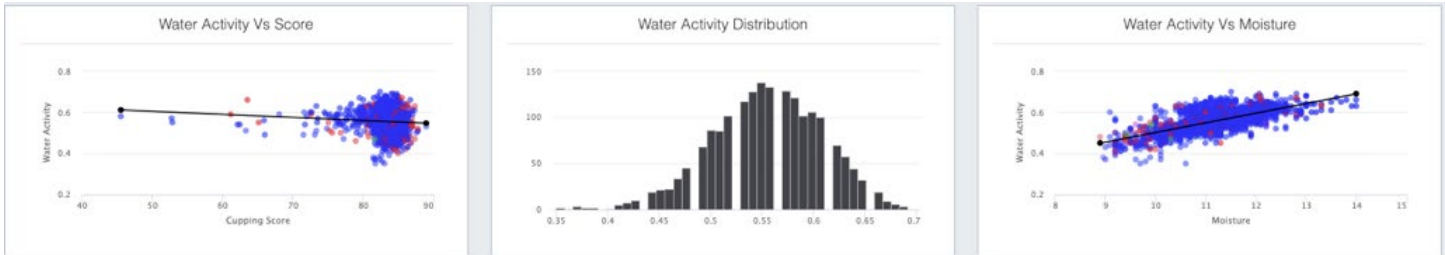


Understanding Water Activity in Relation to Green Coffee and Quality Control

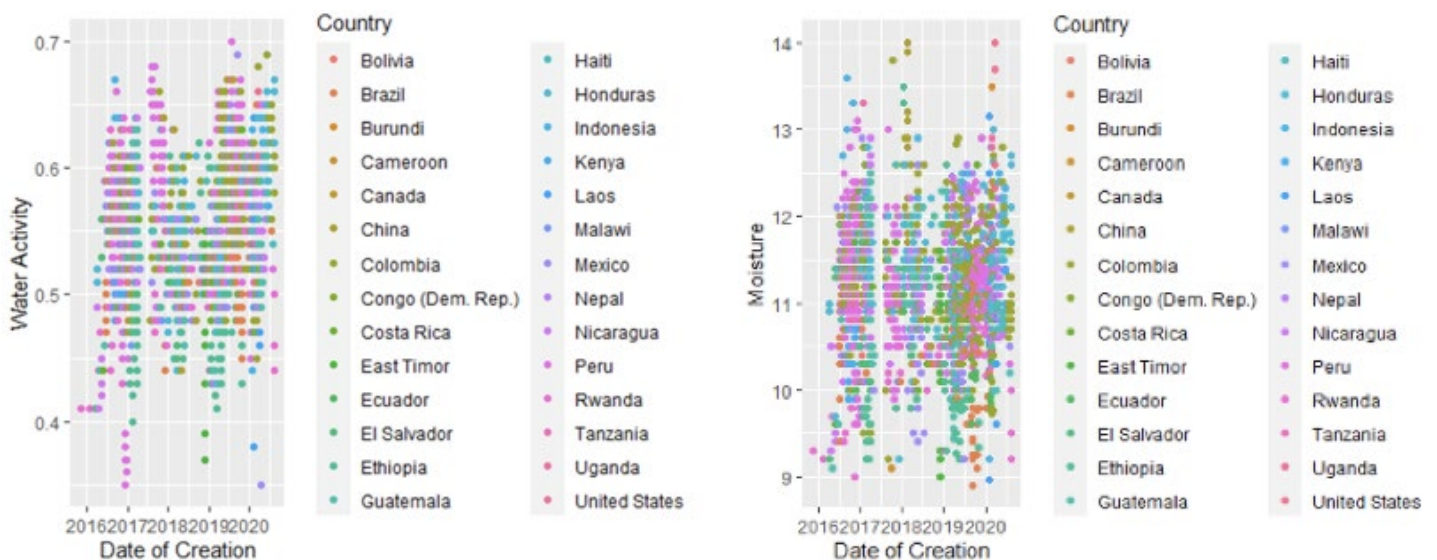


Understanding Water Activity in Relation to Green Coffee and Quality Control



This is an internal, observational study conducted by Sustainable Harvest® between 2016 and 2020.

1,790 samples were evaluated from 28 countries: Bolivia, Brazil, Burundi, Cameroon, Canada, China, Colombia, Congo, Costa Rica, East Timor, Ecuador, El Salvador, Ethiopia, Guatemala, Haiti, Honduras, Indonesia, Kenya, Laos, Malawi, Mexico, Nepal, Nicaragua, Peru, Rwanda, Tanzania, Uganda, and the United States.



WATER ACTIVITY AND MOISTURE GRAPHS OF THE COUNTRIES EVALUATED

Although water activity is considered a quality parameter and its measure is included in the green coffee quality standards set by the Specialty Coffee Association, there has been relatively little research analyzing the relationship between water activity and green coffee quality. This study hopes to shed light on this subject.



Introduction

The world of specialty coffee is ever-changing and evolving at a rapid pace, from the producing level all the way to the consumer world. It seems as though every year, advancements in coffee technology and research influence more and more trends and tastes, opening new doors to scientific and culinary experimentation and exploration. Indeed, it would be safe to say that the current environment of specialty coffee is experiencing a level of curiosity that it hasn't had in the past. Simply put, as our understanding of coffee continues to grow and our tastes continue to expand and develop, what we consider to be "good," and how we consider it, will also change.

One such area that has garnered increasing interest throughout our industry over the past few years has been the subject of "water activity." Although water activity is generally well understood and is an established measurement in other industries, its usefulness when it comes to assessing green coffee quality is less clearly defined.

This is important mainly for its potential impact on the producing world. Currently, water activity is not something that is routinely measured by the vast majority of smallholder, lower-capacity producers. If the industry should impose more rigorous standards for water activity, it should do so to the benefit of producers. The last thing we want to do is make the work of growing and processing coffee harder, and—considering the significant cost of a water activity meter—more expensive, especially if the payoff in better-quality coffee is not there.

Ultimately, the goal of this undertaking, and all similar efforts, is to use this information to help producers improve their growing and processing practices so that they may produce higher-quality coffee consistently and efficiently. If it's found, in the course of research, that there should be more importance placed on water activity, the next steps as an industry should be to make tools and training accessible and affordable for producers so that the burden does not fall solely on them.

With this in mind, by conducting this study we set out to provide insights to the following questions:

How does water activity relate to green coffee quality, and why does it matter?

