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Fundamentals of Water Activity

Improving the food supply. FDA & USDA Compliance.

Modern scientific methods are required to enforce the Federal Food, Drug, and Cosmetic Act. Laws to ensure the wholesomeness of foods and the safety and efficacy of drugs would be impractical without reliable methods of laboratory analysis to determine whether products are up to standard. Food and drug scientists in both government and industry must know the normal composition of products to distinguish them from those that are defective. They investigate the toxicity of ingredients, study the causes of food poisoning, and test the potency of vitamins and thousands of drugs. Their investigations also cover the adequacy of controls over processing, packaging, and storage practices. Any action taken by the FDA must be based on scientific facts which can be supported in court. The principal authority relied on for laboratory methods is:

OFFICIAL METHODS OF ANALYSIS OF THE ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS.

This 1,094-page book of tested methods, published since 1895, is an internationally recognized guide to analytical procedures for law enforcement.

■ *Water activity is a critical measurement in determining the shelf-life and safety of foods and other substances.*

Pure, safe, and wholesome food.

The U.S. food, drug, and cosmetics laws are intended to assure the consumer that foods are pure and wholesome, safe to eat, and produced under sanitary conditions; that drugs and medical devices are safe and effective for their intended uses; that cosmetics are safe and made from appropriate ingredients; and that all labeling and packaging is truthful, informative, and not deceptive.

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■ *When a substance is added to lower water activity, the result can be complicated.*

Ideally, an inert material could be added which would decrease water activity without any other effects such as increased ionic strength and decreased surface tension.

For instance, salt can be added to one reaction mixture and sugar to another.

The amounts can be controlled so that the resulting compounds have identical water activity.

Table 1. **Common spoilage organisms and their a_w limits for growth.**

Microbial Group	Example	a_w	Products Affected
Normal bacteria	*Sa1monella species* *Clostridium botulinum*	**0.91**	Fresh meat, milk
Normal yeast	*Torulopsis species*	**0.88**	Fruit juice concentrate
Normal molds	*Aspergillus flavus*	**0.80**	Jams, Jellies
Halophilic bacteria	*Wallemia sebi*	**0.75**	Honey
Xerophilic molds	*Aspergillus echinulatas*	**0.65**	Flour
Osmophllic yeast	*Saccharomyces bisporus*	**0.60**	Dried fruits

Water activity basics for safety and quality in food products.

WATER ACTIVITY'S USEFULNESS as a food quality and safety measurement was suggested when it became evident water *content* could not adequately account for microbial growth fluctuations. The water activity (a_w) concept has served the microbiologist and food technologist for decades and is the most commonly used criterion for safety and quality. Its usefulness cannot be denied. Biological cells and tissues are not homogeneous solutions; neither are food products. Food products derive most of their perceived consumer benefits (apart from nutritional value) from their physical and chemical differences. Water is not uniformly distributed, nor can it be disregarded exclusively as solvent.

Protecting against food spoilage.

Since yeast, molds and bacteria require a certain amount of available water to support growth, designing a product with an a_w below 0.6 provides an effective control. Water activity is defined as the equilibrium relative humidity (ERH) divided by 100. Some common spoilage organisms and their a_w limits are listed in Table 1. The simplest way to reduce water activity is with a process which drives off water— cooking, baking or dehydration. The high-heat processes also use the lethal properties of heat, while dehydration or freeze drying only work by lowering the a_w to a level that curbs growth.

Binding free water and food design.

The second method involves tying up the free water by the addition of solutes, usually sugars or sodium chloride. This creates an imbalance in osmotic pressure which draws the water from cells. Food designers face new challenges in maintaining sufficiently low a_w with many of today's fat replacers. Fat, which does not contribute to the free water, is replaced by water or a gel to provide lubricity. These gels do not reduce a_w and additional control methods are necessary to prevent spoilage.

Water activity concepts— over 40 years old.

Until recently, water activity as a physiochemical parameter was mainly discussed in two scientific disciplines: physical chemistry and food microbiology. In the former, it measures the thermodynamic free energy of water and in the latter it is used to define the lower limits of growth of food spoiling microorganisms. Microbiologists turned to water activity measurements upon discovering that microbial spoilage of food occurs at widely varying levels of water content. Scott†, in the 1950's, applied the water activity concept to describe the water availability for microbial growth.

The definition of water activity.

Scott defined water activity (a_w) as the ratio of the water vapor pressure over a food (P) to that over pure water (P_0).

$$a_w = P/P_0$$

Thus, multiplication of the water activity by 100 gives the relative humidity of the atmosphere in equilibrium with the food.

$$\text{R.H. } (\%) = 100 \times a_w$$

Water activity is a better index for microbial growth than water content.

