modification by creating a more porous structure to produce highly-crisp fat-free snacks as well as a structure that facilitates the release of a compound from the food matrix and hence increased bioaccessibility and/or extractability of the compound are presented. Use of image analysis techniques to monitor the microstructural changes and a structure-quality indicator, which can relate the changes at the microscopic level to those at the macroscopic level, are also briefly reviewed.

1. Introduction

It is well known that drying, and indeed other thermal and even non-thermal processing, leads to a number of changes of a food material. These changes include physical, chemical and/or biochemical changes. Although only physical changes may seem to relate more directly to microstructural changes of a material, the microstructural changes indeed affect other types of changes viz. chemical and/or biochemical changes as well. This is because the microstructural changes may affect the path through which heat and mass must transfer. This in turn affects the drying characteristics of a material and hence its time/temperature history, which has a direct relationship with the chemical and/or biochemical changes. In the case where drying is performed on a food material that contains a bioactive compound that must later be extracted, microstructural changes may also affect the release of the compound from the food matrix, thus affecting the ability to extract the compound from the matrix (Hiranvarachat et al., 2012). An ability to modify the microstructure of a food material is therefore desirable. A way to monitor such a modification is also needed.

Microstructural modification can be achieved in a number of ways, including the use of appropriate drying technologies, with or without sample pretreatment (Bai et al., 2002; Devahastin et al., 2004; Canet et al., 2005; Hiranvarachat et al., 2011). In terms of monitoring, although microstructural changes of a material can be observed via the use of various microscopic techniques, it is not easy to quantitatively describe the changes of the obtained microstructural images. Fractal analysis has thus been proposed and successfully tested as a means to quantify microstructural images of a food material (Kerdpiboon and Devahastin, 2007; Kerdpiboon et al., 2007; Sansiribhan et al., 2012). Other advanced monitoring techniques, e.g., X-ray microtomography, have also been applied to monitor the changes of food microstructure in a non-invasive fashion (Léonard et al., 2008).

In this review the effects of selected pretreatment methods and drying technologies on the microstructure of foods as well as the use of those processes to create various microstructures for different purposes are discussed. Use of image analysis techniques to monitor the microstructural changes and a structure-quality indicator, which can relate the changes at the microscopic level to those at the macroscopic level, are also briefly reviewed.

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2. Effects of pretreatment and drying on microstructure of food products

2.1. Effect of pretreatment on microstructure

Pretreatment is an important step prior to drying of foods, especially fruits and vegetables. Several methods of pretreatment have been widely utilized; these range from such simple methods as immersion in chemical solutions, hot-water blanching and irradiation to more novel ones such as ultrasonic, high-pressure and pulsed electric filed pretreatments.

Pretreatment by chemical methods is among the most popular means to alter the various properties, including the microstructure, of foods. Several works have indeed reported the effect of chemical pretreatment on the microstructure of foods. Vega-Galvez et al. (2008), for example, studied the effect of chemical pretreatment on the microstructural changes, which in turn affected other properties, of rehydrated dried red bell pepper. The samples were immersed in an aqueous solution of NaCl, which was combined with $CaCl_2$ and $Na_2S_2O_5$ prior to convective drying. The results showed that the cell walls of the pretreated samples did not significantly collapse even after drying; this was reflected by the higher water holding capacity of the samples after rehydration. In addition, thickening of the cell walls might have occurred since the supplied calcium could form calcium pectate through the heat-enhanced activity of pectinmethylesterase.

de Oliveira Alves et al. (2010) monitored the effect of added sugar and alcohols on the microstructure and some selected properties of freeze-dried peki (*Caryocar brasiliense* Camb.) fruit pulps; the objective was to increase the stability and shelf life of the freeze-dried product by reducing the amorphous and hygroscopic structures. Combination of sucrose and ethanol was noted to be effective in inducing the formation of crystalline structure with lower bulk porosity; the product was thus more stable with lower water sorption during storage. The addition of alcohol also helped accelerate the drying process and resulted in the production of protected structures with less collapse.

