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Structure related changes during moistening of freeze dried apple tissue

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Abstract

The knowledge and interpretation of the relationships between structure and properties in foods is of considerable interest. In the present work, freeze dried apple tissue was assumed as a basic plant food structure and some chemical and physical changes associated with a gradual moistening were monitored in order to (a) observe their reciprocal interactions, (b) clarify whether they could be related to water activities (a_w) and/or the glass transition temperatures (T_g) and (c) investigate into the role of the insoluble cell walls structure. Water activity, glass transition and collapse temperatures, shrinkage, consistency, colour and volatiles released were considered in respect to the degree of hydration. The results showed that complex interactions occur among these changes, and that the insoluble fraction plays a role affecting the dependence of such changes from both T_g and a_w. For most properties the main changes occurred at a_w 0.40–0.50 with $(T - T_g)$ in the range of 50–60 °C.

Keywords: Apple; Water activity; Glass transition; Physical properties; Insoluble matter

1. Introduction

Structure is an important and complex determinant of food quality and behaviour. In the last decades, some fundamental aspects of the relationships among material properties and chemical and physical changes in foods have found an improved interpretative tool in the coupling of the concepts related to the water activity with those developed from the glass transition theory. The latter being mainly concerned with the dynamic of changes in low moisture systems. According to the theory, changes are triggered when process temperature exceeds the glass transition temperature (T_g) and proceed with a rate dependent on $(T - T_g)$. The concept of *critical* a_w has been proposed (Roos, 1995a) as the a_w that corresponds to the T_g relevant to a given change. By mean of these approaches, a considerable number of physical phenomena of interest in processing and quality of foods (e.g. collapse, recrystallization, caking, diffusion limited processes) can be predicted on a rational basis. However, while this holds for relatively simple and homogeneous systems, more complex conditions occur when non-homogeneous, multidomain, multicomponent systems are concerned. Fruits and many fruit derivatives may well represent such complexity.

The structural elements of fruit tissues can be described as composed by a watery dispersing medium of low molecular species: sugars, salts and organic acids (Mizrahi, 1978), affecting both T_g and a_w. Within this medium, hydrocolloids, mainly soluble pectins, strongly affects the macroscopic viscosity, but have no effect on water activity and glass transition temperatures (Maltini, Torreggiani, Venir, & Bertolo, 2003). The liquid fraction, i.e. the juice, fills a complex framework of insoluble matter (cellulose, hemicelluloses, proteins, insoluble pectins), where air spaces are also included. The insoluble structure can swell with water and is the main determinant of consistency and perceived texture. In most fruits, although the liquid phase

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represents 85–90% of the total weight, cell walls accounting for a few percentage are responsible for the rigidity and solid like behaviour (Bourne, 1983).

Compared to the number of studies on the dehydration of plant foods (Del Valle, Cuadros, & Aguilera, 1998; Karathanos, Anglea, & Karel, 1993; Karathanos, Kanellopoulos, & Belessiotis, 1996; Krokida, Kiranoudis, Maroulis, & Marinos-Kouris, 2000; Mayor & Sereno, 2004; Moreira, Figueiredo, & Sereno, 2000; Nieto, Salvatori, Castro, & Alzamora, 2004; Ramos, Silva, Sereno, & Aguilera, 2004; Ratti, 1994), there is little reported works on how they behaves during rehydration (Krokida & Maroulis, 2001; Lewicki, Witrowa-Rajchert, & Mariak, 1997; Prothon, Ahrné, & Sjöholm, 2003). In the present work, freeze dried apple tissue was assumed as a basic plant food structure and some chemical and physical changes were monitored, in order to observe their reciprocal interactions, to give evidence of their relations with water activities and/or glass transition temperatures and to elucidate the role of the insoluble cell wall structure.

