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# Influence of shelf temperature on pore formation in garlic during freeze-drying

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**Abstract**

The formation of pores in garlic was examined during freeze-drying at different shelf temperatures (−5, −15, and −25 °C). The moisture content of dried garlic and its temperatures at different locations within the sample were measured as a function of drying time. The apparent porosity of fresh garlic was 0.25 (±0.03), while 72 h dried samples showed about 0.700 for the drying temperatures used in this study. Apparent porosity increased with the decrease of moisture content showing varied curvatures depending on the shelf temperatures. The estimated shrinkage-expansion coefficients from Rahman's model were 0.313, 0.429, and 0.409 for shelf temperatures −5, −15 and −25 °C, respectively. Samples dried at −5 °C showed significantly lower open pore porosity compared with the samples dried at −15 and −25 °C, respectively, although all samples showed similar apparent (i.e. total) porosity. Pore-size distribution and scanning electron micrographs also supported that characteristics of pores are different for samples fried at −5 °C when compared with samples dried at −15 °C and −25 °C.


*Keywords:* Apparent density; Apparent porosity; Drying kinetics; Porosimetry scanning electron microscopy; Shrinkage expansion coefficient

## 1. Introduction

Knowledge on pore formation in foods during processing can be useful in process design and in estimating transport properties such as thermal conductivity, thermal diffusivity and mass diffusivity (Rahman, 2001). Drying methods as well as drying conditions influence porosity of final dried product, thus the same raw material may end up with different characteristics of pores depending upon the drying method and conditions. Freeze-drying is considered one of the best methods for drying of food and biomaterials, which are sensitive to heat. The method incorporates a low-temperature drying process during which most of the water is eliminated by sublimation. Freeze-dried products are usually characterized by higher porosity, better rehydration properties; minimal changes in flavor, color and biological activity compared to products of obtained from air and vacuum drying (Genin, Rene, & Corrieu, 1996; Krokida, Karathanos, & Maroulis, 1998; Krokida & Maroulis, 2000). However, the freeze-drying process involves high production costs. The drying rate is usually low and gives rise to drying times that can range from a few hours up to 3 days. The oxidative stability of freeze-dried product is also lower due to its porous structure, which allows more contact area with oxygen. As a consequence, the use of freeze-drying on the industrial scale is restricted to high added value and selected products.

Kramkowski, Kaplon, and Berdzik (1996) studied the temperature distribution in the sample and change of moisture content in the course of freeze-drying for mushrooms, beef meat and coffee solution. The freeze-drying rates of beef were measured as a function of chamber pressure

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**Nomenclature**

| | |
|---|---|
| $D_i$ | mean pore diameter (μm) |
| $f_v$ | volume pore size distribution function (Eq. (10)) |
| $k$ | drying rate constant ($h^{-1}$) |
| $m_s$ | mass of sample (kg) |
| $M$ | mass ratio at any moisture content relative to the initial mass (Eq. (8)) |
| $P$ | pressure ($lb/in^2$) |
| $X$ | mass fraction |
| $X_w$ | moisture content (w.b., g $H_2O$/g wet sample) |
| $V$ | volume ($cm^3$) |

*Greek letters*

| | |
|---|---|
| $\rho$ | density |
| $\varepsilon$ | porosity |
| $\phi$ | shrinkage/expansion coefficient |

*Subscripts/superscripts*

| | |
|---|---|
| a | apparent |
| e | equilibrium |
| $i$ | component |
| m | material |
| n | total number |
| o | initial, open pore |
| s | substance |
| T | true |

(Bralsford, 1967). Genin et al. (1996) studied the freeze-drying kinetics as a function of heating plate temperatures (0–25 °C), pressure (5–300 Pa), and thickness (4.5–13.5 mm), respectively. Yunfei and Chengzhi (1996) optimized the freeze-drying conditions for low energy consumption and high productivity. The optimum operating conditions for bovin colostrums were as follows: vacuum pressure 54.5 Pa, sample thickness 10 mm, and concentration of bovin colostrums 37%. Similarly Hammami, Rene, and Marin (1999) determined the optimum operating pressure (50 Pa) and heating plate temperature (55 °C) of freeze-drying of apple slices based on the quality attributes (appearance, color, texture, and rehydration). Similarly for strawberry it was 30 Pa and 50 °C (Hammami & Rene, 1997). Thin layer air-drying kinetics of garlic slices (2–4 mm) were measured as function of temperature (50–90 °C), relative humidity (8–24%) and air velocity (0.5–1 m/s), respectively (Madamba, Driscoll, & Buckle, 1996).

The emulsifying characteristics of freeze-dried and spray-dried gluten hydrolysates were studied by Linares, Larre, and Popineau (2001). Otegui et al. (1997) studied the functional properties of spray-dried and freeze-dried faba bean protein concentrates. Freeze-dried lactic acid bacteria survived more when compared to the spray-dried culture. The spray drying caused considerable delay in lactic acid production and reduction in survival (To & Etzel, 1997). D'Andrea, Salucci, and Avigliano (1996) studied the activity of freeze-dried ascorbate oxidase during storage. A sugar-based lyoprotectants provided better stabilization when the freeze temperature was −75 °C. Heat pre-treatment affected lipid composition and pigment contents in freeze-dried spinach as well as drying yield (Choe, Lee, Park, & Lee, 2001). Heat pre-treatment resulted in increased in relative contents of triacylglycerol and free sterols in neutral lipid, sterylglycosides and monogalactosyldiglycerides in glycolipid and phosphatidylinositol in phospholipids of dried spinach. Chlorophyll and β-carotene contents in freeze-dried spinach decreased by heat pre-treatment. Desobry, Netto, and Labuza (1997) found more stability of encapsulated β-carotene during storage when dried by drum drying compared to the spray drying and freeze-drying. Fang, Footrakul, and Luh (1971) studied the effects of blanching, sulfite-treatment, and freezing methods on the quality of freeze-dried mushrooms. Similarly effects of freezing conditions on aroma retention in freeze-dried mushrooms were studied by Kompany and Rene (1995).

The glass transition concept has been proposed to explain minimal shrinkage in material during freeze-drying (Karathanos, Anglea, & Karel, 1993, 1996). However this concept does not hold true for all products or processes (Rahman, 2001; Sablani & Rahman, 2002). Other concepts, such as surface tension, pore pressure, structure, environment pressure, and mechanisms of moisture transport also play important roles in explaining the formation of pores. The complexity of the pore formation mechanism needs further study with diversified food materials and with a wider variation of processing conditions in order to develop a more unified concept of pore formation. The objective of this study was to study the influence of shelf temperature (−5, −15, −25 °C) on the drying kinetics, apparent density, porosity and pore size distribution of garlic processed using freeze-drying.

## 2. Materials and methods

### 2.1. Freeze-drying experiments

Garlic bulbs were purchased from the local market and were stored at room temperature (20 °C) until used for experiments. The initial moisture content of fresh garlic was 71% (wet basis). Brick shaped samples (20 mm × 10 mm × 10 mm) were prepared from garlic cloves with sharp knife. The samples were quickly packed in plastic