Blanching in hot water is another common method of pretreatment. Although it is used mainly to inactivate enzymes in fruits and vegetables, blanching inevitably affects several other characteristics of a material, including the microstructure. Wang et al. (2010), for example, compared the effect of calcium pretreatment and blanching on the microstructure and related properties of potato subsequently dried by freeze drying. The results showed that a firmer texture occurred upon soaking in $CaCl_2$ solution as compared to the structure of a fresh sample. In the case of blanching well coherent potato cells were observed due to starch gelatinization; the cells were filled with the starch gel. Considering the microstructure of the samples during freeze drying, the blanched sample suffered more damage during drying. This is because of the expansion of the gelatinized starch granules, which caused an increase in the internal cell pressure, leading to the disruption of cell walls during frozen and sublimation stages of freeze drying. On the other hand, the calcium-treated sample exhibited straight cell walls due to the formation of calcium pectate, allowing the sample to maintain the porous structure during freeze drying. These different microstructures were directly related to the texture of the dried potato; dried blanched potato had higher hardness than the calcium-treated one.

Irradiation is another effective means to modify the structure of foods. Yu and Wang (2007), for example, investigated the effect of γ-ray irradiation pretreatment on the microstructure and physicochemical properties of rice dried subsequently using hot air at 40 °C. The studied dose of γ-ray was 0–10 kGy. The microstructural observation revealed that the starch granules were destroyed by γ-irradiation; the damage increased with an increase in the γ-ray dose. Structure of the inner endosperm was greater affected by the irradiation than the outer endosperm. In addition, the apparent amylose content decreased with an increase in the γ-ray dose. Basically, apparent amylose content is composed of two components: amylose and partly branched long-chain amylopectin (Vandeputte and Delcour, 2004). The decrease in the apparent amylose content in turn led to increased gel consistency. In addition, the starch viscosity decreased with an increase in the γ-ray dose; the decrease in the viscosity was due to rupture and size decrease of the granules caused by the gamma irradiation.

Ultrasonic pretreatment has gained much attention during the past years as a non-thermal pretreatment process for a wide array of food materials. Microstructural modification via ultrasonic pretreatment is due to acoustic cavitation, which results in damaged cell structure (Fernandes and Rodrigues, 2008). Nowacka et al. (2012), for instance, investigated the effect of ultrasonic pretreatment prior to convective drying at 70 °C on the microstructure and other properties of dried apple cubes and reported that ultrasonic pretreatment led to cavitation of the cells. Cavitation-induced imploding bubbles led to very high and rapid changes in the pressure and temperature, leading to the breakdown of the cells. These caused the dried ultrasonic-treated apples to exhibit higher drying rate, higher porosity and lower density. Ultrasonic pretreatment can also be combined with other pretreatment methods such as osmotic dehydration to modify the microstructure of foods (e.g., Deng and Zhao, 2008).

The use of high-hydrostatic pressure (HHP) in the range of 100–1000 MPa can also lead to changes of the food microstructure, which in turn leads either to softening or firming of the food matrix. An increase in the release of intracellular substances after HHP treatment has also been demonstrated (Ghafoor et al., 2012; Zhang et al., 2006). Vega-Galvez et al. (2011) studied the effect of HHP pretreatment on the microstructure and other properties of *Aloe vera* gel dried later with hot air. The results showed that HHP pretreatment led to a decrease in the intracellular integrity of the cell structure. The intact cellular structure was transformed into a separated and ruptured structure. The cell damages during HPP treatment occurred due to excessive strain in the membranes as well as stresses in the cell walls. The firmness of the dried HPP-treated samples was higher than that of the dried sample without pretreatment due to the development of a compressed structure in the parenchyma tissue, which was formed by structural polysaccharides that provide stiffness to the cell walls. In addition, HHP pretreatment enhanced the antioxidant activity of the samples. This is ascribed to the better extractability of antioxidant components due to the changes in the tissue matrix induced by HHP treatment.

Some other investigations on the microstructural changes of foods upon various pretreatments are summarized in Table 1.

2.2. Effect of drying on microstructure

Drying methods and conditions directly affect the microstructure and various other properties of dried foods. Several works have been devoted to the study of the effect of drying on microstructure of foods. Freeze drying has been noted to be capable of controlling the microstructure of foods; nevertheless, to reduce the drying time combination of freeze drying with different other techniques has been proposed. Huang et al. (2012), for example, investigated the freeze drying (FD) in combination with microwave vacuum drying (MWVD) of apple slices. The cell structure of FD + MWVD sample suffered less collapse than that of the sample dried by MWVD + FD. This is because the free water had been removed from the sample at the end of the FD process and porous