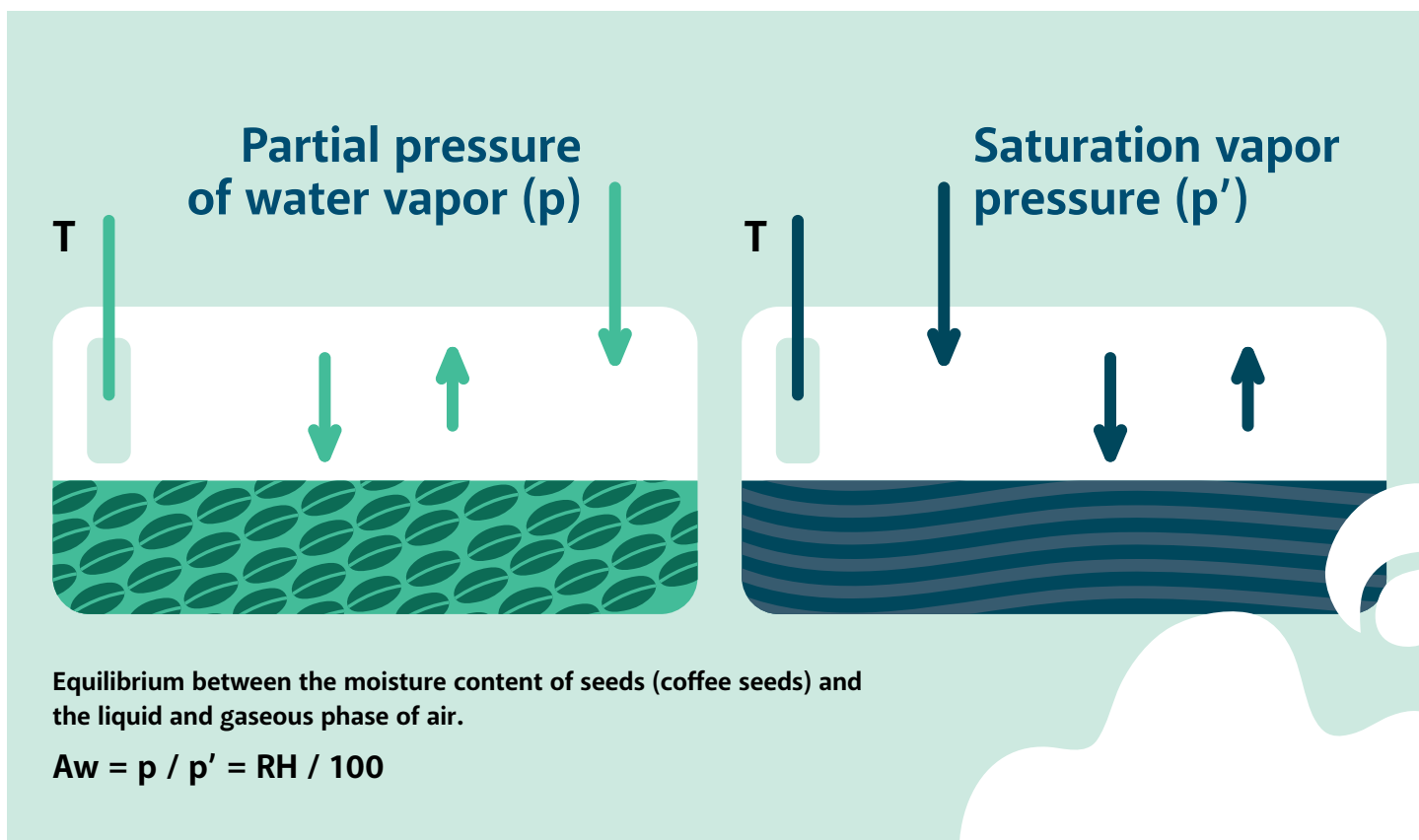
What quality factors does water activity impact the most?

Should more or less importance be placed on water activity as a quality control parameter for producers and importers/roasters?

We can begin by first understanding what water activity is and how it relates to moisture content.



What Is Water Activity?



Strictly speaking, we can define water activity (A_w) as the ratio of the partial vapor pressure of water in a substance (e.g., any food, or in this case, green coffee) relative to the partial vapor pressure of pure water under standard conditions and at the same temperature. Water activity can be calculated by dividing the partial vapor pressure of water in a substance by the partial vapor pressure of pure water, which is 1. Water activity, therefore, is measured on a scale of 0 to 1.

To better illustrate what we mean by “partial vapor pressure,” imagine a sealed container partly filled with pure water. As the water evaporates, the air just above the water fills with water molecules. Because the container is sealed, the pressure inside

the container is increased due to the evaporating water. This is the partial vapor pressure of pure water.

If there were a substance dissolved in the water, say salt or sugar, there would be less water available to evaporate into the atmosphere because some of those water molecules would now be bound to the dissolved substance. The partial vapor pressure of this water would be less than that of pure water.

Water activity describes the chemical availability of water that is unbound and freely able to take part in chemical reactions. Water activity is, therefore, a measure of the energy status of water in a substance.

