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Measuring the food microstructure by two-point cluster function

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ABSTRACT

The clustering of pores of three types of bread was studied by measuring the two point cluster function, $C_2(r)$. The ability of this function in describing the connectivity among the structure elements of bread was proved by comparing the $C_2(r)$ of a "reference" and a "reconstructed" bread image having the same porosity fraction and lineal path distribution function, $L(r)$. The two point cluster function of the void phase of two commercial, "Pan Brioscè" and "Pancarrè", and a non commercial, "White", bread enabled to highlight significant differences of their topological properties. "White" bread was characterized from more homogeneous pores with a lower degree of connectivity while the "Pancarrè" samples exhibited voids highly connected producing pores bigger in size and with a shape extremely complex. Furthermore, for the first time it was proved as the microstructure information of the two point cluster function allows discriminating the 90% of the total variace of bread samples.

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1. Introduction

Several of the effective features of food such as mechanical and electromagnetic properties, mass and heat transfer, as well as sensorial, nutritional and safety quality strictly are dependent from their complex microstructure. Aguilera (2005), who reported the results of several scientific papers, highlighted as the majority of the macroscopic features, which satisfy the consumer's demand, are controlled by microscopic elements, particularly below 100 μm. For instance, by restricting the mobility of reactants as well as separating those in different compartmentalization would be possible to avoid chemical or biological degradation reactions. Slade and Levine (1991) proved as when the foods are in glassy state, which is characterized by a very high viscosity, their physical and chemical stability abruptly increased as a consequence of the reduction of molecular mobility. Robins and Wilson (1994) reported that restricting the ability of a bacterial colony to expand, a reduction of bacterial can be achieved. In terms of mass and heat transfer, several papers reported that the diffusion cannot be considered as the only mechanism involved during dehydration, rehydration, extraction, freeze-drying, roasting, etc., but the pathway in which the molecules may move toward the inner part of food or *viceversa* are of crucial importance for obtaining a high food quality. Datta (2007a, 2007b), who considered the foods as porous media (a solid having pores filled with gas or liquids) reported as liquid transport is affected by the intrinsic permeability, a parameter which defines the solid matrix properties such as pore size distribution, shape of pores, porosity and tortuosity. More generally, as reported from Derossi et al. (2014) a wide series of food may be generally considered as two-phase random media in which a void phase (pores) is entrapped in a solid matrix phase (cells, proteins, crystals, globules, etc) resulting in a very complex three-dimensional microstructure. Some examples are: bread, composed from pores entrapped into the crumb resulting into the so-called crumb texture; sausages, which are characterized from fat globules into a protein phase; ice-cream, which is composed from air bubbles entrapped into a solid (freeze) aqueous solution of several ingredients. On these bases, the quantitative characterization of food microstructure becomes of great importance for the improvement of food processing and/or the quality of food. In the past two decades, a wide series of statistical correlation functions were proposed and used to obtain the description of microstructure of heterogeneous materials (Lu and Torquato, 1992a; Torquato, 2002a; Coker and Torquato, 1995; Quintavalla, 2006). In general, the complete characterization of microstructure requires an infinite set of n-point probability function $S_n(r_1,\ldots\ldots,r_n)$ which gives the probability to find n points in the position $r_1,\ldots\ldots r_n$, in one of the phases of the system (Jiao et al., 2007). However, only low order correlation functions are practically attainable. Among these, the *two point probability function*, $S^i_2(r)$, which defines the probability to have two points in the position r_1 and r_2 both in the phase i, is

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one of basic morphological descriptors of microstructure. Chord-length distribution function, $p^i(r)$, defines the probability to find a chord of length r completely in the phase i (Lu and Torquato, 1993) while the pore-size distribution function, $P(r)$, characterize the voids in porous media (Torquato, 2002a). Moreover, the lineal-path distribution function, $L(r)$, is the probability to find a segment of length r completely in the phase i (Lu and Torquato, 1992a, 1992b); moreover, this function gives connectedness information along a lineal-path (Torquato, 2002b). The above functions have been extensively used to define the microstructure features of several digitized model systems as well as of real materials such as polymer nano-composite, sandstone, magnetic gels, Born modified Ti-alloys (Rintoul et al., 1996; Chan and Govindarajiu, 2004; Singh et al., 2008; Sheidaei et al., 2013) but few applications on the field of food science are available in literature (Derossi et al., 2012, 2013a, 2013b, 2014). Furthermore, in the last years some authors, studying the reconstruction of microstructure of heterogeneous materials from limited morphological description revealed that the clustering information enables to reduce the number of compatible microstructures generating a better reconstruction of 2D and 3D systems (Jiao et al., 2009, Guo et al., 2014). In particular, the *two-point cluster function*, $C^{(i)}_2(r_1,r_2)$, which defines the probability to find both points r_1 and r_2 in the same cluster of phase i (Torquato et al., 1988; Jiao et al., 2009; Guo et al., 2014) may be considered a superior descriptor very sensitive to topological clustering information. The use of this function enables to reconstruct two-phase random systems with high accuracy (Jiao et al., 2009; Guo et al., 2014). Fig. 1 exhibits the events which contributes to some statistical correlation functions. Although the application of the two-point cluster function for obtaining clustering information of microstructure was previously performed for different model systems, none application on food science was reported. Following these consideration, this paper has two main aims: 1. to implement an algorithm able to extract the two-point cluster function, $C_2(r)$, from 2D image of food; 2. to study and compare the clustering of void phases of food microstructure.