Water activity better predicts the growth of microorganisms because microorganisms can only use 'available' water, which differs considerably depending on the solute. On average, ions bind the most water, whereas polymers bind the least water; sugars and peptides fall into an intermediate position. At the same molecular concentration, salt lowers the water activity more than sugar.

When a substance is added to lower water activity, the result can be complicated. Ideally, an inert material could be added which would decrease water activity without any other effects such as increased ionic strength and decreased surface tension. In reality, the choice of substance can have a profound effect. For instance, salt could be added to one reaction mixture and sugar to another. The amounts can be controlled so that the resulting compounds have identical water activity. But the results of the reaction will differ because of the differing influences of salt and sugar on biological reactions. Salt and sugar form different additional hurdles *(see page 4)*.

Water activity and hurdle technology.

Water activity should be regarded as an external parameter like pH or temperature. Under certain conditions, it will act synergistically with other environmental parameters. Under other conditions it will be the sole parameter determining the outcome of a certain process. ■

This is a compilation of thought from several authors. We hope it helps you achieve your product shelf-life goals. —DECAGON

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Hurdle technology improves food preservation.

■ *Apart from the most important and commonly used hurdles such as temperature, pH, and water activity, there are many others of potential value.*

SEVERAL YEARS AGO, HURDLE TECHNOLOGY* was developed as a new concept for the realization of safe, stable, nutritious, tasty, and economical foods. It employs the intelligent combination of different preservation factors or techniques to achieve multi-target, mild but reliable preservation effects.

Mild processing of foods with hurdle technology.

Many promising hurdles have been identified so far, although application of the idea in the food industry has been largely restricted to the meat sector. Recent studies, however, emphasize a much wider potential application, e.g., in bakery products, fish, and dairy products. More specifically, the concept was introduced into mild processing of fruits and vegetables. The design of new hurdles such as gas packaging, bioconservation, bacterocins, ultra-high pressure treatment, and edible coatings aided this development.

Consumers want fresher food products.

Consumers demand fresher and more natural products. This prompts food manufacturers to use milder preservation techniques and could be stimulating the current trend to hurdle technology. There is an urgent need for new or improved methods producing stable and safe foods. The concept of hurdle technology addresses this need.

Preservation factors are *hurdles* to inhibit microorganisms.

Hurdle technology deliberately combines existing and new preservation techniques to establish a series of preservative factors (*hurdles*) that the microorganisms in question are unable to overcome (*jump over*). These hurdles may be temperature, water activity, acidity, redox potential, preservatives, and others. A crucial phenomenon in hurdle technology is known as the homeostasis of microorganisms.

Hurdles disturb homeostasis.

Homeostasis is the constant tendency of microorganisms to maintain a stable and balanced (uniform) internal environment. Preservative factors functioning as hurdles can disturb one or more of the homeostasis mechanisms, thereby preventing microorganisms from multiplying and causing them to remain inactive or even die. Food preservation is achieved by disturbing the homeostasis of microorganisms. The best way to do this is to deliberately disturb several homeostasis mechanisms simultaneously.

★ Hurdle Technology also called: combined processes, combined methods, combination preservation, combination techniques, or barrier technology.

Multiple hurdles affect product quality least.

This multi-targeted approach is the essence of hurdle technology. It is more effective than single targeting and allows hurdles of lower intensity, improving product quality. There is the further possibility that different hurdles in a food not only have an added effect on stability, but can act synergistically.

Shelf-life of fermented sausage: an example.

Using hurdle technology, salami-type fermented sausages are produced that are stable at ambient temperature for extended periods. A sequence of hurdles is important at different stages of the ripening process. The first hurdles used are the preservatives, salt and nitrite, which inhibit many of the bacteria present in the batter. Other bacteria multiply, use up oxygen and thereby cause a drop in redox potential, which inhibits aerobic organisms and favors the selection of lactic-acid bacteria. These bacteria then proliferate, causing product acidification and an increase of the pH hurdle. During the long ripening process of salami, the initial hurdles gradually become weaker: nitrite is depleted, the number of lactic-acid bacteria decreases, redox potential and pH increase. However, since water activity decreases with time it becomes the main hurdle.

An increasing list of hurdles.

About 50 different hurdles have been identified in food preservation. Apart from the most important and commonly used hurdles such as temperature, pH, and water activity, there are many others of potential value. Other *hurdles* include: ultrahigh pressure, mano-thermo-sonication, photodynamic inactivation, modified atmosphere packaging of both non-respiring and respiring products, edible coatings, ethanol, maillard reaction products and bacteriocins. Examples of foods preserved by combined processes are fruit juices and heat-processed, cured meat products. ■

■ ***Annual Code of Federal Regulations (CFR), Title 21 subpart references to water activity.***

In the definitions, §110.3(n), it says: "Safe-moisture level is a level of moisture low enough to prevent the growth of undesirable microorganisms in the finished product under the intended conditions of manufacturing, storage, and distribution.

