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Candy Course

Controlling Water Activity for Consistent Quality

Water activity plays an important role in confectionery production. Consistent quality requires a solid understanding of water activity along with accurate predictions of how these values can drift.

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Technical confectioners need to have a solid understanding of both the starting water activity of each ingredient and the end target, along with a decent prediction of how the product (whether an ingredient or finished good) will change when these expected values drift. Water activity (abbreviated a_W) only dictates a portion of the overall situation.

WATER ACTIVITY FUNDAMENTALS

It is easy to condense all water activity talk into a single number—water activity 0.3, check!—when in the next sentence we should remember that at various temperatures moisture pickup or release follow different rates of change.

The range of 0.2 to 0.3 a_W appears to be the sweet spot for minimal a_W activity (Figure 1). The most stable conditions for long-term product storage are found within this range when enzymatic, oxidative and browning reactions are at their slowest and a_W is too low for microbial growth. Texturally this region is a barren desert, inhabited by few hard boiled candies, crispy cookies and 30-year canned food storage.

In preparation for this presentation I was able to correct a few of my own inaccuracies in trying to illustrate these concepts.

Low moisture confectionery components such as crisp wafers or glassy sugar hard candy will typically pull water from high humidity environments or products in close proximity. The opposite scenario is also expected where higher moisture products will lose water in environments with lower relative humidity. The change is due to the tendency of water molecules to transfer to lower energy state in low water activity regions. We see this reaction in our home kitchens, and the end result is often dependent on the region, weather, and time of year.

Water Activity Stability

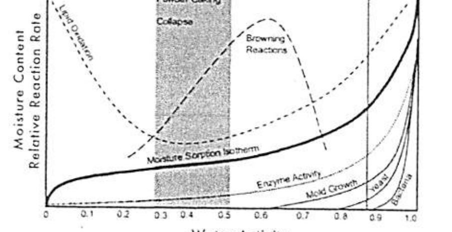

Figure 1 *Labuza, T.P. 1970*

Brandon Jahner, a consultant with Foresight Food Research, previously worked at Callisons, a flavor manufacturer, at the time of this AACT presentation. He also held a product development position at Mars Chocolate prior to Callisons.

Because water activity, not total water content, determines the lower limit of water for microbial growth, reducing a_W is a common tool for food safety of finished products.

A practical application observes a peanut brittle readily uptake environmental moisture, now supple peanut taffy will not yield that moisture as readily when relocated to a drier environment.

If you have a moisture isotherm (correlating water activity to temperature) of each component of a low or intermediate moisture food such as the interior and exterior of a product then you should be able to predict the direction the water will transition at every potential (warm versus cool) temperature. I see this as the distinguishing difference between a pastry chef making a delicate dessert that will be served within a few hours or days, and the technical confectioner's role to extend brand distinguishing textural nuances over months and years.

For a deep dive into the mechanics of generating a personalized moisture isotherm, specifically calculating the hyperbolic and sigmoidal curves of water activity at various temperatures, I would recommend looking to previous AACT presentations by Anthony Fontana and Wendy Ortman for a more detailed review of the mechanics of generating a personalized moisture isotherm, specifically how to calculate the hyperbolic and sigmoidal curves of a_W at various temperatures.

Microbial Growth

Controlling microbial growth is an important benefit of manipulating a_W since limiting water available for metabolic processes also limits microorganism proliferation. Because a_W, not total water content, determines the lower limit of water for microbial growth, reducing a_W is a common tool for food safety of finished products.

Each microorganism has a specific a_W threshold (Figure 2), and food scientists must pay specific close attention to these thresholds for guidance in processing and preservative systems.

Common a_W Microorganism Growth Thresholds

0.91	Gram Negative Bacteria
0.86	Gram Positive Bacteria
0.88	Yeast (practical limit)
0.80	Production of mycotoxins
0.70	Molds (practical limit)
0.62	Osmophilic yeast (spoilage of sweet goods)
0.61	Xerophilic molds (the cacti of molds)
0.60	Typical limit for all microbe growth

Figure 2 *Brady Carter, Meter Group*

Food industry wisdom holds $pH \leq 4.6$ and $a_W \leq 0.85$ as benchmarks where most problematic and pathogenic microbes no longer freely grow. This measure is well-known for high moisture foods. However, adhering to this standard is no guarantee dormant microbes or spores couldn't flourish later during processing or over shelf life.

