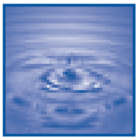
WATER ACTIVITY TOOLS

HOW TO PROFIT FROM PROVEN PRODUCT-QUALITY TECHNIQUES IN 5 QUICK LESSONS



Water is the cheapest ingredient available. It doesn't cost much to add **water**. Unless you add the wrong amount. Then **water** can be incredibly expensive. Add too much and your product will mold on the shelf. Get the amount wrong, and your product will lose its crunchiness or softness. Combine two ingredients with incompatible **water** levels and get a clumpy mess that gums up the factory machinery. Store a combination of ingredients at unstable moistures and end up with an ingredient so hard and dried up that it breaks a customer's tooth and causes a lawsuit. For a cheap ingredient, **water** can cause a lot of expensive headaches.

DECAGON

MORE ABOUT WATER AND YOUR PRODUCT INSIDE

Lots of food processors try to get a handle on the problem by finding out how much water is in the product. They weigh, dry, weigh, burn up a lot of product, and in the end get a crude measurement that doesn't answer their questions. Quantity doesn't tell you much about quality. And good food quality is what good food science is all about. Measure **water activity**, and you have a fast, accurate, powerful measurement of food quality. Know the **water activity**, and you know not just how much **water** is in your product, but what that **water** is doing and what it will be doing as the product sits on the shelf. **Water activity** lets you see the total quality picture. And when you see the whole picture, **water once again becomes the cheapest ingredient in your product.**

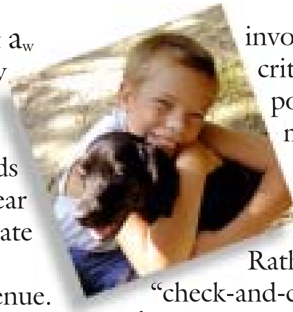
CONTENTS

DOLLARS AND CENTS

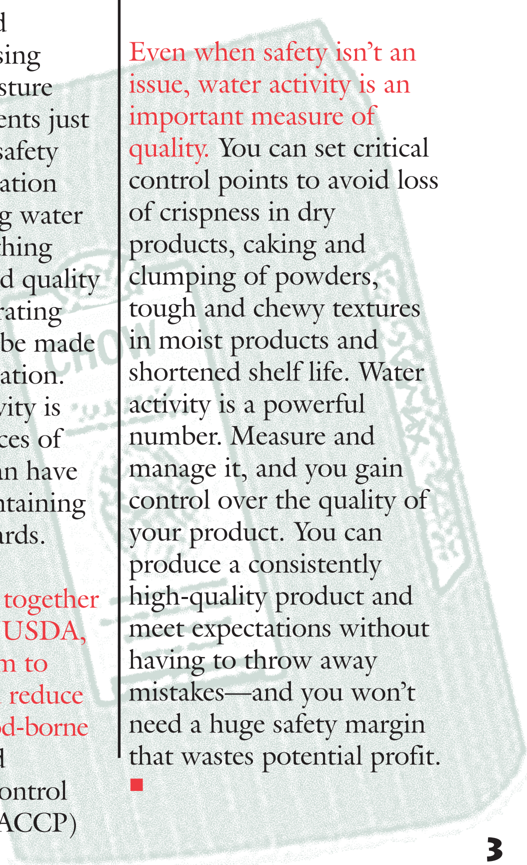
#1: DRYING HEALTHY DOG FOOD

PRODUCT SAFETY and quality is the bottom line. Spoilage and poor quality hurt or destroy sales. You set quality standards and stay within them. But where do you set the standard, and how much of a safety margin do you need? Too many manufacturers measure moisture content and use a by-guess-and-by-golly standard. For example, a pet food manufacturer we know was producing to 8% moisture content. Why? Because at that level, he had never had spoilage problems or shelf life concerns. He had a safe product. But he discovered that he was drying up profit. Then he used water activity measurements to get a more accurate food quality picture. The water activity of his product was 0.50 a_w. A little additional information revealed that he needed only to stay below 0.65 a_w to produce a quality shelf stable product that was below the mold growth limit.

Without knowing his exact costs, we can still infer the profit margin represented by a difference in 0.50 aw and 0.65 a_w. If he produced 20,000 pounds of product per hour, operating sixteen hours a day five days a week, and sold the product for forty cents a pound, raising the target a_w level would allow him to produce an additional 1,877,314 pounds of product per year and would generate an additional $750,925 in revenue. Even better, much of that would be profit since this change would reduce utility costs while keeping man hours, raw material costs, and wear and tear on equipment the same.



