Predictive Modeling of Textural Quality of Almonds during Commercial Storage and Distribution

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EXECUTIVE SUMMARY

Moisture sorption isotherms were developed for major California almond varieties to provide the industry with information to control processing and storage conditions. Moisture sorption characteristics were obtained for whole Carmel (raw and blanched), Monterey (raw, pasteurized and blanched), and Nonpareil (raw and pasteurized) at various temperatures and over a range of water activities (a_w). Thermodynamic properties were determined and showed that the process of moisture adsorption of almonds is driven by the enthalpy (heat content) of the system. *At a constant temperature,* the equilibrium moisture content (EMC) of the almonds increased with a_w (and the diffusion coefficient decreased with a_w), so it takes longer for the almonds to reach an equilibrium condition at higher a_w. On the other hand, *at a constant a_w* the EMC of the almonds decreased with temperature (and the diffusion coefficient increased with temperature), so the almonds reach an equilibrium condition faster at high temperatures. Texture attributes of these whole almond kernels were also assessed at different storage conditions. Based on these data, researchers developed an online Adobe Flush model that predicts how storage humidity and temperature can affect almond moisture and texture. This online model is being evaluated by industry members.

MAJOR FINDINGS

Moisture adsorption isotherms and thermodynamic properties of almonds:

Fresh almonds were dried in desiccators to an initial moisture content of <3.5% and then stored at selected temperatures and a_w levels.

- a_w level influenced the time needed to achieve equilibrium moisture content (EMC); almonds stored under higher humidity needed longer times to reach equilibrium.
- Blanched almonds are less hygroscopic than unpasteurized and pasteurized almonds.
- Mold started to grow on almonds (raw, pasteurized) stored at 25 or 35°C when a_w >0.83, and on blanched almonds after about 5 days storage at 35°C when a_w = 0.97.
- The relationship between equilibrium moisture content and a_w was established by fitting the data to the GAB model.
- The thermodynamic properties (isosteric heat of sorption, differential enthalpy and entropy) were also determined.

Kinetics of moisture adsorption by almonds:

Carmel almonds were stored at nine a_w levels (0.11–0.97) and at 25, 35 and 45°C until samples reached equilibrium moisture content (EMC).

- At low a_w (<0.23) samples lost weight during storage because the initial moisture content was greater than the relative humidity of the environment.
- Adsorption isotherms for both raw and blanched Carmel almonds in the range of 25–45°C were well described by the GAB model.

Nonpareil and Monterey almonds were stored at six a_w levels (0.11–0.98) and at 7, 25, 35 and 50ºC until samples reached EMC.

- Fick's second law of diffusion was used to determine the diffusion coefficient (Deff) of almonds.
- A simple empirical model was used to describe the kinetics of water adsorption.
- The linear relationship between the diffusion coefficient and activation energy indicated that the temperature dependence of the sorption rate of the almonds can be described by the Arrhenius model.

Texture attributes of almonds:

After almond samples reached equilibrium conditions, a Texture Analyzer (TA.XT2) was used to measure the mechanical properties, which could, in turn, be related to texture attributes. For Carmel almonds, four different tests (penetration, cutting, uniaxial compression, and three-point bending tests) were assessed; the penetration test was found to be the most appropriate test to demonstrate clear trends in storage. For Monterey and Nonpareil almonds, both the penetration and cutting tests were used; in previous studies, the blade cutting test was able to cut small samples, such as nuts and seeds, without compression of soft or brittle samples.

- The mechanical properties of almond samples were highly dependent on a_w.
  - At the low a_w range (0.11–0.32), the mechanical properties for all samples did not show any significant difference.
  - At a_w levels above 0.65, almonds began to lose their brittleness.
  - At a_w levels above 0.75, moisture adsorption showed a significant plasticization effect on almonds.
- Fermi's distribution model was used to describe the relationship between the mechanical properties (fracture force, firmness, toughness and stiffness) of almonds and the combined effects of water activity and temperature.

OUTCOMES

1. *Publications*: The moisture isotherm and thermodynamic research results have been published in two papers (see below) and a full report to ABC has been submitted.
   a. Taitano, L.Z. and R.P. Singh. 2012. *Moisture adsorption and thermodynamic properties of California grown almonds (varieties: Nonpareil and Monterey).* International Journal of Food Studies 1: 61–75. Available at: http://www.iseki-food-ejournal.com/ojs/index.php/e-journal/article/view/46/52
   b. Taitano, L.Z., R.P. Singh, J.H. Lee, F. Kong. 2012. *Thermodynamic analysis of moisture adsorption isotherms of raw and blanched almonds*. Journal of Food Process Engineering 35: 840–850.
2. *Online predictive model*: An online model to assess the impact of humidity and temperature on almond moisture and textural properties has been developed and is being tested. The instructions for testing the online predictive model are attached.

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