Food microbiological research demonstrating which microbes grow at various water activities continues to expand as confectioners' traditional practices are challenged in the wake of numerous food safety flare-ups. A thorough literature review alone can often provide the critical mass of background justification for a product developer to reduce the manufacturer's risk when it comes to food safety. Cautious manufacturers pursue process validation studies to evaluate their products when the risks are justified by expert opinion. Typical kill step processes look for at least 5-log reductions of non-pathogenic analogue microorganisms as part of evaluating critical control points *(FDA, n.d.)*.

In processes such as cooking caramel, baking biscuits, or roasting cocoa beans, the microbial kill step is also tasked with moisture removal (steam) to create desired flavors and textures achievable at lower moisture content. For example, peanut roasters typically process nuts at approximately 350°F (180°C), a temperature theoretically sufficient to kill salmonella in a short period *(CDC, 2009)*. However, high fat and low moisture matrices often shield microbes with an insulative effect *(H. Ledenbach & T. Marshall, 2009)*. Learning from the 2009 salmonella outbreak in peanut butter (a_W 0.7), low moisture foods can suspend microbes such as salmonella indefinitely. Only screening a certificate of analysis may not raise flags as peanut butter would typically fly under the radar of the traditional 0.85 a_W threshold for potential microbial risks.

Best practices would dictate using a_W as one in a series of steps to control microbial growth, along with the complementary practices of high quality raw materials, effective kill steps, and sanitary handling. Knowing the a_W of our raw materials and finished goods helps the development of risk assessments.

When evaluating suppliers, request moisture-related data from multiple lots (3–4 is usually appropriate) to demonstrate consistency of ingredients. For example, sweetened condensed milk typically has sufficient dissolved sugars and heat treatment to prevent microbial growth (a_W 0.85). However, a sample with higher water activity (a_W 0.86) theoretically could facilitate growth of *Staphylococcus aureus.* Because the toxins produced by this microbe are not denatured (killed) by further heat treatment *(Schelin et al., 2011)* food safety managers should be consulted during the development and review of risk assessment.

I bring up sweetened condensed milk because high concentrations of low-solubility lactose readily crystallize, evident in a gritty texture. Even though lactose will dissolve again at high temperatures, over time crystallized sugars yield water effectively increasing the relative water activity. If the milk's water activity rises above the microbe's growth threshold then we must rely on our remaining product safety hurdles like partnerships with high quality suppliers with reliable GMPs.

Texture

Texture differentiation between layers or inclusions is typically what makes a product interesting and engaging. A decadent dessert sandwiching crisp inclusions such as pretzels or delicate wafer with fluid caramel sauce can be challenging enough to scale up and even more demanding to ensure each component retains its signature texture.

The simplest recommended solution when combining multilayer or aggregate components is to develop all semi-completed parts with the same water activity (such as a_W 0.5). Adjust each segment with the proper humectant balance to retain the desired textural attributes. Packaging aside, when each component has the same a_W, there theoretically shouldn't be any moisture migration.

The majority of chocolate, caramel, taffy, nougats, marshmallow, frappe, and dried fruit host water activities between 0.55 and 0.65. When these components are paired together, even slight moisture discrepencies can detract from desired profile. Each of these examples are primarily sweetened with sucrose which has limitations driven by solubility.