Just a tricky little story problem? Not at all. Many manufacturers have decreased costs and increased profits using water activity. Moisture content measurements just can't give you the safety and quality information you need. Knowing water content reveals nothing about the total food quality picture. Good operating decisions can only be made using good information. Usually, water activity is one of the best pieces of information you can have in setting and maintaining food quality standards.



The food industry, together with the FDA and USDA, is adopting a system to improve safety and reduce the incidence of food-borne illness. The Hazard Analysis Critical Control Point program (HACCP) involves setting critical control points that measure food quality throughout production. Rather than "check-and-chuck" at the end, these critical control points detect problems all along the production line. Water activity is a critical control point in many processes. It defines critical limits for microbial and chemical parameters which must be controlled to prevent food safety hazards.

Even when safety isn't an issue, water activity is an important measure of quality. You can set critical control points to avoid loss of crispness in dry products, caking and clumping of powders, tough and chewy textures in moist products and shortened shelf life. Water activity is a powerful number. Measure and manage it, and you gain control over the quality of your product. You can produce a consistently high-quality product and meet expectations without having to throw away mistakes—and you won't need a huge safety margin that wastes potential profit. ■

FRESH BAKERY TRANSPORT
#2: GROCERY DISTRIBUTION & SHELF-LIFE

MOM AND POP Bakery baked exceptional cakes. Local demand was high. Mom and Pop wanted to increase sales by expanding. Unfortunately, their delicious cakes had a shelf life of three days. A three-day shelf life left no time to ship the cakes. How could they keep their quality and simultaneously get longer shelf life? Once again, water activity is the answer. Water activity is a well known predictor of microbial growth. A simple chart shows water activities below which certain molds will not grow. And there's just one chart. These values are the same whether you are measuring the water activity of brie or dog food. They don't change when you change your recipe.

Why is water activity the better predictor? Water content measures quantity, it tells you how much water is in the product. Water activity measures quality because it tells you what the water is doing inside the product. Some water is 'bound'—tied up chemically within the product. The rest is 'free'. The 'free' water may be used by passing microbes—but only if there is enough available. Some microorganisms need more water while others need less, but all need a certain amount of 'free' water. Moisture content tells only how much water there is, not how much is available. If you measure the water activity of your product, you will know which bacteria, molds, or fungi can grow on and in it. By reducing the water activity, you can rule out the growth of whole classes of microbes. At low water activities (>0.60), you can preclude the growth of anything at all.

As Kimberlee J. Burrington writes in Food Product Design (Aug. 1998), "Development of many baked products involves maximizing moisture content to produce the best possible eating qualities while minimizing a_w. Lowering the a_w increases product stability in terms of susceptibility to microbial growth."

You can reduce your product's a_w in several ways. Adding humectants like salt and sugar 'binds' the water in the product. You haven't reduced the water content, but you have reduced the water activity. You can dry the product in a number of ways; air drying, vacuum drying, freeze drying, and osmotic dehydration all reduce water activity. You can also lower water activity by lowering the temperature of the product. In many cases, a minor recipe change can bring water activity to a safe and shelf-stable level.

Mom and Pop solved their problem with a minor change. They manipulated their recipe while keeping an eye on the changing water activity. The final product kept all the tastiness of the original but with a lower water activity. Their new 9–12 day shelf life made shipping—and successful expansion—possible. ■

■ Shelf-life Tale

"... I don't think [Hostess has] made a Hostess Twinkie in 45 years. Think of the efficiency. Churn out 800 million Twinkies every 50 years, then fire everybody but your marketing and distribution people."

http://www.textfiles.com/magazines/MOOSE/m00se21

■ Twinkie Truths

Recommended Twinkie shelf-life—14 days.

Twinkies baked each year ≈ 500 million.

