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THE ROLE OF WATER WHEN CANNING FOODS

Water is the major constituent of many food products, which can be described as aqueous solutions; dispersions; or suspensions of proteins, carbohydrates, lipids, inorganic salts, organic acids (etc.) and their mixtures. The characteristics, behavior, and interaction of water with solutes under pressure are very important (Fennema 1996; Palou et al. 1999). Water molecules, consisting of dipoles of two hydrogen atoms attached to an oxygen atom, form a unique, extensively hydrogen-bonded network with localized and structured clustering, with a number of anomalous properties. These anomalies have been explained by dynamic equilibrium of open low-density and condensed higherdensity structure bending, but not breaking, some of the hydrogen-bonds (Chaplin 1999; Symons 2001). This two-state structural model for water, with its interconverting mechanism between a cavity form capable of enclosing small solute molecules and another form able to collapse because of competition of bonded and nonbonded molecules, explains many of water's anomalous properties including its temperaturedensity and pressure-viscosity behavior; and the solvation and hydration properties of ions, hydrophobic molecules, carbohydrates and macromolecules (Chaplin 1999).

Functionality of water is attributed to its two proton donor sites and two proton acceptor sites, while cooperativity is determined by the strength of hydrogen bonds which depends on the number of such bonds (Symons 2001). Many properties of water change with pressure according to an initial breaking of hydrogen-bonded structures, reducing the structure (Bridgman 1931). Water influences the structure, appearance, and taste of foods and their susceptibility to spoilage. From a chemical and physical standpoint, water is an excellent solvent because of its polarity, high dielectric constant and small size; its behavior as a carrier of solutes, a reactant and reaction medium, a lubricant and plasticizer, a diffusion medium, a stabilizer of biopolymer conformation; and because it probably facilitates the dynamic behavior of macromolecules, including their catalytic (enzymatic) properties (Cheftel 1992; Tauscher 1995). Because of the complexity of foods and interactions between food components and preservation or biophysicalchemical-transformation factors, the role of water may not be easily identified in some cases (Palou et al. 1999). Thus, in high-pressure food processing, if pressure and temperature affect water properties, changes in density, compressibility, surface tension, viscosity, thermal properties, dipole moment, dielectric constant (which are all solutesolvent sensitive) are expected with their related consequences on food structure and stability. The presence of different solutes has varying effects on physicochemical properties of the solution. Solutes interfere with cluster equilibrium by favoring either open or collapsed structures. Any of these effects, which are pressure and temperature sensitive, will cause the physical properties of the solution, such as density, compressibility or viscosity, to change. Also, water is a more reactive environment when the extent of hydrogen bonding is reduced by pressure toward unstructured water (Ludemann 1992). Local clustering will be affected by the presence of solutes, thus changing the nature of water and making solutions to behave non-ideally. However, the extension of these pressure effects on the structure of aqueous solutions and its consequences to pressure processing of foods is still to be determined. High Pressure as a Preservation Process for Foods.

The ability of high pressure to inactivate microorganisms was first demonstrated more than 100 years ago by Roger (1895). A few years later, Hite and co-workers (Hite 1899a; Hite et al. 1914) demonstrated the microbial shelf stability of milk, meat and fruit products by using high pressure as a food preservation method. As a preservation technique high-pressure processing is primarily based on reducing the microbial load to prevent growth in populations of food-spoilage and pathogenic microorganisms. The preservation of other quality attributes is also a concern (Farr 1990; Cheftel 1991; Mertens and Knorr 1992; Tewari et al. 1999; Knorr 1999b; Cano et al. 1999; Palou 2000). Other important applications aim to improve quality and process efficiency by means of pressure-shifting phase transitions (Knorr et al. 1998; Hayashi et al. 1998). Researchers have shown that high pressure inactivates microorganisms by inducing changes to the morphology, biochemical reactions, genetic mechanisms, and cell membranes (Hoover et al. 1989; Earnshaw et al. 1995; Isaacs et al. 1995; Smelt 1998; Abe et al. 1999; Farkas and Hoover 2000; Smelt et al. 2002; Brul 2002).

Resistance of microorganisms to high pressure varies greatly as shown by a number of experimental works, and reduction of microbial loads is directly related to the level of hydrostatic pressure applied (as well as temperature, which is also pressure-dependent due to adiabatic heating), type and growth phase of microorganism, food matrix, and environmental conditions (e.g., physicochemical and synergistic factors) (Aleman et al. 1994; Arroyo et al. 1997; Linton and Patterson 2000; Farkas and Hoover 2000; Furukawa et al. 2002; He et al. 2002; Ludwig et al. 2002). Kinetics of pressure inactivation observed with different microorganisms varies from first order, to a change in slope, to a two-phase pattern, to even more complex kinetics, depending on the food system, microorganism, and experimental conditions (Earnshaw 1995; Heinz and Knorr 1996; Palou et al. 1997b; Ludwig and Schreck 1997; Braddock et al. 1998). Spores of bacteria have been identified as the most resistant form of microorganisms, requiring either higher pressures or combination with other treatments, such as moderately high temperatures (Hayakawa et al. 1994b; Takeo et al. 1994; Balasubramaniam 1999), modified atmosphere containing CO2 (Enomoto et al. 1997a; Enomoto et al. 1997b; Ballestra and Cuq 1998; Park et al. 2002; Corwin and Shellhammer 2002), lytic enzymes such as lysozyme (Lechowich 1993), freezing pre-treatment, and gamma irradiation (Gould and Sale 1972). These factors would sensitize bacterial spores by induced germination, cellwall weakening, internal vital solute extraction, and pH decrease (caused by carbonic dissociation in the case of CO_2), consequently reducing pressure resistance. Inactivation of bacterial spores is of special interest for the sterilization of low-acid foods, as opposed to acid foods (fruit juices and jams, yogurt, and acidified meats) where the low pH would act as inhibitor for bacterial growth.

There is also experimental evidence that pressure sterilization conditions can be improved further when processing is done at low temperature, including sub-zero temperatures (Hashizume et al. 1995, 1996; Hayashi et al. 1998). As water is much more densely packed around the ions than around the corresponding undissociated molecules, weak acids ionize, increasing the number of formal charges. So when charges are created, substantial volume contraction occurs due to solvation effects or electrostriction of water molecules around the ions as pressure favors the ionized form (Hui Bon Hoa et al. 1992). This has profound effects on water hydration and ionization. In addition, indirect pH measurements reveal discordance in the magnitude of pH shift due to pressure, and direct measurement under pressure presents a number of technical problems that currently prevent this approach (Hayert et al. 1999). For accurate control of the treatment intensity required for the desired microbial reduction, numerical models of heat transfer can be used that must consider the pressure and temperature dependence of thermophysical properties of foods.