FOOD PRODUCT DESIGN
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Managing Moisture in Food Formulations

By Donna Berry, Contributing Editor

Product designers willing to explore technologies that manipulate moisture often discover unique and, typically, quite economical opportunities for innovative product development. This is because water, the most abundant, yet often frequently overlooked constituent in the food supply, is basically a free ingredient that can impact a food's structure and increase yield, all for zero calories. What product developers cannot afford to overlook is careful management of moisture in commercially manufactured foods, as too much or too little, or not being in the right matrix, can be detrimental to product quality and safety.

For the love of water

All living creatures have a biological need for water, the molecule consisting of two hydrogen atoms covalently bonded to a single oxygen. When it comes to designing multi-ingredient food systems, water is well-recognized as a near-universal solvent and plasticizer. The latter refers to water's ability to be absorbed, embodied and bound, which impacts a food system's mobility and eventual water availability in terms of food quality, safety, stability and technological performance.

Water content influences a food's structure, appearance, taste and even susceptibility to degradation. Depending upon the foodstuff, water might function as a free-flowing liquid or be a component of a larger matrix, visibly (pudding) or invisibly (granola bar).

Water is used as an ingredient in many food formulations, and most food ingredients also contain noteworthy amounts of water. This must be carefully considered when attempting to manage moisture. For example, butter is approximately 17% water; whole eggs are more than three-fourths water; lettuce is about 95% water; and wheat flour is about 12% water.

With moisture coming from so many sources, product designers must make sure water stays where it is supposed to be and does what it is supposed to do. Sometimes this requires taking the necessary steps to prevent evaporation, while other times the goal is to prevent the food from absorbing moisture from the surroundings. When dealing with a multicomponent prepared food, the issue might be moisture migration, or the prevention of water seeping from one component to another. Still another challenge is making sure the water is not available for the growth of undesirable living organisms.

Managing the water content of food products is necessary for efficient processing, packaging selection, and distribution and storage conditions. Further, there are legal limits to the maximum or minimum amount of water that can be present in certain types of food, and various foodstuffs require "added water" declarations on product labels. Economically, the cost of many foods depends on the amount of water they contain.

Determining moisture contents

Before one can manage moisture, one must know how much water a foodstuff contains. In principle, the moisture content of a food can be determined by measuring the number or mass of water molecules present in a known mass of sample. However, for the most part, it is challenging to directly measure the number of water molecules present in a sample because too many molecules are involved.

Thus, sometimes moisture contents are based on calculations using predetermined water contents of known food ingredients. There are also various analytical techniques, ranging from vacuum to microwave ovens, to determine the moisture content of foods. It is critical that the technique be able to distinguish water from other components in the food matrix. This can be challenging, because despite having the same chemical formula (H_2O), the water molecules in a food may be present in any of four varieties of molecular environments, depending on their interaction with the surrounding molecules, and thus they possess different physiochemical properties.

The most basic form is as bulk water, which is when water is free from any other constituents. Each water molecule is surrounded by other water molecules and its physicochemical properties resemble pure water.

Trapped water, also known as capillary water, is moisture held in narrow channels between certain food components. This trapped water is surrounded by a physical barrier that prevents the water molecules from easily escaping, such as all that water in a lettuce leaf. This type of water tends to have physicochemical properties similar to that of bulk water.

Physically bound water molecules are in molecular contact with other food constituents, such as proteins, carbohydrates and minerals. These food constituents bind with water, creating a system that no longer recognizes the water as free bulk water. The bonds between water molecules and these constituents are quite different from water-water bonds.

Finally, there are chemically bound water molecules. This is when water molecules present in a food are chemically bonded to other molecules as water of crystallization or as hydrates. These bonds can be very strong.

Although the water content of a food is expressed as a percent, this number does not reflect how the water exists in the food. Food product designers must consider all four forms of water—bulk, capillary, physically bound and chemically bound—when trying to manage moisture. Further, commercially manufactured foods may contain water in different physical states, such as gas, liquid or solid. This is the reason why moisture management is necessary and can be quite challenging.

Understanding water activity

In addition to quantifying water content, product designers must consider water activity (a_w), which describes the energy status or the escaping tendency of the water in a sample.

"Water activity is a thermodynamic concept expressed as a ratio of the vapor pressure of water in a food to the vapor pressure of free water at the same temperature. It indicates how tightly water is bound in a foodstuff," says John Zeugschmidt, technical advisor, Decagon Devices, Inc., Pullman, WA. "Whereas moisture content is a quantitative measurement of the amount of water in a system, water activity is a qualitative measurement of the energy, quality and chemical stability of the water in a system. In most cases, water activity is the best measurement to use when evaluating safety and quality."

Water activity is often described in terms of the amount of bound water and free water. Although these terms make the concept of water activity somewhat easier to conceptualize, the reality is that all water in food is somewhat bound; after all, it is contained in the food. Thus, water activity is a measure of how tightly water is bound and relates to the work required to remove water from the system.

"Water activity predicts safety and stability with respect to microbial growth, chemical and biochemical reaction rates, and various physical properties," Zeugschmidt adds. "Therefore, by measuring and managing water activity, it is possible to predict which microorganisms will or will not grow in a food system; maintain the chemical stability of the food; minimize nonenzymatic browning reactions and spontaneous autocatalytic lipid oxidation reactions; prolong the activity of enzymes and vitamins; and optimize the physical properties of foods such as moisture migration, caking, clumping and even stickiness."

Zeugschmidt provides an example of a cake with a 15% moisture content that is topped with a 7% moisture frosting. "You might assume that water will migrate from the cake into the frosting, resulting in a dry cake with soggy frosting," he says. "It doesn't. In fact, it actually migrates the other way, from the frosting into the cake. As the cake sits on the shelf, it will actually take up water, while the frosting becomes drier." This is a function of the two components' water activities.

