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The Art of Precision Measurement

APPLICATION NOTE

MAINTAINING GREEN COFFEE QUALITY THROUGH WATER ACTIVITY CONTROL

The international coffee market is valued at $102 billion. It includes everything from freeze dried instant coffee to specialty blends carefully sourced from specific growing locations. Not surprisingly, the highest quality coffee comes at the highest price along with the highest quality expectations. Coffee beans are harvested as a coffee cherry that is then processed to remove the fleshy cherry covering to produce green coffee beans. These green coffee beans are the form in which the coffee is stored and transported. When it is time to produce coffee, the green beans are roasted to create the familiar roasted coffee beans that are purchased at a store or utilized at a coffee house. The roasted beans are ground and brewed to produce the familiar cup of coffee. Obviously, each of these steps provide their own challenges and each can impact the quality of the coffee produced.

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INTRODUCTION

Coffee quality is tracked throughout processing from harvest to coffee production. Initially, quality of green beans and roasted beans is done visually based on size and appearance, which is followed by the most important quality measurement of the coffee produced, a process called cupping. This cupping process looks at flavor, aftertaste, acidity, body, and uniformity among others and gives a score between 1-100 with specialty coffees expected to score 80 or higher (1). Unfortunately, finding that a sourced coffee bean does not cup well may be too late as the beans have already been purchased. It would be preferrable to be able to conduct tests on the green beans themselves at the time of harvest to predict the cupping quality. Water activity has been investigated as a potential measurement on green coffee beans to predict the cupping quality of sourced coffee beans.

THEORY OF WATER ACTIVITY

Water activity is defined as the energy status of water in a system and is rooted in the fundamental laws of thermodynamics through Gibb's free energy equation. It represents the relative chemical potential energy of water as dictated by the surface, colligative, and capillary interactions in a matrix. Practically, it is measured as the partial vapor pressure of water in a headspace that is at equilibrium with the sample, divided by the saturated vapor pressure of water at the same temperature. Water activity is often referred to as the 'free water', but since 'free' is not scientifically defined and is interpreted differently depending on the context, this is incorrect. Free water gives the connotation of a quantitative measurement, while water activity is a qualitative measurement of the relative chemical potential energy. Rather than a water activity of 0.50 indicating 50% free water, it more correctly indicates that the water in the product has 50% of the energy that pure water would have in the same situation. The lower the water activity then, the less the water in the system behaves like pure water.

While water activity is an intensive property that provides the energy of the water in a system, moisture content is an extensive property that determines the amount of moisture in a product. Water activity and moisture content, while related, are not the same measurement. Moisture content is typically determined through loss-on-drying as the difference in weight between a wet and dried sample. For coffee beans, moisture content provides a standard of identity for point of sale but does not determine if the product is microbially safe. Water activity and moisture content are related through the moisture sorption isotherm, but this relationship is nonlinear and product specific.

For green coffee, 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 Equilibrium Relative Humidity (ERH) in the headspace using a sensor. The relative humidity can be determined using a resistive electrolytic sensor, a chilled mirror sensor, or a capacitive hygroscopic polymer sensor. Instruments from Novasina, like the Labmaster NEO, utilize an electrolytic sensor to determine the ERH inside a sealed chamber containing the sample. Changes in ERH are tracked by changes in the electrical resistance of the electrolyte sensor. The advantage of this approach is that it is very stable and resistant to inaccurate readings due to contamination, a particular weakness of the chilled mirror sensor. The resistive electrolytic sensor can achieve the highest level of accuracy and precision with no maintenance and infrequent calibration. Coffee beans can be tested whole or crushed with crushing providing advantages in testing time and repeatability.

LabMaster aw-neo
Most reliable water activity meter on the market

WATER ACTIVITY AND CUPPING QUALITY

The value of tracking water activity of green coffee beans is not directly in a correlation to cupping score. In other words, 2 coffee beans at the same water activity will not necessarily have the same cup score, nor will the cup score increase by a predictable amount as water activity either increases or decreases. Consequently, some studies have concluded that water activity is not useful enough to justify testing and that relying on moisture content should be sufficient (2). The problem with this conclusion is first, moisture content analyses are in almost all cases more difficult and much less reliable than water activity testing. Secondly, the value of water activity is not in a direct correlation to cupping score, but in providing an optimal range for storage to avoid microbial contamination, slow degradative chemical reactions, and maintain metabolic activity. The recommended optimal water activity range for stored green coffee beans is 0.45-0.55 a_w (3). Drying and storing green coffee beans at this water activity range will not improve the cupping quality of the green coffee beans, but instead will maintain the quality for 6-8 months.

