Green Coffee Analytics IV - Density
By Chris Kornman

An undervalued, understudied coefficient in our series about analyzing green coffee (Part I - Moisture and Water Activity, Part II - Screen Size, Part III - Visual Defects) is density. The fact of the matter is that we don't have a complete understanding of the myriad factors influencing green coffee density (elevation, cultivar, nutrients) or its varied effects on quality. There are a few things worth discussing, however, including the methods used to sort and measure density, and the observable effects on the quality of the cup, the style of roast, and the implications for trade.

Definition

Very briefly, density is a measurement of the amount of something (coffee, in our case) that can fit in a given 3-dimensional space, mathematically expressed as mass divided by volume. In a perfect environment, for example, 1.0 g of water fills exactly 1.0 mL (or 1.0 cubic centimeter) of space, meaning that the density of water is 1.0 gram per milliliter. (This is one of the things I love about metric measurements. The straightforwardness of fact that two separate measurements - mass and volume of water - are interchangeable for practical purposes makes calculations and comparisons easy.)

As far as written expression, the scientific community is fond of observing density in terms of lbs/ft³ (pounds per cubic foot) or kg/m³ (kilograms per cubic meter), though really any weight measurement divided by any volumetric measurement is acceptable. I've defaulted in most cases to g/mL.

Measurement Methods

There are a number of ways to measure density; the simplest is to use a graduated cylinder. This method determines “freely settled” density, also referred to as “free-flow” or “bulk density.” Simply fill coffee up to a line denoting a particular volume, weigh the coffee, and divide the weight by the volume. The International Organization for Standardization (ISO) has recommended this...
method for whole bean green and roasted coffee, likely because it corresponds readily to real-world-scenarios: coffee freely settles into jute bags or retail packages.

Using this method, one can obtain measurements of coffee that are distinct enough for analysis: I know that when I measure a coffee at 0.64 g/mL it's relatively low density, while my measurements of 0.66 g/mL are fairly average and anything above 0.68 g/mL I consider pretty dense. The margin of error is fairly slim, but I've been able to reproduce results by performing multiple readings and maintaining consistent methods.

You can actually do this using any vessel. Simply measure the amount of water it takes to fill it up to the top, then measure the weight of coffee it takes to fill that same vessel up, and divide weight of coffee by volume of water. Note: this gets complicated if you prefer English measurement units, as volumes in liquid ounces and gallons don't correspond so readily to weights in pounds and ounces. So, either use this converter, or do yourself a favor and switch to metric.

Freely settled density readings are easy enough, but there's an anomaly with the numbers: green coffee sinks in water. This means that the actual density of green coffee must, by definition, be greater than water, which has equal mass to volume ratio, thus a density of 1.0 g/mL. This fact doesn't correspond to the measurements we've been talking about above, because of the small amounts of space between the beans in a cylinder. We must use a different method to determine the actual density of coffee.

A low cost way to very accurately measure true density, as discovered by Archimedes, is displacement. By adding a known weight of green coffee to a volume of water, and observing the change in water volume (the displacement) one can ascertain the actual volume of coffee. Divide the coffee's original weight by its actual volume, and you'll find that its true density is well over 1 g/mL. Eureka!

I took measurements of two very different coffees: a fairly dense washed Ethiopia, and a
fairly low density wet-hulled Sumatra. Check out the differences I measured via different methods.

<table>
<thead>
<tr>
<th>Coffee:</th>
<th>Freely Settled</th>
<th>Freely Settled Avg</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freely Settled 1</td>
<td>Freely Settled 2</td>
<td>Freely Settled 3</td>
</tr>
<tr>
<td>Washed Ethiopia Yirgacheffe Grade 1</td>
<td>0.685</td>
<td>0.678</td>
<td>0.678</td>
</tr>
<tr>
<td>Wet-hulled Sumatra Ketiara</td>
<td>0.641</td>
<td>0.631</td>
<td>0.652</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Displacement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee mass</td>
<td>Water Volume added</td>
</tr>
<tr>
<td>25g</td>
<td>28.6 mL</td>
</tr>
<tr>
<td>25g</td>
<td>26.5 mL</td>
</tr>
</tbody>
</table>

While adding water helped accurately assess true density, it isn't really a great storage method for coffee and you'll have to be willing to sacrifice some green. In terms of absolutes and theoreticals, displacement is more accurate, but in terms of real-world behavior free settling is more appropriate.

The point to take away from all this is that if you're consistent with your methods, you should be able to observe data that are meaningful, regardless of whether you are freely settling or displacing.

**Sorting by Density Prior to Export**
Before coffee is exported, it will nearly always undergo density sorting at least once at the dry mill. However, in many cases parchment and even cherry density sorting may take place. So let’s start from the beginning.

In some countries (particularly places like Rwanda and Burundi who continue to struggle with eliminating potato defect) coffees can be separated by density before pulping at locations especially concerned with high quality. Farmers bringing their day’s harvest of coffee cherries will simply drop their cherries in a net, then lower them into a bucket or tank of water. Any floaters are removed, and all the dense coffee is sold to the washing station for processing. This is a relatively effective method of sorting out floaters and other damaged coffee before depulping.
For fully washed coffees, density sorting happens again after fermentation. Moving depulped coffee parchment through narrow channels of flowing water, coffee that floats (usually hollow seeds) can be separated from the higher grade parchment that sinks. In many cases, three quality
tiers can be delineated by this process, and the slowest, heaviest, densest coffees tend to taste the best and sell for the highest price.