http://weeklywire.com/ww/04-10-00/chicago_a.html

Water Activity and Growth of Microorganisms in Food*

Range of a_w	Microoranisms Generally Inhibited by Lowest a_w in This Range	Foods Generally within This Range
1.00–0.95	*Pseudomonas, Escherlchia, Proteus, Shigells, Klebsiella, Bacillus, Clostridium perfringens,* some yeasts	Highly perishable (fresh) foods and canned fruits, vegetables, meat, fish, and milk
0.95–0.91	*Salmonella, Vibrio parahaemolyticus, C. botulinum, Serratia, Lactobacillus, Pediococcus,* some molds, yeasts *(Rhodotorula, Pichia)*	Some cheeses (Cheddar, Swiss, Muenster, Provolone), cured meat (ham)
0.91–0.87	Many yeasts *(Candida, Torulopsis, Hansenula), Micrococcus*	Fermented sausage (salami), sponge cakes, dry cheeses, margarine
0.87–0.80	Most molds (mycotoxigenic penicillia), *Staphyloccocus aureus, most Saccharomyces* (bailii) spp., *Debaryomyces*	Most fruit juice concentrates, sweetened condensed milk, syrups
0.80–0.75	Most halophilic bacteria, mycotoxigenic aspergilli	Jam, marmalade, marzipan, glacé fruits
0.75–0.65	Xerophilic molds *(Aspergillus chevalieri, A. candidus, Wallemia sebi), Saccharomyces bisporus*	Jelly, molasses, raw cane sugar, some dried fruits, nuts
0.65–0.60	Osmophilic yeasts *(Saccharomyces rouxii),* few molds *(Aspergillus echinulatus, Monascus bisporus)*	Dried fruits containing 15-20% moisture; some toffees and caramels; honey
0.60–0.50	No microbial proliferation	Dry past, spices
0.50–0.40	No microbial proliferation	Whole egg powder
0.40–0.30	No microbial proliferation	Cookies, crackers, bread crusts
0.30–0.20	No microbial proliferation	Whole milk powder; dried vegetables

* Adapted from L.R. Beuchat, Cereal Foods World, 26:345 (1981).

GLASSY PRODUCTS

WATER ACTIVITY does not perfectly describe the chemical processes occurring during clumping and caking. Some products, like milk powders, may contain amorphous crystalline compounds. These products are subject to a phenomenon known as "glass transition". When processed or stored above the glass transition temperature, these powders show stickiness, collapse, and crystallization due to the viscosity decrease above Tg, and the increased plasticization by water. During collapse, moisture is released from the crystallized to the amorphous regions, leading to the formation of inter-particle liquid bridges, causing particles to stick together. There is no routine method currently available to monitor glass transition during processing. However, by monitoring water activity and keeping the product below a specific water activity, caking and clumping can be avoided even in glassy products. ■

IN HIGH, dry Salt Lake City, a salt shaker is a salt shaker. Turn it upside down, and the little grains pour out. In rainy Seattle, when you flip and shake, you are much more likely to hear a "thunk" and get next to nothing. Even around the house, clumping and caking can cause problems. On the production line, those problems get big and expensive.

A small dry soup manufacturer was determined to avoid clumped-up soup base. One day he was processing a base with 3% moisture content. He measured some newly received pepper and found it to also have 3% moisture content. Sure that it was safe to mix the two components, he did so and headed out to lunch. The manufacturer returned from lunch, flipped on his processing machinery and discovered that the whole batch had clumped. He had to throw away the lot. His loss felt even worse as he spent considerable time cleaning up his equipment.

Caking and clumping are ubiquitous problems in the food and pharmaceutical industries. Predicting—and avoiding—the problem means paying attention to three things: time, temperature, and water activity. Over time, free flowing powders will move through the stages of caking. The particles within the powder will get wet, then sticky. Sticky particles will agglomerate, compact, and finally reach the liquefaction stage. The process is affected by particle shape and size,

■ Generally, air drying of aromatic herbs is an effective method of preservation that inhibits the growth of microorganisms and delays the onset of some biochemical reactions in the final product.
—From Yousif,A.N. (2000) J. Food Sci. 65:926-930

A SOUP MIX STORY
#3: CAKING & CLUMPING

temperature, moisture available within the system, applied pressure, and chemical composition. The problem can be avoided by keeping the powder below a certain water activity.

The soup manufacturer thought he had the process under control. His soup base was dry, the temperature and relative humidity in his processing plant were fine, so why did he end up with a mess? This manufacturer was distracted by moisture content numbers. Just like the fruitcake producer in Lesson Five, he thought he had his eye on the ball, but he was actually out of the game completely. He thought that dry enough for soup base was also dry enough for pepper. But it isn't the quantity of water, it's the quality—not how much there is, but how much is available. And the 3% water in the pepper was free enough to wreak havoc. Had he measured water activity, he would have found that the soup base had a water activity of 0.28, while the freshly ground pepper was at 0.69 a_w. When he combined the two, he brought the water activity of the mixture above the critical clumping point.