"Moisture will move between the components of a multicomponent food system until their water activities—not their moisture contents—are equal," Zeugschmidt says. "In this example, the frosting has a relatively high a_w of 0.79, while the cake is lower, having an a_w of 0.61. Therefore water moves from the frosting to the cake."

Ingredient assistance

Baked goods, by far, are one of the most challenging food systems in which to manage moisture. Other critical categories include frozen foods, dairy products, and meat and poultry items. What makes the moisture management effort even more challenging are the numerous approaches to the process and the wide variety of ingredients claiming to assist. In fact, there are carbohydrates (gums, starches, fibers, etc.), proteins (dairy, egg, gelatin, etc.) and even fat ingredients (functioning as a barrier) that have the potential to manage the moisture in and out of foodstuffs.

"There are different moisture management considerations for each application," says Dilek Uzunalioglu, senior associate, applications, National Starch/Corn Products International, Bridgewater, NJ. "For some, it's about keeping moisture out, and in others it's about keeping moisture in the product." Sometimes, this is accomplished by reducing the moisture content, modifying water activities or including a barrier to separate components of a multicomponent system.

Not only do moisture-management systems vary by application, other factors to consider include product storage conditions (ambient, frozen and refrigerated), the potential of temperature extremes, shelf-life expectations, and the overall objective of keeping moisture in, out or contained in a product.

When it comes to keeping moisture in a product, many product designers turn to the category of ingredients known as hydrocolloids. The primary function of all hydrocolloids is alluded to in the name, where the prefix "hydro" means water and "colloid" means a gelatinous substance. Basically, hydrocolloids bind with water to create gels. Most hydrocolloids are carbohydrates and are classified as gums and starches. However, collagen proteins, such as gelatin and collagen peptides, are also considered hydrocolloids due to their strong affinity to bind water.

"Gelatin can absorb five to 10 times its weight in cold water," says Mindi McKibbin, specialist, edible technical services, Gelita USA, Sergeant Bluff, IA. "In gelatin desserts and dairy-based products, such as yogurt, gelatin binds the water in the system, helping prevent syneresis." Specifically, with yogurt, gelatin prevents whey from being expelled from the casein gel. This is because the gelatin molecules form a lattice in the casein gel during the gelling process that gets stabilized by hydrogen bonding.

"In nutrition bars, collagen peptides help to bind ingredients, and at the same time help maintain bar softness over shelf life and prevent drying out," McKibbin continues. "In meat applications, gelatin can help reduce fat by binding more water but still keep the fat-like texture due to gelatin's melting profile. Although gelatin is a natural performer on its own, when combined with other hydrocolloids, texture can be modified, melting point can be increased and freeze/thaw stability can be improved."

Such other hydrocolloids include gums and starches. "These ingredients work together synergistically, allowing for a moisture management system with different characteristics than when used alone," explains Daniel Bailey, research and development scientist, Gum Technology Corporation, Tucson, AZ. "Where starches fall short, gums can extend the textural attributes and provide better moisture retention. We've developed many blends of hydrocolloids, keeping moisture management at the heart of the design. The synergy is especially helpful with organizing water particles to prevent moisture migration in applications such as icing, baked goods and fillings."

Hydrocolloids also help prevent staling, which results from the retrogradation of starch in baked goods. Retrogradation releases moisture over time, leading to staling. "Starch molecules compress, and moisture is lost through syneresis. Loss of moisture causes the soft crumb to turn dry and hard," says Karen Silagyi, food scientist, TIC Gums, Inc., White Marsh, MD. "Temperature abuses during distribution and storage can accelerate the staling process. Because gums do not undergo the retrogradation process, they can slow the staling process by holding onto moisture. Additionally, gums may be able to absorb the excess moisture from starches to maintain moistness and extend shelf life."

Uzunalioglu adds: “When such shelf-stable products are exposed to warm temperatures, moisture and volatiles can evaporate into the headspace of the package. Upon cooling, these molecules will condense, which can lead to undesirable separation of moisture and other ingredients.”

Frozen foods present their own set of unique challenges. “Freezing food products can lead to water separation from the bulk food due to formation of ice crystals,” Uzunalioglu says. “Upon thawing, these crystals melt to provide separate layers or zones of separated water. The separation of water from the different food components, such as vegetables or meats, can lead to undesirable changes in the texture of these components and degrade the quality of the food. For emulsified foods, such as soups and sauces, freezing can lead to emulsion instability and separation of phases.” Hydrocolloid systems can assist in keeping the moisture bound and intact.

With some meat and poultry products, in particular luncheon meats, sausages and formed, breaded chicken, formulators will often turn to phosphates for moisture management. In such products, the phosphates retain moisture and cook juices, which improves yield, as well as flavor protection. Phosphates are often added to whole muscle pieces through the addition of an industrial marinade, which is added by a protein packer by either injection or tumbling.

Phosphates can also be added to curing solutions and cured product formulations. They help reduce shrinkage by preventing loss of moisture, as well as purge or cook-out of fermented and cured comminuted products during further processing.

With so many ingredient options and variables to consider, Uzunalioglu says, “When matching applications with water management systems, formulators must keep process conditions, formulation, storage conditions, and clean label or modified requirements top of mind.”

Bailey adds: “Some moisture-management systems can be very effective; however, some may change the mouthfeel and texture of a product. Mouthfeel can be very important to how a customer perceives the quality of a product, so it’s important that the system you choose to manage moisture is also in line with the texture you are looking to achieve. Sometimes it’s a blend or combination of ingredients that will result in both good moisture management and the desired texture.”

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