2. Material and methods

2.1. Theoretical background

A random medium is a domain of space $V(\omega)\,\varepsilon\,R^3$ (the realization ω is taken from some probability space Ω) where the volume V is characterized from two-phases: phase 1 in the region Υ_1 with a volume fraction ϕ_1, and phase 2 in the region Υ_2 with a volume fraction ϕ_2. For a given realization ω, the characteristic function $I_{(x)}$ of phase 1 may be reported as:

$$I_{(x)} = \begin{cases} 1, & if\ x \in \Upsilon_i \\ 0, & otherwise \end{cases} \quad (1)$$

where Υ_i, is the region occupied by phase i (Equal to 1 or 2) (Lu and Torquato, 1992). As defined by Torquato et al. (1988) a cluster of the phase i is defined as that part of the phase i which can be reached from a point of the phase i without passing through the phase j, $j \neq i$. Under this consideration the two-point cluster function, $C^i_2(r_1,r_2)$, is defined as the probability of finding two points r_1 and r_2 in the same cluster of phase i.

2.2. Raw materials and images acquisition

Bread was chosen as model because its structure may be considered as a two-phase system in which the void (pores) is the phase 1 and the solid matrix (crumb) is the phase 2. Also, since the position of pores produced during yeast fermentation is extremely affected from several random variables such as air incorporation, dough preparation, etc., bread structure may be considered a random system. Particularly, three types of bread were used: 1. the "Pan brioscè" bread (Mulino bianco, Italy) locally purchased; 2. the "Pancarrè" bread (Mulino Bianco, Italy) locally purchased; 3. a not commercial "White" bread manually prepared in laboratory by using soft wheat (*triticum durum*). These types of bread were chosen for their differences in terms of visual aspect of their crumb texture since that the "White" bread appeared to be characterized from the bigger pores, the "Pan Brioscè" from pores the majority of which have a small size, while the "Pancarrè" bread visually shows a void phase characterized from pores extremely small. 10 loaves for each type of bread were cut to obtain slices with a thickness of 1 cm and the images were acquired by using a flat scanner mod. Hp 3600 (Hp, Scanjet) covering the samples with a black box to obtain a good contrast between the background and the samples, and to guarantee constant lightness conditions. Five images for each loaves were acquired for a total of 50 image for each type of bread. The images for each loaves were acquired by positioning the top of the slice sample parallel with the light of scanner (x axis) with the aim to avoid the effect of sample's position on lineal-path distribution function. In all cases a square region of interest (ROI) of 400 * 400 pixels was used. The choice of this image size was the result of preliminary experiments in which the differences in terms of lineal-path distribution function and two-point cluster function were evaluated as a function of the size of the ROI in a range between 100 * 100 pixels and 700 * 700 pixels. The results showed as by using a ROI greater than 400 * 400 pixels no changes in terms of $L(r)$ and $C_2(r)$ were obtained allowing to state as this image size enables to capture the overall microstructure features of the three types of bread studied. A

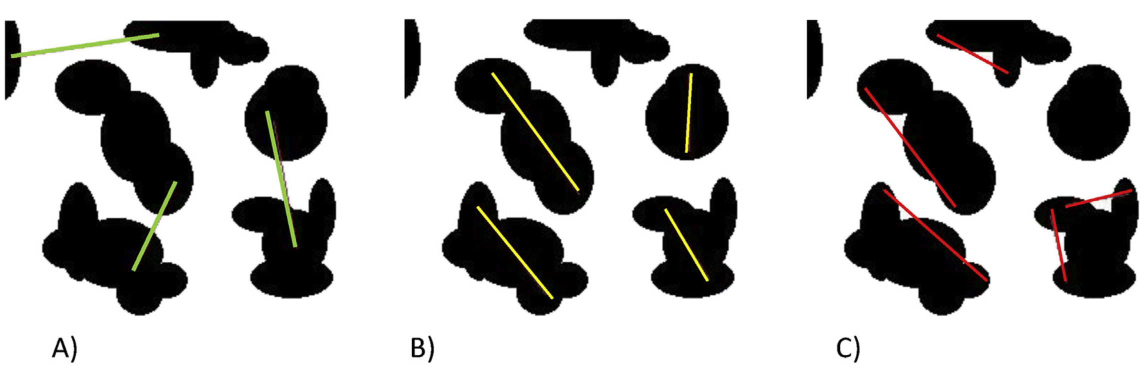

Fig. 1. Schematic representation of the some statistical correlation functions. A) Two-point correlation function, $S_2(r)$; B) Lineal-path distribution function, $L_2(r)$; C) Two-point cluster function, $C_2(r)$.

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