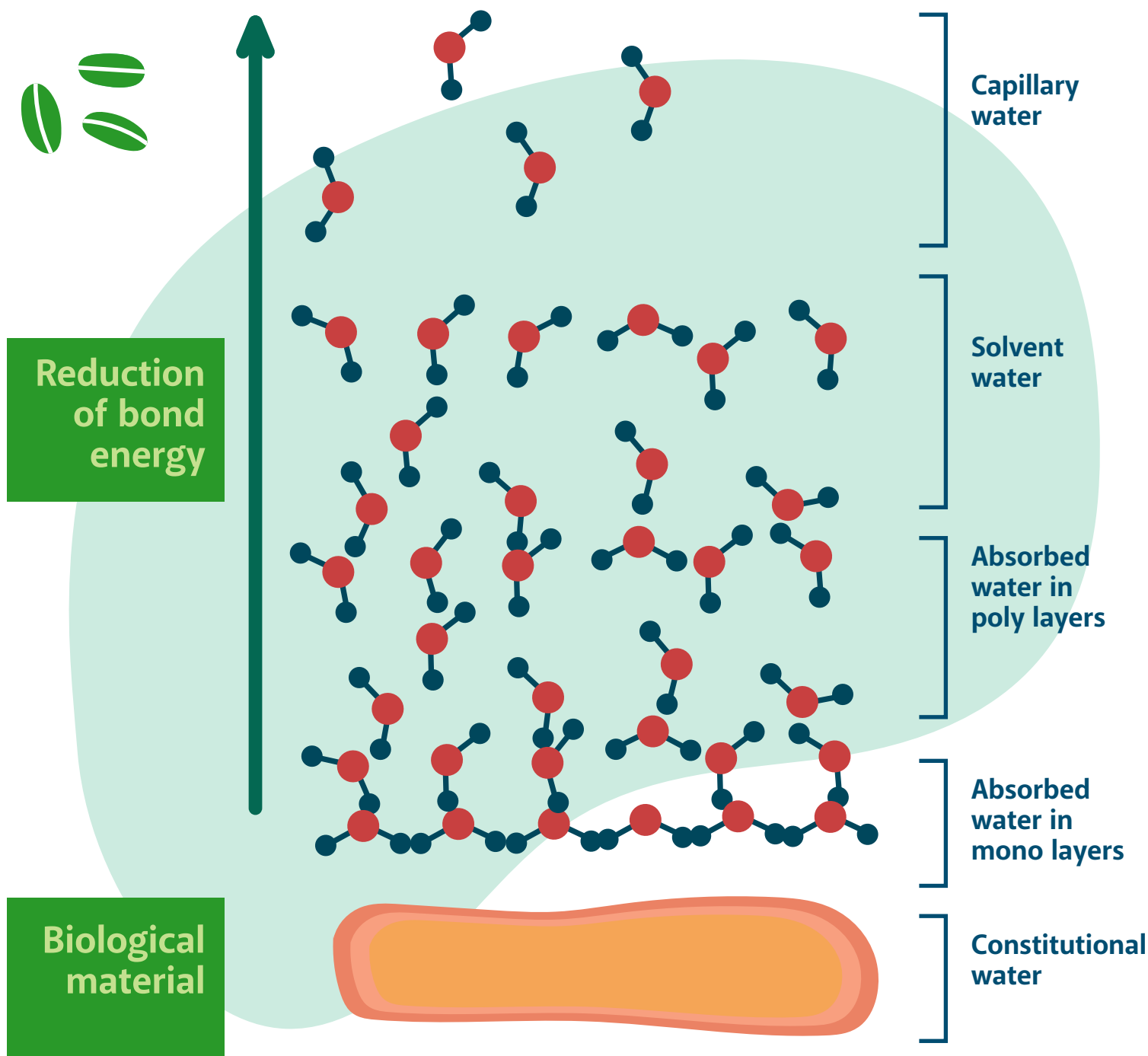
A sample containing only pure water, therefore, has a water activity of 1 ($A_w = 1$) because all of the water molecules are unbound and chemically available.

It is worth noting that water activity takes into account the different degrees to which water molecules are bound in the coffee seed.

The types of water found in the coffee fruit and seed are:

1. Constitutional water
2. Water absorbed into the molecular and macromolecular components of the coffee fruit and seed
3. Solvent water, which is found under osmotic tension. This type of water has biological functions that allow chemical reactions to occur and fungi to develop.
4. Absorbed water that exists within the capillaries and empty spaces inside the fruit and seed.

Below graphic referenced from Borem / Handbook of Coffee Post-Harvest Technology





Why Is This Important?

A higher measure of water activity means that more water is available to support the growth of microorganisms, such as bacteria, yeast, and mold, and to accelerate chemical and enzymatic reactions that lead to food spoilage¹. In other words, higher water activity means that a food is less shelf “stable,” microbiologically, chemically, and physically. A lower water activity generally means that a food will retain the same physical qualities over a longer period of time.

Reducing water activity in a food slows the rate at which these biochemical processes occur; reducing A_w to $<.60$ causes growth of bacteria, yeast, and mold to cease. Between $.60$ and 1 lies a “danger zone” where a food product is more prone to degrade, have a reduced shelf life, and experience the growth of unwanted microorganisms that can lead to the generation of harmful toxins.



A note on mycotoxin development

The most common and serious toxin found in coffee is a mycotoxin called ochratoxin A (OTA). This mycotoxin is produced by certain fungi, such as *Aspergillus carbonarius* and *Aspergillus ochraceus*. As per the SCA in their standards for water activity:

“The fungus *Aspergillus ochraceus* is the leading producer of (ochratoxin A) in coffee. It develops in environments with temperatures between 8°C and 37°C , with the optimum temperature between 24°C and 31°C . The minimum water activity for its development is 0.76 at 25°C , with the optimum A_w ranging from 0.95 to 0.99 and pH between 3 and 10 (Hocking and Pitt, 1997). Although *Aspergillus ochraceus* develops from a water activity of 0.76 , the toxin is produced in coffee beans from 0.85 , and 0.97 is the optimal A_w (Moss, 1996).²

Development of Mycotoxins

0.8

More than 4 days
without losing water

0.95

1

Cenicafé mentions some of the HACCPs, or Hazard Analysis and Critical Control Points, that should be in place during coffee processing. Water activity higher than 0.8 must be avoided for long periods of time. Coffees held at this water activity or higher for more than four days are at high risk for developing mycotoxins, not only of the ochratoxin A type, but also of other types of mycotoxins such as aflatoxins B1, which are characterized as those of the highest toxicity.³



¹ <https://www.food-safety.com/articles/4420-water-activitye28099s-role-in-food-safety-and-quality>

² <https://sca.coffee/research/coffee-standards>

³ https://www.usfx.bo/nueva/vicerrectorado/citas/TECNOLOGICAS_20/Quimica_Industrial/1.pdf