The maximum safe moisture level for a food is based on its water activity (a_w).

An a_w will be considered safe for a food if adequate data are available that demonstrate that the food at or below the given a_w will not support the growth of undesirable microorganisms.

■ *Since yeast, molds and bacteria require a certain amount of available water to support growth, designing a product with an a_w below 0.6 provides an effective control against any microbial growth.*

Measurement of water activity for product quality.

Advantages chilled-mirror dewpoint sensors.

THE IMPORTANCE OF THE CONCEPT OF WATER ACTIVITY cannot be overemphasized. Water activity is a measure of the energy status of the water in a system. More importantly, the usefulness of water activity in relation to microbial growth, chemical reactivity, and stability over water content has been shown. (see Figure 1)

Microbial Growth

Water Activity is a critical factor that determines the shelf life of products. Water activity, not water content, determines the lower limit of available water for microbial growth. While temperature, pH, and several other factors can influence whether an organism will grow in a product and the rate at which it will grow, water activity is often the most important factor. The lowest aw at which the vast majority of spoilage bacteria will grow is about 0.90. The aw for molds and yeast growth is about 0.61 with the lower limit for growth of mycotoxigenic molds at 0.78 aw.

Chemical/biochemical reactivity. Water activity influences not only microbial spoilage but also chemical and enzymatic reactivity. Water may influence chemical reactivity in different ways. It may act as a solvent, reactant or change the mobility of the reactants by affecting the viscosity of the system. Water activity influences non-enzymatic browning, lipid oxidation, degradation of vitamins, enzymatic reactions, protein denaturation, starch gelatinization, and starch retrogradation (see Figure 1).

Physical Properties

In addition to predicting the rates of various chemical and enzymatic reactions, water activity affects the textural properties of foods. Foods with high aw have a texture that is described as moist, juicy, tender and chewy. When the water activity of these products is lowered, undesirable textural attributes such as hardness, dryness, staleness, and toughness are observed. Low aw foods normally have texture attributes described as crisp and crunchy, while at higher aw the texture changes to soggy. Also, water activity affects the flow, caking and clumping properties of powders and granules.

Controlling moisture migration. Water activity is an important parameter in controlling water migration of multicomponent products. Some foods contain components at different water activity levels, such as cream filled snack cakes or cereals with dried fruits. Undesirable textural changes are often the result of moisture migration in multicomponent foods. Moisture will migrate from the region of high aw to the region of lower aw, but the rate of migration depends on many factors. For example, moisture migrating from the higher aw dried fruit into the lower aw cereal causes the fruit to become hard and dry while the cereal becomes soggy.

Free water vs. bound water. Water activity instruments measure the energy status (sometimes referred to as free, unbound or active water) of the water present in a sample. A portion of the total water content present in sample is strongly bound to specific sites on the components in the sample. These sites may include the hydroxl groups of polysaccharides, the carbonyl and amino groups of proteins, and other polar sites. Water is held by hydrogen, ion-dipole, and other strong chemical bonds. Additionally, some water is less tightly bound, but is still not available (as in a solvent for water-soluble components). Many preservation processes attempt to eliminate spoilage by lowering the

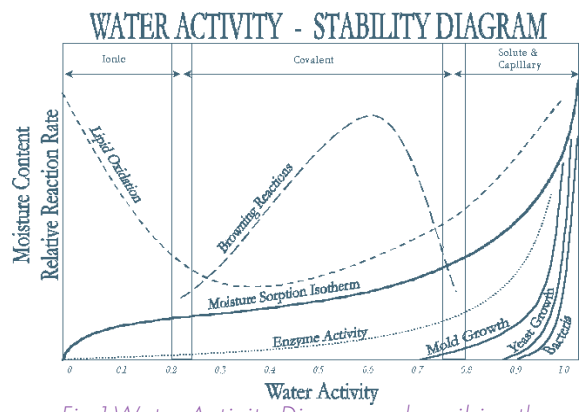

Fig 1 Water Activity Diagram—describing the affects on microbial growth and reaction rates—

Reference: Fontana, Anthony 1998. Water activity: why it is important for food safety. Proceedings of the First NSF International Conference on Food Safety. pgs.177-185.

availability of water to microorganisms. Reducing the aw also minimizes other undesirable chemical changes occurring during storage. The processes used to reduce the aw include techniques like concentration, dehydration, humecants, freezing, and freeze drying. These techniques control spoilage by making water unavailable to microorganisms. Because water is present in varying energy states, analytical methods that attempt to measure total moisture in samples don't always agree. Water activity tells the real story.