WHY LESS THAN 0.55 a_w – MICROBIAL GROWTH

The main reason for using 0.55 a_w as the upper limit for stored green coffee beans is to prevent microbial growth. Each microorganism has an ideal water activity inside their membrane and their ability to reproduce and grow depends on maintaining that water activity. When a microorganism encounters an environment where the water activity is lower than their internal water activity, they experience osmotic stress and begin to lose water to the environment since water moves from high water activity (energy) to low water activity. This loss of water reduces turgor pressure and retards normal metabolic activity. To continue reproducing, the organism must lower its internal water activity below that of the environment. It tries to achieve this by concentrating solutes internally. The ability to reduce its internal water activity using these strategies is unique to each organism. Consequently, each microorganism has a unique limiting water activity below which they cannot grow (4, 5). Notice that an organism's ability to reproduce and grow does not depend on how much water is in its environment (moisture content), only on the energy of the water (water activity) and whether it can access that water for growth.

A list of the water activity lower limits for growth of common spoilage organisms can be found in Table 1. These growth limits indicate that all pathogenic bacteria stop growing at water activities less than 0.87 while the growth of common spoilage yeasts and molds stops at 0.70 a_w, which is known as the practical limit. Only xerophilic and osmophylic organisms can grow below 0.70 a_w and all microbial growth stops at water activities less than 0.60. Molds and their accompanying mycotoxins would be the most likely contaminants on green coffee beans and their presence can result in musty off flavors and odors or worse, a reaction to the mycotoxins. However, at water activities less than 0.55, green coffee beans would not support the growth of any microorganisms, thereby justifying the ideal range being below 0.55 a_w.

Microorganism	a_w limit	Microorganism	a_w limit
Clostridium botulinum E	0.97	Penicillum expansum	0.83
Pseudomonas fluorescens	0.97	Penicillum islandicum	0.83
Escherichia coli	0.95	Debarymoces hansenii	0.83
Clostridium perfringens	0.95	Aspergillus fumigatus	0.82
Salmonella spp.	0.95	Penicillum cyclopium	0.81
Clostridium botulinum A B	0.94	Saccharomyces bailii	0.8
Vibrio parahaemoliticus	0.94	Penicillum martensii	0.79
Bacillus cereus	0.93	Aspergillus niger	0.77
Rhizopus nigricans	0.93	Aspergillus ochraceous	0.77
Listeria monocytogenes	0.92	Aspergillus restrictus	0.75
Bacillus subtilis	0.91	Aspergillus candidus	0.75
Staphylococcus aureus (anaerobic)	0.9	Eurotium chevalieri	0.71
Saccharomyces cerevisiae	0.9	Eurotium amstelodami	0.7
Candida	0.88	Zygosaccharomyces rouxii	0.62
Staphylococcus aureus (aerobic)	0.86	Monascus bisporus	0.61

Table 1. Water activity lower limits for growth for common spoilage organisms.