In a candy bar with crisp pretzels, roasted peanuts and creamy nut butters, a_W differences and changes over shelf life are minimal. However, with bakery-type inclusions such as cookie bits or pretzels, a water activity of around 0.3 is the threshold for where consumers feel a loss in crispness, perceived as tasting stale, old or "expired." Coating low a_W ingredients with high-viscosity gumming solutions, lipid-based chocolate or stabilized vegetable oils can help form a barrier against such quality-degrading changes caused by moisture migration. Even within tightly organized and thick layers, moisture can still permeate through minute openings *(C.M. Lee and A.V.A. Resurreccion, 2005)*. ➤

Best practices would dictate using water activity as one in a series of steps to control microbial growth along with high quality raw materials, effective kill steps and sanitary handling.

Water also provides a protective barrier between lipids and environmental oxygen.

Chemical Reactions

Low moisture and a_w does not mean lack of activity. Similar to immersing cut fruit in water to prevent enzymatic browning by dilution and blocking oxygen from the browning enzymes, water also provides a protective barrier between lipids and environmental oxygen. While ingredients aren't typically stored for 30 years, research shows ingredients undergo chemical changes even under the most ideal conditions *(Jonathan Swindler and Michelle Lloyd, 2014)*.

Attempting to control browning and enzymatic reactions through over-drying to reduce a_w reaches a functional threshold where lipid oxidation increases exponentially. Evaluating more effective gas and moisture control packaging components such as multilayer film and metallized packaging along with nitrogen flushing can help ensure consumers receive the consistency and quality they desire.

Enzymes

Enzymes work within specific temperature, pH and solute systems. Often the temperature will dictate activity rate to the point of enzyme (protein) denaturation. For example, invertase activity in cherry cordials creates a unique textural contrast over a few weeks. This textural juxtaposition would be nearly impossible to produce in a liquid-centered confection using reacted products as starting components. Enzymes will continue to work until all substrate is consumed or some denaturation disables the protein. For invertase, the focus should be on providing the moisture to facilitate reaction and solubilize reactants for desired liquid consistency, since sucrose is both the reactant and readily divulges water upon crystallization making this a sweet match.

To control the rates of action, we use water activity to measure the potential for the chemical reaction. A fondant-dipped cherry will have sufficient crystallization to yield the water needed for enzymatic activity. An intermediate moisture fondant may be easier to handle (doesn't dry out), but water contributed in a high-sucrose fondant is a necessary precursor for the enzyme to have the molecular mobility to convert the substrate.

In a soft mint fondant, depositing lightly-acidified starch will sufficiently harden the shell to enclose a thin center. After enrobing, fondant yields water through crystallization to equilibrate the fondant moisture, and enzyme activity restarts. If considering an enzymatic texture step, plan out the significance of each enzyme-enabling variable: sufficient water activity, water volume, target pH, and temperature to drive the desired reaction *(Asare-Brown & Bullock, 1988)*. Regardless, my impatience waiting on enzyme activity is still quicker than sucrose inversion.

Formulating for Water Activity

To formulate for better control of water activity, look at what drives sucrose crystallization and graining. These fundamentals give direction to which variables to manipulate. Begin with the experience consumers should expect when enjoying the product. Then, determine which elements of texture or sweetness are negotiable and those that are not, such as clean label endpoint, drastic browning reactions and environmental conditions. These choices can help build a framework to better direct R&D resources.

Reformulate for Delayed Shortening

The tendency of sucrose toward crystallization raises a_w because water is formed as the syrup precipitates crystals. Sugar crystallization occurs in any type of polysaccharide that has enough saturation and molecular mobility. Because of this, collecting a measurement immediately after production will likely indicate different water activity ➤

after the product ages a few hours or days and carbohydrates recrystallize.

Additionally, adding aged rework is likely to increase both sugar seed crystals and slurry of higher a_w constituents. In some cases, graining provides a nice non-tacky chew texture, or a fine crystallized mouthfeel. Adding a few percent (1–3%) rework may not cause major problems with crystallization or a_w if the candy mass has sufficient small sugars like high DE corn syrup to interact with the released water.

Adding higher levels of aged rework (10–20%) would dramatically change the texture and water activity even if the macro ratios are similar. Water not adequately managed can migrate through product or permeate the packaging. Condensation inside packaging can lead to stickiness or graining.