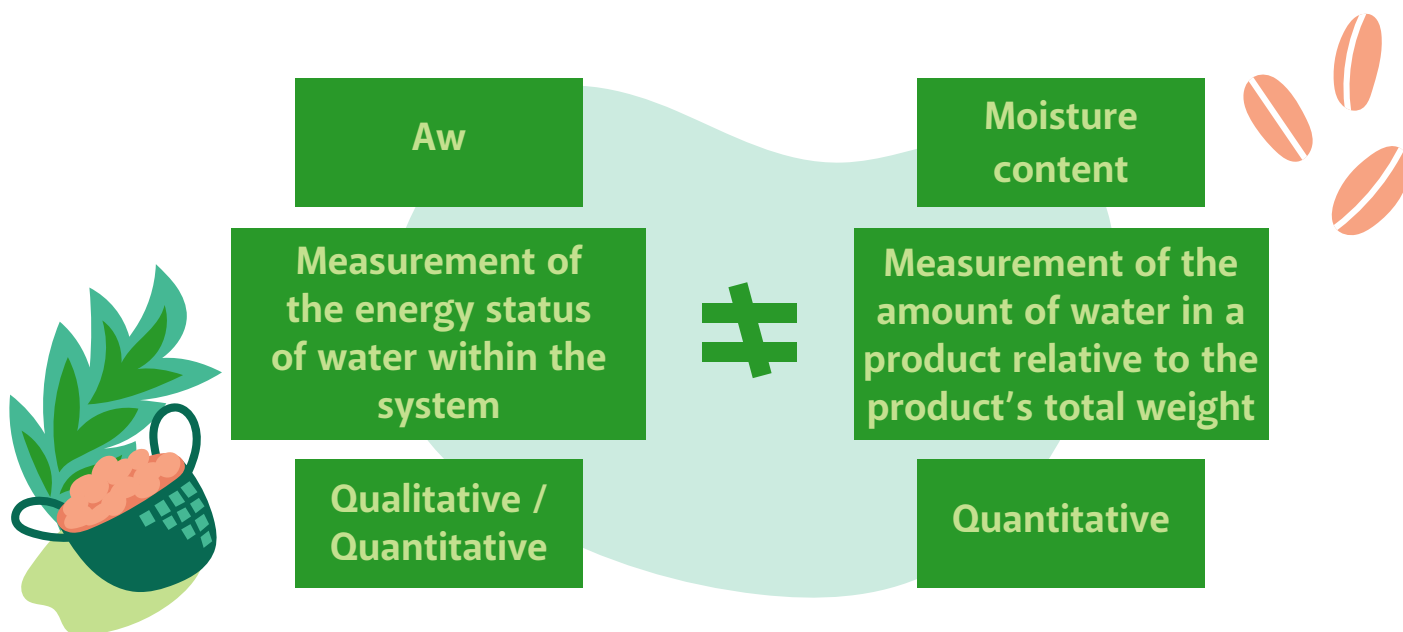
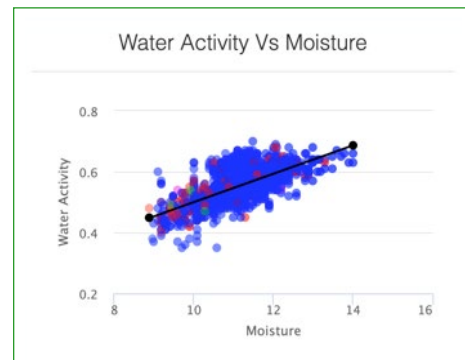
Water Activity Vs. Moisture Content

Water activity should not be confused with “moisture content”

Whereas Aw measures the amount of unbound water in a product, moisture content is a measurement of the amount of water in a product relative to the product's total weight and is expressed as a percentage. A moisture content reading of 20%, for example, means that 20% of that product's weight is attributed to water. Water activity is a thermodynamic parameter defined as the “chemical potential” of the water in seeds, referring to the state of energy of the molecule in the system. It expresses the potential availability of the water to participate in chemical and biochemical reactions, particularly their biochemical viability and readiness to develop fungi.

While these measurements are related, water activity and moisture content do not have a direct relationship when it comes to green coffee—e.g., a reading of .65 Aw does not always correlate to any one specific moisture content reading.

In our findings, we've seen that water activity can and will fluctuate even if moisture content remains the same. Generally speaking, as moisture content increases or decreases, so too will the average water activity. It could be safe to say that a certain moisture content reading will relate to a certain range of water activity measurements. The reverse is true as well: A certain water activity reading can have a range of moisture content readings.

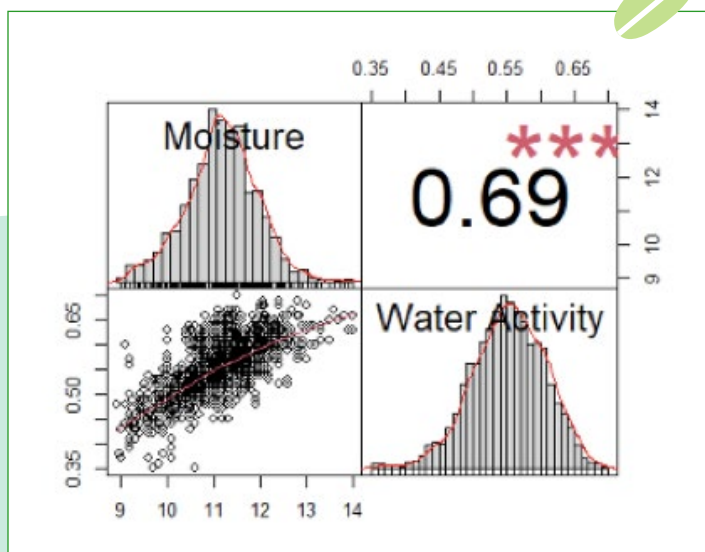
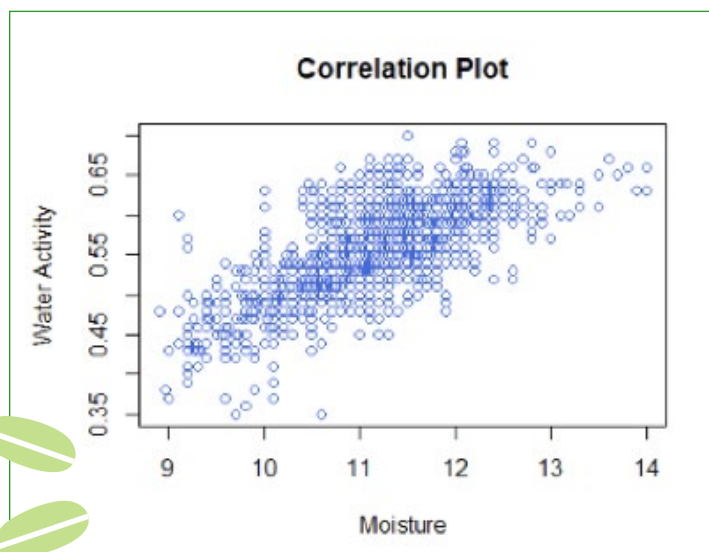


But it is also important to highlight that in analyzing the data we did find a correlation between Aw and moisture content of coffee; this was a moderate positive correlation of 0.69.

Going by the data, the relationship between water activity and moisture content can be expressed as a “moderate positive correlation,” with a coefficient of 0.69. The correlation coefficient is expressed on a scale of -1.0 to 1.0. A value of 0 means that there is no correlation.

When there is a positive correlation ($r > 0$) between two variables, one variable moves proportionally with the other variable: If one variable increases, the other increases, and if one variable decreases, the other also decreases.

When there is a negative correlation ($r < 0$) between two variables, when one increases, the other decreases. The value of 1.00 is a “perfect positive correlation,” meaning that the variables will move together by the exact same percentages in the same direction. In general, a value a between 0.4 and 0.7 would be considered a moderately strong relationship; values above 0.7 would be “strong,” and values below 0.4 would be “weak.”