WHY LESS THAN 0.55 a_w - CHEMICAL STABILITY

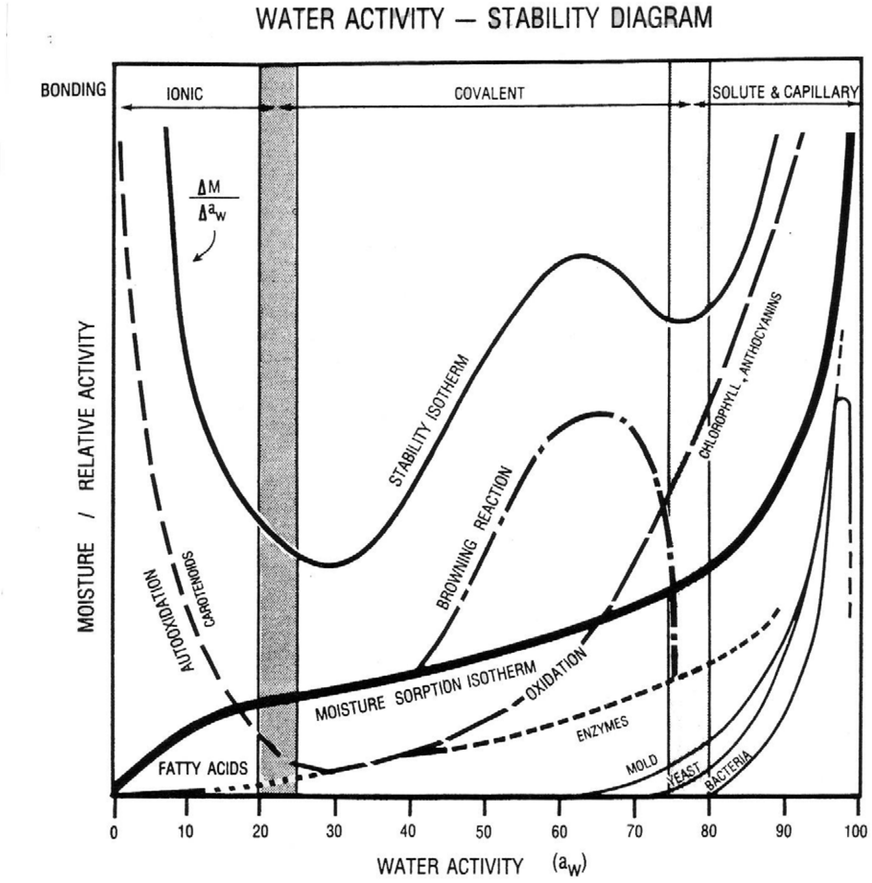

Figure 1. The impact of water activity on various stability factors in food.

An additional reason to for maintaining green coffee beans at water activities less than 0.55 is to limit the rates of potentially harmful chemical reactions. In general, as water activity increases so do reaction rates, but lipid oxidation is unique in that the reaction rate also increases at very low water activity. Examples of reactions that can result in the degradation and end of shelf life of green coffee beans are Maillard browning (changes in color and flavor), lipid oxidation (rancidity) and staling (Figure 1).

Keeping the water activity of green coffee beans below 0.55 a_w will slow the rate of these reactions, but they will still occur. The time required for the reaction to have progressed to the point of unacceptability at a given water activity and temperature will be the product's shelf life. If the rate constants for these reactions at several different storage conditions are determined, a predictive model can be used to estimate the time needed for the reaction to proceed to an unacceptable level under any storage conditions. To do this, the progress of the reaction will need to be tracked using some type of quantitative assessment. Examples of methods for quantifying common reactions include:

Lipid Oxidation/Rancidity

- Peroxide values
- Tbar values
- Oxygen consumption
- Sensory

Browning Reactions

- Color changes
- Sensory
- Formation of reaction products

While there are examples of shelf life models in the literature, the only fundamental model that includes both water activity and temperature is hygrothermal time (6). It is derived from a form of the Eyring (7) equation for rate change and Gibbs equation for free energy and is given by

$$r = r_0 \exp\left(Ba_w - \frac{E_a}{RT}\right) \tag{3}$$

Where T is the termperature (K), R is the gas constant (J mol-1 K-1), Ea is the activation energy (J mol-1), B is the molecular volume ratio, a_w is the water activity, and r0 is the rate at the standard state. In practice, the values for B, Ea/R and r0 will be unique to each situation and are derived empirically through least squares iteration. Shelf life models like this one were used to provide the estimated shelf life of 6-8 months when stored in the ideal water activity range.

WHY GREATER THAN 0.45 a_w - METABOLIC STABILITY

The main reason for not allowing the water activity of stored green beans to drop below 0.45 a_w is to maintain the viability of the green seeds including the enzymatic activity that is critical to maintaining the expected flavor and aroma profile for a coffee. Green coffee beans at water activities less than 0.45 a_w will potentially lose their viability, resulting in aged flavors when the coffee is roasted. In addition, at water activities less than 0.45, the surface of green coffee beans can potentially become more rigid and brittle, resulting in poor grinding performance in preparation for roasting.

IDEAL WATER ACTIVITY FOR GREEN COFFEE

Like most products, green coffee is sold on a weight basis, so maximizing the amount of water, the cheapest ingredient, that can be in a product while remaining safe and stable will maximize profitability. The ideal water activity range for storing green coffee beans has been identified and moving above or below this range will render the product undesirable. A green coffee with a cupping quality of 88 stored outside the ideal water activity range can experience multiple point drops in cupping score in just 1-2 months. The key then to maximizing profitability while ensuring quality is to make sure that the water activity of green coffee beans is in the 0.45-0.55 a_w range. Water activity testing of green coffee beans can be easily achieved with a simple test using the fine equipment available from Novasina. To learn more about testing for water activity, please contact Novasina or one of its global partners.

THE AUTHOR

Dr. Brady Carter is a Senior Research Scientist with Carter Scientific Solutions. He specializes in Water Activity and Moisture Sorption applications. Dr. Carter earned his Ph.D. and M.S Degree in Food Engineering and Crop Science from Washington State University and a B.A. Degree in Botany from Weber State University. He has 20 years of experience in research and development and prior to starting his own company, he held positions at Decagon Devices and Washington State University. Dr. Carter currently provides contract scientific support to Novasina AG and Netuec Group. He has been the instructor for water activity seminars in over 23 different countries and has provided on-site water activity training for companies around the world. He has authored over 20 white papers on water activity, moisture sorption isotherms, and complete moisture analysis. He has participated in hundreds of extension presentations andhas given talks at numerous scientific conferences. He developed the shelflife simplified paradigm and hygrothermal time shelf life model.

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