The critical point at which a product will cake or clump is product-specific. It must be determined by putting the product at different humidities and measuring the water activity at which the product begins to clump. Maintain the product below that value, and you will avoid clumping. As the soup manufacturer discovered, adding ingredients at higher water activities can change the water activity of the product. In addition, high ambient humidity and increases in temperature can raise the water activity of the product. ■

PREVENT CAKING

Solutions to prevent caking of powders:

- Dry powder to lower a_w.
- Treat powder at low humidity atmospheres.
- Package powder in high moisture barrier packaging.
- Use in-package desiccation.
- Agglomeration
- Add anti-caking agents.

■ The total number of outbreaks attributed to contaminated spices in the last 30 years is low and no reported outbreak has occurred in the United States. Since several bacterial pathogens and pathogen indicators may at times be isolated from herbs and spices, such a low number of outbreaks may in part be attributed to the role of spices as ingredients, and the inhibitory or lethal effects of low water activity. —From the American Spice Trade Association (ASTA)

ISOTHERM COMPARISONS

#4: PECANS & AIRBAGS

MANY manufacturers use the "loss-on-drying" method to measure water content. They weigh the original product, dry it out, and weigh again. Since "dry" means really dry, and since it usually needs to be done in a hurry, many people rapidly dry the product in a vacuum oven, microwave or moisture balance for that middle step. As one fish processor noted, "This is a really stinky process." Unfortunately, it's also slow, crude, and often misleading.

Misleading because when you measure moisture content, you need to know how dry is dry enough. The water content of a safe product varies from product to product and from recipe to recipe. In corn seeds, safe storage means a water content of 12.5% while in mustard seeds, it's 7.5%.

All the varying water contents are related to the same water activity. A simple chart shows the water activity values below which certain molds do not have enough 'free' water to grow. For example, below 0.6 a_w, water is so tightly 'bound' that it is unavailable to even the most xerophytic fungi. That number is the same for every product, ingredient, and substance.

Water content measurements are crude because measurement methods may not be very accurate. A pecan grower discovered this in the fourteenth year of his operation. He grew pecans for school fundraising. Every year he dried his pecans to a moisture content of 4%. For thirteen years, the method worked perfectly. Year fourteen could have been titled "The Return of the Moldy Pecan." He was bewildered. Understanding water activity gave the total food quality picture. A 4% moisture content relates, in pecans, to 0.68 a_w. That's pretty safe. Anything under 0.60 a_w will be totally free from microbial growth. In pecans, that relates to 3.8% moisture content. Unfortunately, the moisture content measurement was only accurate to ±0.5%. That means his fourteenth year pecan shipment had probably closer to 4.5% moisture content and was outside the safe zone.

Using an a_w meter solves the accuracy problem. The difference between the pecan producer's borderline numbers— 0.68 and 0.70— is huge to a water activity meter with an accuracy of ±0.003 a_w. The pecan manufacturer can measure water activity and be confident of product safety with every shipment.

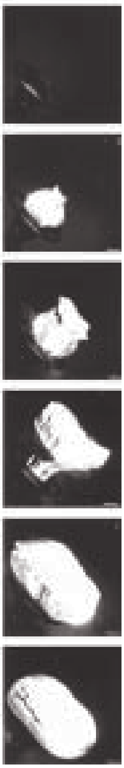
In fact, the better accuracy, speed and easy measurements of water activity are attractive even to people who need to measure water content. An airbag manufacturer needed to control water content in the chemical propellant (cupric oxide) used in the airbags. He needed a tight control. If the cupric oxide's water content wasn't within spec, the airbag wouldn't inflate. Cupric oxide has a water content of about 0.05%— so low that measurements were hard to make. They required a high precision moisture balance and

■ Nothing is more memorable than fish flakes roasting in a water content drying pan.

■ During the three seasons, 1999-2001, the utilized production of pecans averaged 310,650,000 pounds per year and grossed growers $261,846,000.

Pecan meats sold as halves are premium-priced products used for decoration. Broken nut meats are used in baked goods, confections, and ice cream.

About 78 pecans go into a pecan pie.