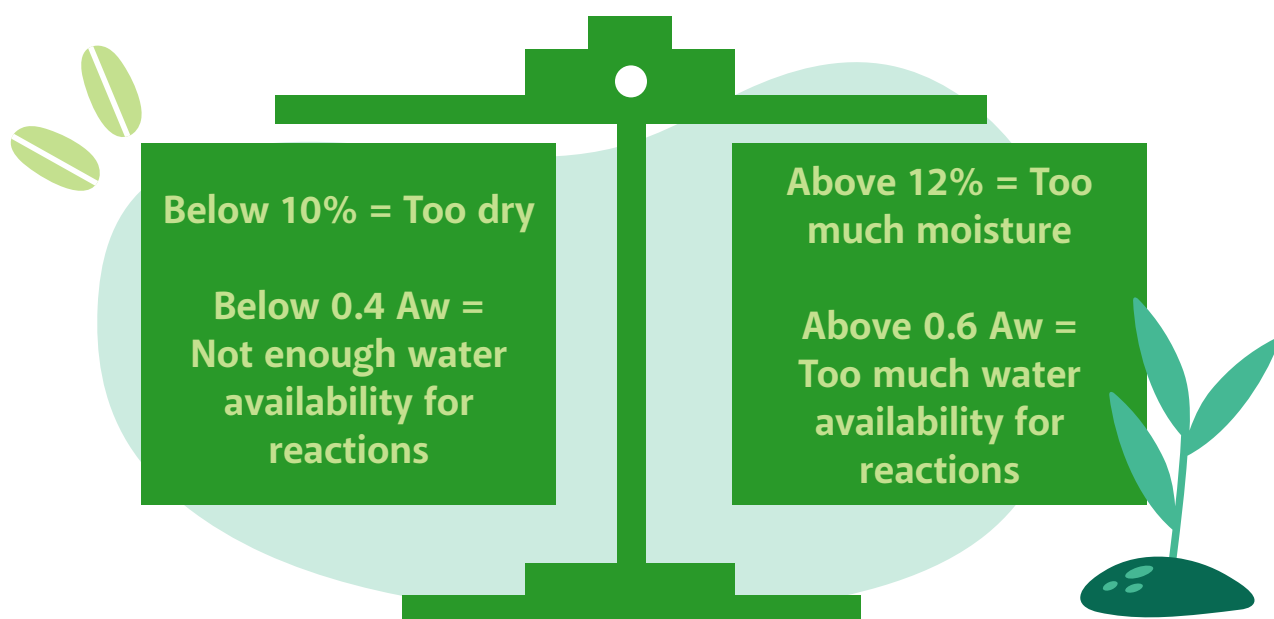




Water Activity and Drying

In specialty coffee, it is generally accepted that 10-12% is the ideal moisture content for green coffee before shipping. This roughly correlates to a water activity range between 0.4 and 0.6 A_w .

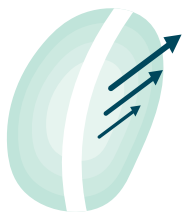
Water influences several properties of food, particularly its propensity to spoil. Physical, chemical, and biological processes are carried out by the amount of water available. This water is represented in moisture content and water activity. But this amount of water can be reduced in the drying process so that the bean or the seed is stable and does not deteriorate easily.



Different processing methods (natural, washed, honey, wet-hulled, etc.) do not only have a dramatic effect on how flavors develop in coffee, but also critically influence water activity, leading to a more or less stable end product.⁴ The drying stage of coffee processing is essentially how water activity and moisture content are controlled prior to storage.



⁴ <http://biblioteca.cenicafe.org/bitstream/10778/399/1/avt0371.pdf>



During the drying process, water migrates from the innermost part of the coffee seed to the outermost part. Coffee seeds can be dried in different ways, some more ideal than others. Whether the coffee is dried quickly, slowly, or with interruptions, it is possible for a coffee to reach an ideal moisture content at the end of drying; yet, the process by which the water migrates inside of the bean can vary widely and have a significant impact on the end quality. Even though moisture content might be the same across different samples, water activity can vary and affect seed shelf life and stability.

The coffee bean, being a living seed, remains metabolically active throughout the drying process. Depending on the specific method of drying, and whether the process occurs evenly or unevenly, constantly or intermittently, this activity will either stabilize or accelerate. In most cases, an uninterrupted drying will allow for the proper movement of water through the seed, leading to more stable metabolic activity and a higher likelihood of achieving an ideal, stable water activity, so that the seed is better preserved.

The below graphs show variations between the different processing methods, from which we can deduce that the chosen processing method has an influence on the end water activity in the samples. These differences are a result of multiple factors such as:

- Environmental conditions and microclimate variations
- Processing techniques.
- Drying conditions and the method used

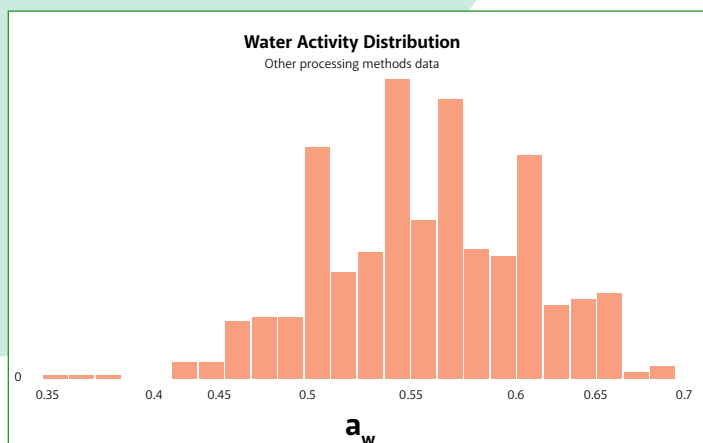
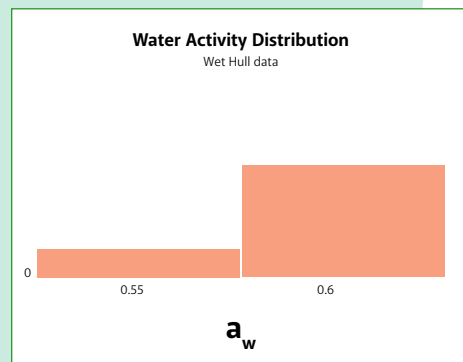
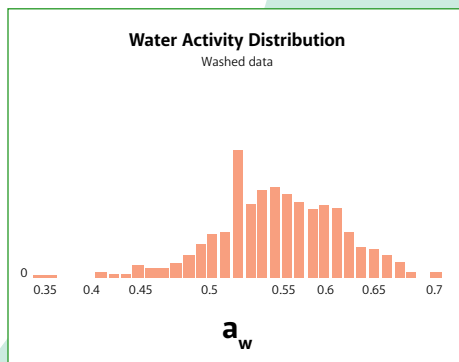
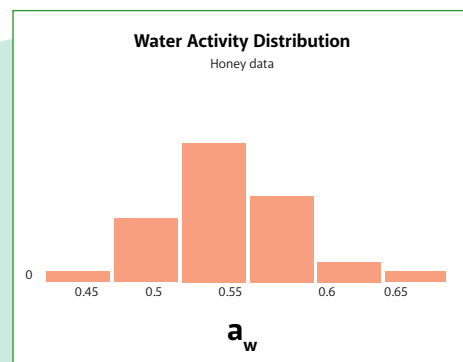
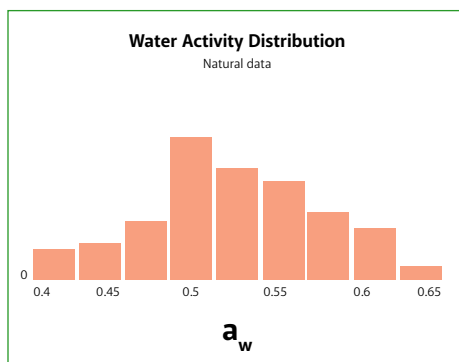
Natural: The highest concentration of samples measured at 0.50 a_w with a range between 0.4 and 0.65.