The monitored properties were

- Sorption isotherm and glass transition temperatures in the 0–0.86 a_w range. Dehydration of matrices to low water contents often results in the formation of metastable glasses, especially in carbohydrate containing foods, which are plasticized by the increase of water content or temperature (Roos, 1995a; Roos & Karel, 1991a). Above the glass transition temperature, many physical properties can be significantly affected by increased molecular mobility and decreased viscosity (Roos, 1995b; Roos & Karel, 1991a; Roos & Karel, 1991b; Roos & Karel, 1991c; Slade & Levine, 1991).
- Collapse temperatures (T_c), and related phenomena such as consistency and volume contraction (shrinkage). In freeze-dried systems an extensive pore network is left by the sublimation of ice and to the presence of intracellular air spaces. Collapse and shrinkage of the pore network have been found to depend on the water content and temperature and to occur above T_g (Levi & Karel, 1995a; Roos, 1995b).
- Colour. Chemical phenol oxidation and both enzymatic and Maillard reactions can be involved in browning of unblanched apple tissue. Browning mechanisms can be influenced by molecular diffusion and the physical state of low moisture foods has been suggested to be one of the rate-defining factors (Buera & Karel, 1995; Slade & Levine, 1991).
- Volatiles release. Unexpected high retention of volatiles in model systems and foods was observed in early studies on freeze drying by Flink and Karel (1970, 1972) and Chirife and Karel (1973) among others. A strong decrease in the retention of volatiles following moisture adsorption and structural collapse was evidenced (Chirife & Karel, 1974; Flink & Karel, 1972; To & Fink, 1978). It was proposed that volatiles may become entrapped in the amorphous matrices resulting from rapid dehydration and that the release of entrapped volatiles may be triggered by structural collapse. According to the glass transition concepts, both structural collapse and the release of volatiles in low moisture systems, can occur in carbohydrate glasses above T_g, with a rate dependent on $T - T_g$ (Levi & Karel, 1995b).

2. Materials and methods

2.1. Samples

Apples from the cv. *Golden Delicious* were purchased in a local market. Apples were peeled, cored and cut in 1.2 cm side cubes and immediately dipped in a 5% citric acid solution (Carlo Erba, Milan, Italy) to avoid enzymatic browning. Apple cubes were frozen at −30 °C and freeze-dried in a pilot plant freeze drier (Edwards Alto Vuoto, Mini Fast 1700, Milan, Italy) at a residual pressure of 0.08 mmHg. Freeze-dried samples were further dehydrated over P_2O_5 for 1 week, after which they were considered to be anhydrous (Lievonen, Laaksonen, & Roos, 1998). Aliquots of whole apple cubes were equilibrated over standard saturated solutions for 3 weeks, prior to chemical and physical analysis. Three weeks were considered a length of time sufficient to allow measurable changes to occur.

Apple juice was separated by vacuum filtration from grounded and homogenised (Polytron PT 3000, Kinematica, Littau, Switzerland) fresh apple. The juice was freeze dried and stored under P_2O_5 at 10 °C until used.

Cubes of insoluble cell wall (CW) tissues were obtained by washing apple cubes under flowing water up to a refractometric index of the liquid phase of 0° Brix (pbi Unirefrax refractometer, SA, Betuzzi, Milan, Italy). CW cubes were plentifully rinsed under deionised water, freeze dried and stored under P_2O_5 until used.

2.2. Sorption isotherm

Adsorption data at 25 °C were determined gravimetrically after exposure of dried samples (apple cubes and apple cell walls) at different relative humidity. Water activity was measured with an AquaLab CX-2 (Decagon devices Inc., Pullman, WA) water activity meter at 25 °C.

2.3. Glass transition temperatures

Glass transition temperatures (T_g) were determined by differential scanning calorimetry (Mettler TA 4000 system equipped with TC11 TA Processor, DSC 30 measuring cell and Graph Ware TA 72PS.2 software, Mettler, Greinfensee, Switzerland). Heat flow calibration was performed with indium, temperature calibration was done with *n*-hexane, distilled water and indium.

Samples for DSC were equilibrated directly into 40 μl aluminium DSC pans at the selected relative humidity; pans were cooled to at least 40 °C below the expected T_g