Anticipate the amount of crystallizing sugar obtained through rework. An example of this would be to formulate using model rework prior to downstream rework such as edge trim, then adding humectant ingredients to slow or stop excessive crystallization. Model rework can be used during product startup where sufficient rework volume may not have accumulated. Decide how you will replace this with a blend of precrystallized sugars, fats and proteins for consistent starting product and minimize time necessary to reach steady state production. Depending on the component, moisture-managing humectants can include hydrocolloids, polysaccharides or polyols.

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Example Scenarios

Problem: Hard taffy/marshmallow/nougat

Activity: Likely moisture drawn away from component

Resolution: Increased water holding, slow or limit graining

Imagine the situation of a multi-layered confection experiencing failure (defined as unacceptable texture due to premature hardening). The likely culprit would be moisture being drawn from one component into a lower water activity region (potentially even the space between the candy and the packaging or environment). First approach the problem by increasing the proportion of polysaccharides to bind water, after evaluating the various additional humectants (glycerin, higher de syrups) that could be used such as corn syrup ratio to slow graining. Slowing the graining affects the condition the product would be entering the supply chain of getting product out the door through distribution. Typically the product would need to grain within a few days to meet outgoing quality expectations. Looking at the whole process, there would still be sufficient time for the product to finish graining during warehousing, transport and staging.

Alternately, we could increase the water activity of the culprit component layer (tracked by measuring water activity of time zero and product again after faulty product was evaluated). The difference in the water activity potential is similar to the energy potential and the right techniques help slow the changes that will occur. Proactively formulating for water activity means skillfully negotiating texture as a function of many different tools from using the right humectants and providing a preferred path for any moisture migration bound to wander.

Problem: Trail mix with crisp cookies and chewy fruit

Activity: Fruit will give up enough moisture to stale cookies

Resolution: Reduce water as tenderizing humectant in fruit, and minimize moisture

Building a trail mix of many different components that will sit together jumbled in a bag is asking for the worst case scenario. Textural differences and visibility of each ingredient are appealing to a customer; short of compartmentalizing each piece, the best option is to harmonize the water activity of each component.

Glycerin infused fruit, where tenderness comes from another humectant (other than water), and using fewer fruit pieces will reduce the overall mass of water in the package. Consider using sealed fruit pieces; moisture may be restricted inside chocolate or yogurt coatings. Additionally selecting cookies with more compatible shelf life may require having specialty starches or using more highly saturated oils to maintain textural crispness.

Controlling Water Activity

Packaging variables should be considered just as important as ingredients since it helps maintain quality that extends to the consumer.

Tools to Guide Water Activity

The following tools can be used to guide a_W and mitigate risks.

1. Moisture—Reduce volatile water or formulate for common water activity
2. Temperature—Kinetic energy means more molecular mobility
3. Doctoring ingredients—Slow or reduce crystallization using proteins, salts, humectants, sugars, acids and non-sucrose ingredients
4. Rheology—Reduce water mobility and help slow movement within the product through high solids or hydrophilic polysaccharides like starches and gums
5. Seeding—Selectively controlling seeding through shear or introducing seed can direct the size and dispersion of sucrose crystal formation
6. Edible barriers—Fats/lipids/waxes may not stop moisture, but can help defer or contain moisture in the desired regions, encouraging targeting crystallization
7. Water activity meters, moisture isotherms and hyperspectral NIR—Quantify and heat map how moisture migrates over time and through ingredient revisions.

PACKAGING

Once a stable product is achieved, review packaging and film specifications for both oxygen and water vapor transmission rates. Select a packaging supplier with ability to help measure and analyze results to provide support. Packaging variables should be considered just as important as ingredients since it helps maintain quality that extends to the consumer. In some cases. packaging costs can be reduced by using less restrictive film.

SUMMARY

Before addressing water activity, identify the attributes that make the product successful. If moisture is suspected as an issue, review the tools available to selectively reroute moisture to the areas where it is most easily managed. When ingredients and processes are satisfactory, involve packaging engineers to ensure product reaches consumers with optimal moisture and shelf life. □

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