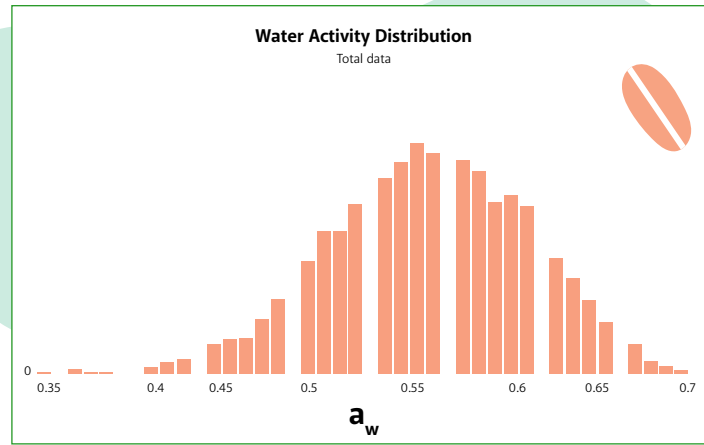
Honey: The highest concentration of samples measured at 0.55 a_w with a range between 0.45 and 0.65.

Washed: The highest concentration of samples measured at 0.5 a_w with a range between 0.35 and 0.70.

Wet hulled: The highest concentration of samples measured at 0.60 a_w with a range between 0.55 and 0.60.

Other processing methods: These were samples that fell outside standard methods for processing and include “experimental” processing methods not officially recognized by the CQI or SCA.

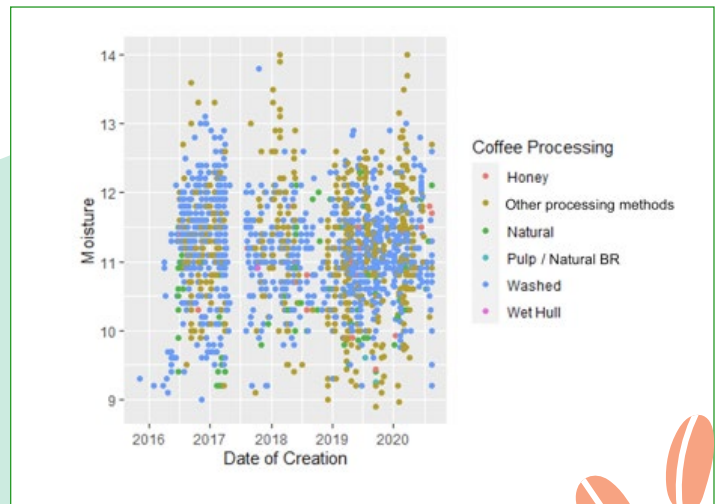
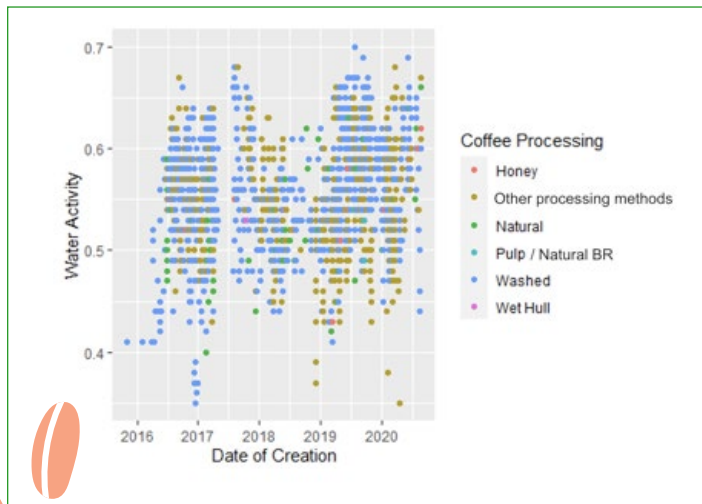