◄ Airbag Deployment

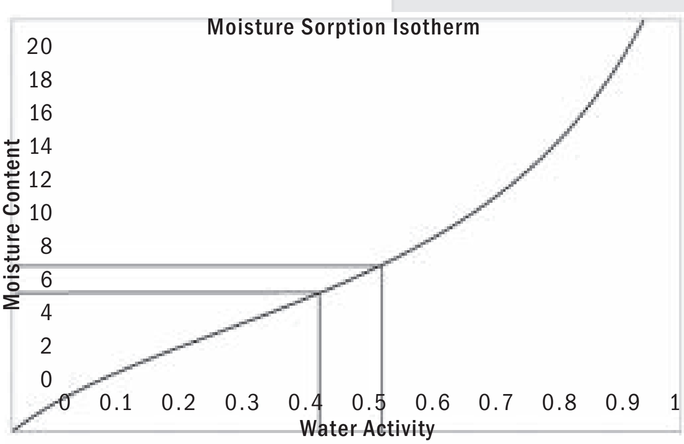
scrupulous attention to scientific technique. Even under the best conditions, readings were hard to get. After finding the relationship of water content to water activity for cupric oxide, they found that a change as small as 0.02% water content related to a change of 0.2 a_w. The a_w meter accuracy of ±0.003 a_w let them measure to tighter controls—and made the measurements much easier to get. ■

DEVELOPING AN ISOTHERM

But I really really really need to measure moisture content!

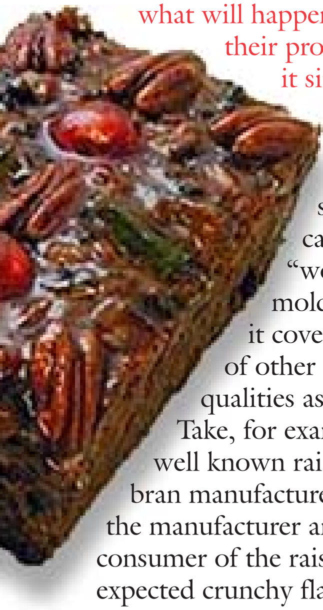
Water activity is always the most relevant and powerful measurement of food quality. But some manufacturers also need to know moisture content. They may be selling on a weight basis, have labeling issues, or need to determine certain nutritional values. If this applies to you, it is possible to have the best of both worlds. Water activity and water content are related. This relationship, called the moisture sorption isotherm, is unique to each product. It changes depending on whether it was obtained by wetting or drying the product. Typically, large safety margins are built into water content specifications to allow for these uncertainties. A vegetable dehydrator needed to measure water content. They wanted the speed and accuracy of measuring water activity on the production floor. They developed a sorption isotherm for their product (see table). They needed to dry to a 6% moisture content specification. The 6% moisture corresponds to 0.462 a_w using their unique isotherm curve. Once they switched to measuring water activity, they discovered that they had much better control over moisture content. Their old moisture balance method, in addition to being slow and painstaking, was only accurate to ±0.5%. That meant product moisture content varied from 5.5% to 6.5%. The ±0.003 a_w accuracy of their water activity meter gave them much greater precision. They were able to specify a ±0.01 a_w tolerance on the production line. Now moisture content in their product varies from only 5.86 to 6.14%.

A sorption isotherm is ideally produced using the process that will bring the product to its final water content—baking for cakes, standard drying process for potato flakes. To get specific information on developing the isotherm, contact Decagon. ■



MOISTURE MIGRATION

#5: FRUITCAKE & FRUIT CEREAL SURPRISE

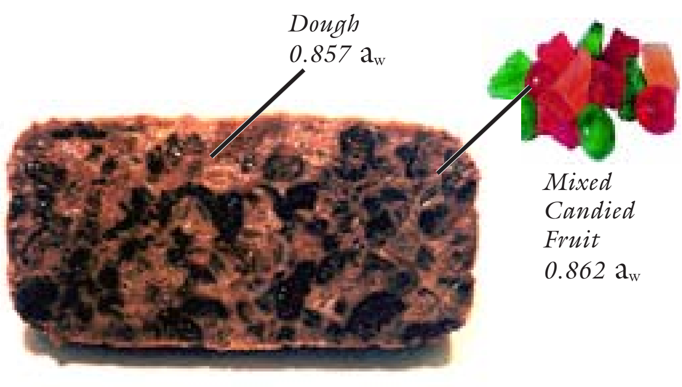


EVERY FOOD producer needs to know what will happen to their product as it sits on the shelf. Shelf stable can mean "won't get moldy," but it covers a lot of other food qualities as well. Take, for example, a well known raisin bran manufacturer. Both the manufacturer and the consumer of the raisin bran expected crunchy flakes and chewy raisins. The consumer got a surprise when he bit into a rock hard raisin and broke a tooth. The manufacturer soon after got a surprise in the form of a lawsuit. Fortunately, not all moisture migration problems end up in a court of law. But if you produce and sell products that contain discrete ingredients, you need to know where the moisture will go as the product sits on a shelf.