Chilled mirror dewpoint theory.
In a chilled mirror dewpoint system, water activity is measured by equilibrating the liquid phase water in the sample with the vapor phase water in the headspace of a closed chamber and measuring the relative humidity of the headspace. In the AquaLab, a sample is placed in a sample cup which is sealed against a sensor block. Inside the sensor block is a fan, a dewpoint sensor, a temperature sensor, and an infrared thermometer. The dewpoint sensor measures the dewpoint temperature of the air, and the infrared thermometer measures the sample temperature. From these measurements the relative humidity of the headspace is computed as the ratio of dewpoint temperature saturation vapor pressure to saturation vapor pressure at the sample temperature. When the water activity of the sample and the relative humidity of the air are in equilibrium, the measurement of the headspace humidity gives the water activity of the sample. The purpose of the fan is to speed equilibrium and to control the boundary layer conductance of the dew point sensor.

Speed and accuracy
The major advantages of the chilled mirror dewpoint method, which is a primary method approved by AOAC International, are speed and accuracy. Chilled mirror dewpoint is a primary approach to measurement of relative humidity based on fundamental thermodynamic principles. Since the measurement is based on temperature determination, chilled mirror instruments make accurate (±0.003aw) measurements in less than 5 minutes. For some applications, fast readings allow manufacturers to perform at-line monitoring of a product's water activity. Processing changes can then be made during production. With AquaLab's chilled mirror technology, temperature control is unnecessary for most applications, but available if required.

Water activity—accepted and approved.
Water activity is an important property. It predicts stability with respect to microbial growth, rates of deteriorative reaction, and physical properties. The growing recognition of measuring water activity is illustrated by the U.S. Food and Drug Administration's incorporation of the water activity principle in defining safety regulations. The purpose of the regulations are to detail the specific requirements and practices to be followed by industry to assure that products produced under sanitary conditions and are pure, wholesome, and safe. In the past, measuring water activity was a frustrating experience. New instrument technologies, like AquaLab, have vastly improved speed, accuracy, and reliability of measurements. ■

■ AquaLab water activity meter.

Are you in compliance with HACCP? Identifying your products critical control points.

■ ***What does HACCP mean?***

HACCP stands for Hazard Analysis and Critical Control Points. It is a way for industry to control and prevent problems, and ensure safe food by controlling the production process from beginning to end, rather than detecting problems at the end of the line. HACCP identifies where hazards might occur in the food production process, and puts into place actions to prevent the hazards from occurring. By controlling major food risks, such as microbiological, chemical, and physical contaminants, the industry can better assure consumers that its products are safe.

As of January 26, 1998 HACCP is now law for meat, poultry and seafood processors in the US. This science-based system will improve food safety and reduce the incidence of foodborne illness attributed to meat and poultry products. The old food inspection program was based on a "see, smell and touch" approach that relied more on detection of potential hazards than prevention. Today, microbiological and chemical contamination are of greater importance to food safety.

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How does HACCP work?

There are seven principles that serve as the foundation for a HACCP system.

1 Conduct a hazard analysis to identify potential hazards that could occur in the food production process.

2 Identify the critical control points (CCPs, *see next column*) - those points in the process where the potential hazards could occur and can be prevented and/or controlled.

3 Establish the critical limits that must be met at each identified CCP. A critical limit is a criterion that must be met for each CCP.

4 Establish CCP monitoring requirements to ensure each CCP stays within its limit. Monitoring may require materials or devices to measure or otherwise evaluate the process at CCPs.

5 Establish corrective action to be taken when there is a deviation identified by monitoring of a CCP. In case a problem occurs, corrective actions must be in place to ensure no public health hazard occurs.

6 Establish effective record keeping procedures that document the HACCP system is working properly. Records should document CCP monitoring, verification activities and deviation records.

7 Establish procedures for verifying that the HACCP system is working properly. Verification consists of methods, procedures and tests used to determine that the HACCP system is in compliance with the HACCP plan.

What are critical control points (CCPs)?

A CCP is defined as any point or procedure in a specific food system where loss of control could result in an unacceptable health risk. Each CCP will have one or more control measures to assure that the identified hazards are prevented, eliminated or reduced to acceptable levels. For microbiological hazards, for example, a target water activity must be established to prevent hazardous organisms from growing.

What are critical limits?

A critical limit is a maximum and/or minimum value to which a biological, chemical or physical parameter must be controlled at a CCP to prevent, eliminate or reduce to an acceptable level the occurrence of a food safety hazard. Critical limits may be based on factors such as: temperature, time, water activity, or pH. A critical limit is used to distinguish between safe and unsafe operating conditions at a CCP. Critical limits should not be confused with operational limits, which are established for reasons other than food safety. ■

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