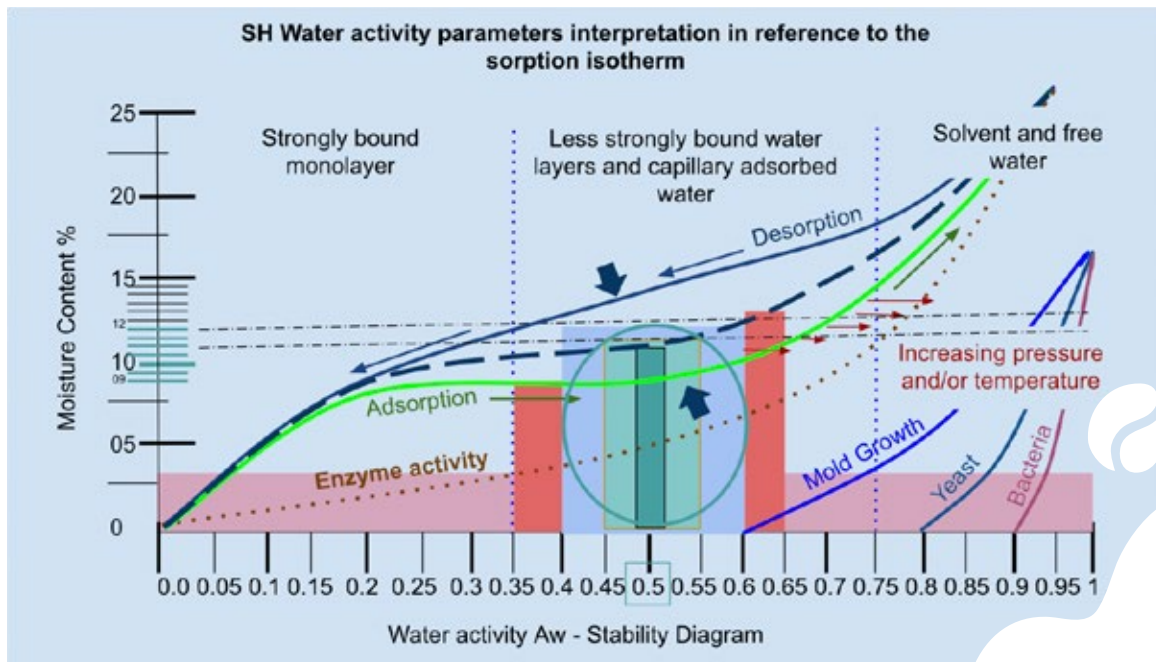
All samples fell within a range of 0.35 and 0.70 A_w .

Currently, the allowable upper limit for water activity for a coffee to be considered as “specialty grade” per SCA guidelines is 0.70 A_w .

Based on our sample data, a water activity of 0.70 A_w will reliably correlate to a moisture content much higher than 12%; 12% tends to be on the lower end of the range of moisture content associated with a water activity of 0.70 A_w . While current research has not ruled out the possibility of a coffee having high water activity but low moisture content, or vice versa, it is extremely unlikely. Such a coffee would also more than likely not have a consistent and stable reading of either water activity or moisture content over time (especially when considering storage conditions).



Based on our results, we believe that 0.70 Aw is too high of a water activity for specialty coffee in essentially every instance. Coffees with that high of a water activity are much more prone to mold growth, rapid degradation, and a reduced shelf life.



This is a stability diagram of water activity from our data in the sorption isotherm taken from the Journal of Food Protection, Vol. 46, No.2, Pages 129-134 (February 1983).⁵

The water activity ranges and their related areas of risk are illustrated thusly:

- 0.0 - 0.35 Aw / 0.65 - 1.0 Aw:** These ranges are dangerous. 0.0 - 0.35 Aw: The very low water activity in the bean exposes it to more oxygen, generating lipid oxidation. 0.65 - 1.0 Aw: The high water activity can lead to seed instability, enzymatic activity, growth of mold, toxins, yeast, and bacteria.
- 0.35 - 0.40 Aw / 0.60 - 0.65 Aw:** Several attributes of coffees in this range are at risk of being affected, including sensory quality, development of flavor, and the shelf life of the bean.
- 0.40 - 0.60 Aw:** The blue zone represents the range where we have found the best stability of the seed.
- 0.45 - 0.55 Aw:** All coffees within this range had greater stability; their physical and sensory deterioration only occurred after one year of storage, as long as storage conditions were adequate.
- 0.50 Aw:** Coffees at this water activity preserved their physical and sensory qualities even after 18 months of storage, as long as storage conditions were adequate. This is the most stable point for achieving a long shelf life of green coffee.

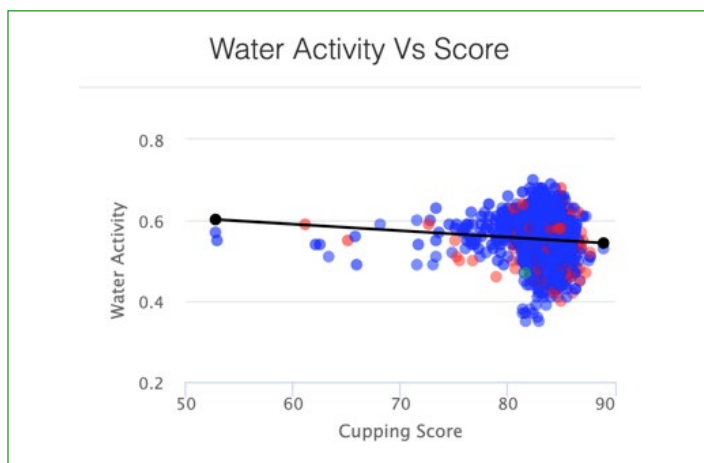
⁵ Methods to Measure Water Activity. John Troller. Water Activity Concept and Its Role in Food Preservation Sandulachi, E.



Water Activity and Cup Score

As the graph at right shows, water activity and moisture content alone are not reliable predictors of cup score, given that many other factors are at play when it comes to evaluating a coffee's sensory qualities. It is quite possible for a coffee to have good measures of both water activity and moisture content, yet score poorly, or have less than ideal measurements but score highly.

What we have found, however, is that coffees outside of the 0.40 - 0.60 range for water activity are more likely to drop in score over time, and that the chances of cup score decreasing increase as water activity increases. A coffee with high water activity could potentially cup well, but that score will most likely drop in a short period of time.



Water Activity and Green Coffee Shelf Life

We can safely say that higher water activity in a coffee will, in most cases, result in a shortened shelf life for that coffee and will most likely result in a drop in cup score. Coffees with high water activity are also at an increased risk of developing mold.

Coffee is hygroscopic, meaning that it tends to absorb and hold onto moisture from the surrounding air. Coffees with readings above 0.60 Aw are more likely to absorb even more moisture from the air than coffees with lower water activity, resulting in:

- Rapid physical deterioration, such as bean discoloration (bean whitening)
- Development of off flavors and defects such as phenol
- Loss of sensory qualities, i.e., muted flavors and aromas
- Potential generation of mycotoxins during storage, particularly ochratoxin A.

These issues can be exacerbated if storage conditions are not optimal—i.e., if warehouse conditions are too humid, temperatures are too high, or there are large changes in warehouse temperature and humidity.

Coffees initially warehoused at a lower water activity and moisture content tend to be more stable during storage. This practice also allows for any fluctuations that do occur to be less of a concern, as any moisture that is gained or lost by the coffee during storage is less likely to be a significant amount and will still allow for the coffee to maintain acceptable parameters.

Under good storage conditions, the coffees that best maintained consistent quality in their physical and sensory characteristics over a longer period of time were coffees in a range of:

- a) Moisture content between 10.5 and 11.5% (within the ideal moisture content range of 10 to 12%).
- b) Water activity between 0.45 and 0.55 (within the ideal range of 0.4 to 0.6 Aw).

