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Water properties in wheat flour dough II: classical and knudsen thermogravimetry approach

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Abstract

Thermo-Gravimetric Analysis (TGA) investigations suggest that water in a wheat flour dough is partitioned in various states related to the different disperse phases of the system. Classical TGA results indicate the gross water partition at the macroscopic level, while Knudsen TGA investigations, that allow evaluation of the relative humidity of the dough at room temperature, suggest the involvement of water in the structure of the dough at a supra-molecular level. The overall moisture content, the mechanical stresses and the presence of extra non-starch polysaccharides and/or soluble proteins, can affect this partition, either promoting water displacements across the inter-phases, or modifying the supra-molecular structure of the system. The investigations, extended to bread crumb during ageing, indicate that water undergoes displacements and forms stronger links with the components of the aged crumb with a kinetic law that can be influenced by the presence of extra non-starch polysaccharides.

Keywords: Water; Bread dough; Thermogravimetry; Knudsen TGA

1. Introduction

Water is ubiquitous in food products, where, because of its small molecular mass, is the major mobile component. As it easily forms hydrogen bonds with a number of substrates, water can either solvate ions and/or polar molecules (or functional groups) keeping them apart from one another, or become a structure component of supra-molecular clusters. Water that occupies intermediate sites between solvated molecules, thanks to its high mobility, acts as a plasticizer of the whole system (Slade & Levine, 1995). For these reasons, water is responsible for many physical properties of food systems, as well as for the microbial growth, which can produce degradation processes and texture changes. Studies on the role of water may therefore be referred to as a major sector of the literature on food science.

A number of papers (Bell & Labuza, 2000 and therein quoted literature) are devoted to the thermodynamic activity of water, a_W, which seems phenomenally related to the effects produced by this component. a_W is usually determined at room temperature as a function of the water content, the results of these investigations being typically reported in the form of adsorption/desorption isotherms. Usually, when a true equilibrium is attainable, three regions can be recognized (monolayer water, multilayer and capillary linear region, and solvent or "free" water region) along a given adsorption/desorption isotherm. Unfortunately this description does not match many food systems (were it so, food science and in particular food chemistry would be much simpler). In practice since in most food products water is partitioned among different phases, either as a result of the preparation process or as a consequence of the thermodynamic incompatibility between the polymer components of the system, a single a_W value may have a reliable physical meaning only if a true equilibrium has been attained, i.e., when the system is thermodynamically stable. However almost every food can be referred to as a system far from the true thermodynamic equilibrium

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(Slade & Levine, 1991; Roos, 1995), especially when it is kept below its lowest glass transition threshold (a heterogeneous system has several glass transitions). This means that water in a food system can be found in various states, each with its own water activity. As a consequence, the experimental adsorption and desorption isotherms actually describe a phenomenological property that is time dependent and may not be representative of the whole water content of the system.

A wheat flour dough is an example of such a system. The major components of wheat flour (starch and non-starch polysaccharides, gluten proteins, etc.) are polymers incompatible with one another (Tolstoguzov, 1997; Grinberg & Tolstoguzov, 1997; Fessas & Schiraldi, 2004) and therefore compete for the available water forming separate aqueous phases, each with a peculiar composition. The effects of the whole moisture content on the overall properties of the dough (and the resulting bread) must therefore be explained assessing the behaviour of water in each single phase of the system.

In a previous paper appeared in this Journal (Fessas & Schiraldi, 2001), a description of the properties of the water in a wheat flour dough was drawn from Thermogravimetry (TGA) investigations. The experimental results supported the picture of water partitioned in at least two main states, namely, free to evaporate (with a fickian diffusion law from the core to the surface of the dough), and trapped within a gluten rich phase, from which water can escape only above a high temperature threshold. It was also found that the dough overall moisture and the mechanical stresses and/or relaxations experienced by the sample at room temperature could affect the water partition. These conclusions find some confirmation in recent works (Kim & Cornillon, 2001) where displacements of water in a hard wheat flour dough were determined with NMR relaxometry.

The present paper aims at perfecting the interpretations of the role of water in a wheat flour dough correlating the TGA data with determinations of the relative humidity, RH, of dough samples in isothermal conditions and extending the investigations to the bread crumb at various aging times. The role of other dough ingredients which can be added in small amounts to modify the dough recipe and have proved influence in breadmaking (Fessas & Schiraldi, 1998), like globular proteins and non-starch polysaccharides (water-extracted pentosans), are also described.

2. Materials and methods

2.1. Flour and extracts

Wheat flour was a commercial product with the following non-starch content (w/w with respect to the flour mass): proteins 9.85 ± 0.47 (Kjedahl nitrogen, conversion factor = 5.7), water 14.5 ± 0.2, lipids 1.19 ± 0.01, ash 0.45 ± 0.01. Moisture was determined gravimetrically by heating samples in a ventilated oven at 105 °C for 24 h. This moisture value is only indicative and used for the formulation in the dough preparation. The true dough moisture was attained by thermogravimetry (see below). Soluble (globular) proteins (albumins and globulins in the sense of Osborne) and water extractable pentosans were extracted from centrifuged water suspensions of flour according to a previous work (Fessas & Schiraldi, 1998).

2.2. Dough samples

The wheat flour dough was prepared with wheat flour and distilled water, without adding any salt and yeast for the sake of reducing the number of variables that could affect water partition within the dough. The recipe was modified by changing the water content and/or by adding globular proteins or water-extracted pentosans.

Mixing. Previous observations shows that the mechanical stresses influence the water partition in the dough. In order to compare the results with previously published data (Fessas & Schiraldi, 2001) mixing was performed according to the two procedures described below.

- *Manual mixing dough*. For each type of dough, 30 g of water–flour mixture were manually mixed for 10 min (2 min in a beaker, and 8 min with manual kneading). Two types of dough were prepared in this way: (a) with an overall 42% moisture and no extra ingredients; (b) with an overall 42% moisture added with 0.48% (w/w with respect to the flour mass) liophylized soluble proteins.
- *Mechanical mixing dough*. Dough was prepared mixing 300 g flour + desired amount of water with mechanical mixer (Hobart mixer, USA) for 30 min. The dough was let at rest for 2 h before any measurement. The following types of dough were prepared in this way, namely, (a) with a 40%, 42%, 43.5%, 47% (w/w) overall moisture and no extra ingredients; (b) enriched with 1% (w/w with respect to the flour mass) water-extracted pentosans and an overall 40% (w/w) moisture (aqueous solutions of water-extracted pentosans were used to prepare this type of dough, carefully planning the water content of the solution in order to achieve the desired overall dough moisture).

2.3. Crumb samples

Bread crumb samples were directly produced in the thermobalance pans loaded with 50 mg of a given starting dough [dough was prepared mixing 500 g flour and 52.7% water (w/w with respect to the flour mass) with a mechanical mixer (Hobart mixer, USA) for 10 min. No rest time was allowed. The thermal treatment