A fruitcake manufacturer wants to predict conditions over time in her fruitcake. She doesn't want the cake to get soggier as the fruit pieces get dry and hard. So she measures moisture content. The cake contains 30% water, while the fruit pieces have 50% water. She knows that water wants to come to equilibrium. Therefore, she assumes that water will migrate from the wetter ingredient (the fruit) into the drier ingredient (the cake).

Unfortunately, she has her eye on the wrong ball. While she's watching the water content and feeling confident of the score, a whole different game is going on at the water activity level. If she continues without knowing the score of that game, she'll suddenly be confronted with a surprise ending—in this case, dried up cake and soggy fruit, because the cake had a higher water activity than the fruit pieces at these moisture contents.

In this case, water content is nothing more than a distraction. Pay attention to that number, and the outcome feels like sleight-of-hand. True, unless acted on by other forces, water does want to come to equilibrium. But, equilibrium occurs when the partial specific Gibbs free energy is the same everywhere in a system. Water activity is a measurement of Gibbs free energy. Water content has nothing to do with the energy of the water. To understand this concept better, think of two tanks of water. One is almost full at 10,000 gallons. The other huge tank is nearly empty, containing only one gallon. Which way will water move? Knowing the water content of the tanks is completely misleading. The volume of water is irrelevant. Water moves from higher pressure to lower pressure, not from full to empty. If we raise the pressure of the nearly empty tank by putting it on top of the almost full tank, that last gallon of water will quickly leave its spacious tank.



"Sure enough, the next Christmas ... my mother, installed [the fruitcake] as a doorstop ...someone ate a few slices of this loaf, [it] is still as pristine as it was over 10 years ago!"
—The Fruitcake Hate Page
www.anet.net/~penfold/ihatefruitcake.html

Likewise, water activity, not water content, predicts how water will migrate within a product. The fruitcake manufacturer can develop a recipe in which cake and fruit pieces both have the same water activity. No moisture surprises when this cake is stored and sold—it is a safe, palatable, and shelf-stable product.

Knowing the water activity of discrete ingredients can help you decide how to process them. One solution to a moisture migration problem is to lower or raise the water activity of discrete components until they have the same water activity value. You can also retard the diffusion process within a component by increasing its viscosity. An edible barrier, like chocolate

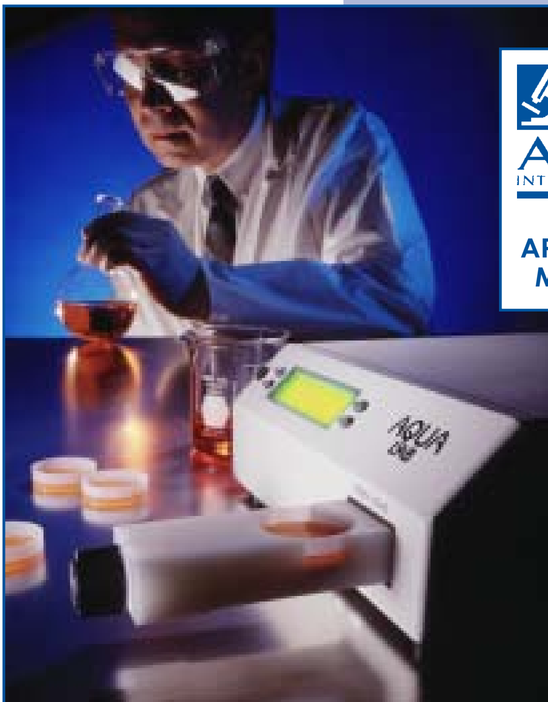
coating on the inside of an ice cream cone, can prevent moisture migration. Sometimes aw differences that can't be equalized require separate packaging. ■

WATER ACTIVITY

- Determines direction of moisture transfer
- Most degradative reaction rates increase with increasing water activity
- Most degradative rates correlate better with water activity than moisture content.
- Undesirable textural changes due to moisture transfer
- Crispness, crunchiness lost if $a_w > 0.4$
- Softness, chewiness lost if $a_w < 0.5 - 0.6$

The Lesson Chart	w	
Dough	0.857	24.5
Fruits (mixed)	0.862	52.2

WATER ACTIVITY TOOLS



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DECAGON
950 NE Nelson Court
Pullman, Washington 99163
800-755-2751
fax 509-332-5158
aqualab@decagon.com
www.decagon.com/aqualab