The best-performing coffees, however, fell between 0.45 and 0.55 Aw, which correlates to the ideal range of moisture content (10.5 to 11.5%). These coffees maintained quality well past eight months, the point at which other coffees that fell outside of that range began to show signs of age and degradation.





Conclusion and Takeaways

To summarize, we believe that a moisture content range of 10.5-11.5% is ideal for all coffees. Coffees that measure within this range will most likely relate to a water activity between 0.45 to 0.55 Aw; under good storage conditions, these coffees will have the best chance at maintaining quality over longer periods of time.

We reiterate that while this correlation between water activity and moisture content may not always be the case, it is a reliable enough relationship to be useful in the vast majority of instances, especially when referencing these parameters. A coffee with a moisture content of 11%, for example, will almost certainly have an ideal water activity. A coffee with a

moisture content of 12%, however, may or may not have an ideal water activity, and, in fact, has a greater chance of having a water activity that is too high, leading to reduced shelf life and greater possibility of mold and toxin development. In most cases, a moisture content at or greater than 12% will almost certainly not have an acceptable water activity.

At the beginning of this study, we identified a number of questions that guided our research. While we believe more investigation is needed, below are a few insights into the behavior of water activity and green coffee that we are confident in.

Water activity is not a useful predictor of cup score. In our findings, we could not draw a relationship between higher and lower water activity as a general indicator of better or poorer cup scores. We did, however, observe a trend where coffees with higher water activity tended to drop in score sooner and more rapidly, as well as presenting visual physical deterioration in the beans.

Water activity can be a predictor of coffee shelf life and stability. Coffees with a water activity measuring at the upper end of the range can be expected to degrade faster than those at the lower end. If not stored properly, this degradation process will be accelerated.

What does this mean for producers? At this time, we do not recommend imposing the measurement of water activity at the producer level. Doing so would only serve to unnecessarily complicate an already complex, laborious process, and would not substantially aid producers to improve their drying or processing practices. Producers should focus their efforts and resources on improving drying and processing techniques to guarantee the stability of the seed and coffees without the risk of ochratoxin A. The drying stage is very important to having a stable water activity.

What does this mean for buyers? If your coffee is between 10.5 and 11.5% moisture content, and it is being properly warehoused, you should be assured that coffee quality will be preserved for at least eight months and likely well beyond. It does not mean that coffees that are not in this range cannot last or cannot be used for storage; it only means that coffees that are not in this range may be more susceptible to rapid deterioration and that you should prioritize these coffees to avoid that happening.



Yimara Martinez Agudelo

Quality Control Specialist at Sustainable Harvest

Q Arabica Grader / QP3 - Q Processing Expert

CQI Q Processing Instructor, Generalist and Professional

Equipment Used for Data Collection



Model 920C Portable
Moisture Testing Package

Moisture meter

Shore Model 920C Portable

Moisture Tester Package

The Shore Model 920C provides quick, accurate moisture results for a large variety of commodities. Results are displayed directly, without the need for moisture or temperature conversion tables.

The moisture content of each sample was taken as an average of three measurements, with 250 g per sample evaluated.



Water activity meter

Pawkit Water Activity Meter Decagon Devices, Inc.

Capacitance sensor limits accuracy to ± 0.02 Aw.

Sample taking:

The general sample received is homogenized.

A portion of the sample is taken and placed in a measuring cup.

The sample taken remains below the midline of the measuring cup.

Once the measuring cup with the sample portion is ready, a reading is taken.

Each measurement takes 5 minutes to complete the reading. The readings are taken once for each sample.

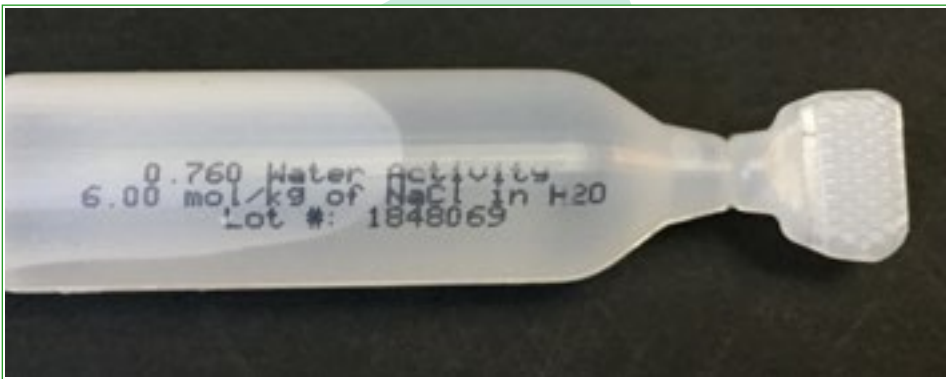
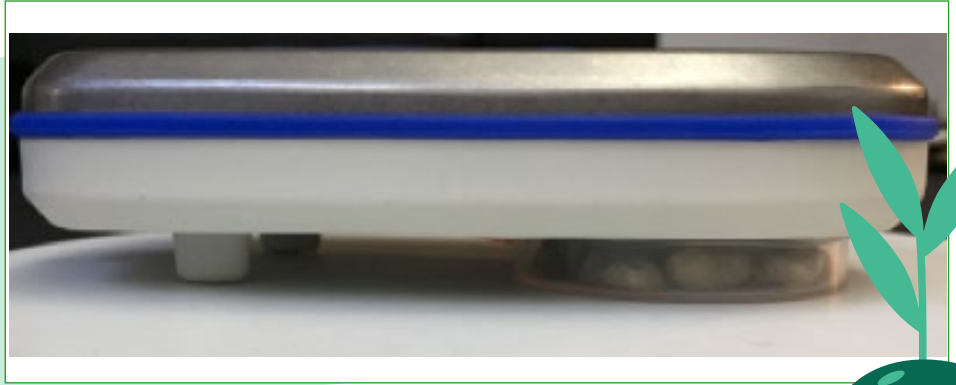
Periodically standardized and calibrated equipment—for coffee in our QC, we standardized with:

The standard solution is 0.760 Aw; 6.00mol/kg of NaCl in H₂O.

When the standard reading is not at 0.760 Aw or within ± 0.02 , we send the equipment to be calibrated.

For these evaluations, the ambient lab temperature was always between 20°C to 24°C.

All of these samples are a combination of the pre-shipment samples, offers, landed/ arrived, and controlled inventory in the warehouse at our main laboratory in Portland, OR.



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