However, even coffees that are not washed will be sorted by density at the dry mill. Using vibrating tables with grooved surfaces set at a slight angle, low density material (like broken seeds, hollow shells, dry parchment, and even foreign objects) can be removed. While fickle, a properly calibrated density table can sort down to a preset number of defects in many cases. Conversely, poorly calibrated tables can lead to excessive defect counts, low cup quality, and/or roasting difficulties.

Common Trends

While there are plenty of exceptions, density often varies from place to place in predictable ways. East African coffees, particularly those from Ethiopia and Kenya, tend to register very high on the density spectrum, as do coffees from Colombia and (as I’ve noticed in recent analyses) coffees from the Catracha Project. Conversely, coffees from Sumatra and Brazil tend to generally be pretty low density by comparison. High elevations and smaller screen sizes tend to be denser than larger ones (with plenty of exceptions), washed Centrals trend towards the middle, Natural coffees are often less dense than their washed counterparts, and contrary to popular opinion wetter coffees are less dense than dry ones (we’ll examine this allegation in detail below).

Financial Significance

It’s not hard to infer from the sorting techniques employed postharvest that a coffee’s density matters. The implications are interrelated with its quality in the cup and its value on the market. Let’s talk finances first.

Remember that grade school riddle? Which is heavier: a pound of feathers or a pound of lead? The answer of course is that they weigh exactly the same… a pound. It’s the density that’s different: a pound of lead is significantly denser, taking up less space. Likewise, a 60 kg bag of low density coffee weighs exactly the same as a 60 kg bag of high density coffee. The difference is that it takes more low-density coffee beans, and more space, to equal 60 kgs.

Consequently, high density coffee is more valuable. In any given space, dense coffee outweighs low density. Each high density coffee bean that is picked, processed, and sorted is more valuable because it weighs more and/or takes up less space than one of low density. Want to see the math? Let’s use our Sumatra vs. Ethiopia example from above again.
(Note: I’ve used freely-settled figures to get practical numbers, and converted to slightly larger units for efficiency: 1.0 g/mL = 1.0 kg/L. I’ve rounded down to 0.68 kg/L for the Ethiopia and 0.64 for the Sumatra.)

To fill a 60 kg bag with the Ethiopian coffee at 0.68 kg/L will require a volume of 88.2 liters. To fill the same weight with the lower density Sumatra at 0.64 kg/L, you would need 93.8 liters of space. That’s 6.3% more of the Sumatran coffee to fill a 60 kg bag!

In this scenario, the Sumatran farmers have to pick 6.3% more coffee cherries. Because the Sumatran coffee in our example takes up 6.3% more space, it could be more expensive to ship if a given container maxes out on space before hitting its weight limit. Low density coffees tend to lose a higher percentage of their weight during roasting, meaning they are also less cost effective for a roaster. If the two coffees were selling from origin at say $3.50 per pound, that’s means the Ethiopian coffee is about $0.20/lb. more valuable. The Sumatran coffee is down more than $8,500 on a 300 bag container in potentially lost profit FOB, simply due to 0.04 kg/L difference in density.

Crazy, right? Lower density coffee, across the entire supply chain, is less cost effective.

Here’s another revelation I stumbled on, but you might have already guessed it: sometimes, coffee producers and exporters are accused of shipping wetter coffee, the line of thinking is that “because it’s full of water it weighs more and is more valuable.” But remember how we discussed that using displacement, coffee is actually denser than water? This means, cup quality notwithstanding, there is negligible value added by shipping wetter coffee. Higher water content in green coffee equals lower density.

To demonstrate, I surveyed 50 recent Crown Analyses. A trend emerged, demonstrated below. As density increases (left to right), moisture decreases (top to bottom), to the tune of about 1% for every 0.04 g/mL, freely settled.
When I was crunching these numbers, I remembered I had coffee left over from our temperature tracking experiment. The same coffee, in two packaging types, arrived with different total moisture content, so I could test this theory on an actual coffee.

It had been a few months since the last moisture measurement, but sure enough the GrainPro packed sample read 11.4% while the jute sample was higher at 12.1%. Over four freely settled measurements and two small displacement measurements per coffee, the drier GrainPro coffee was denser (0.673 g/mL freely settled, 1.19 g/mL via displacement) than the wetter jute coffee (0.659 g/mL, 1.16 g/mL).

This was just one quick experiment, but having the same coffee preserved at two different moisture readings at my disposal gave
me some confidence reiterating that yes, drier coffee is denser, because its makeup is a higher ratio of coffee to water. Wetter coffee will lose a higher percentage of its weight during storage and roasting, as well, further decreasing its value.

**Qualitative Significance**

I have no more numbers to show you; I don’t have especially solid research on the area of density as it relates directly to sensory quality. But based on a little experience, I think we can anecdotally share some observations about what density means in the roasting machine and in the cup.

In the past few months as we’ve been putting coffees through our Crown Analyses, Jen Apodaca and I have noticed that dense coffees respond uniquely in the roaster to heat application. Regardless of moisture content, the densest coffees have a similar activity during late-stage Maillard reactions and the entrance to first crack: they lose momentum. Coffees with high density tend to stall out, and require extra heat energy to avoid exothermic reactions that will bake the coffee and flatten the flavor profile (here’s a good example of this phenomenon in a recent Crown Jewel analysis).

In response, Jen & I take very similar approaches to addressing this phenomenon. First, we tend to charge with a hot drum temperature, but a low flame. This means the retained heat in the roaster is quite high, but the lower heat application initially allows the coffee to achieve equilibrium with the drum a little more slowly, which helps to avoid overheating the exterior of the bean before the heat can penetrate the dense interior.

Secondly, we tend to ramp up heat after the color begins to change. Whether via a single adjustment or many, the idea is to maintain, or if necessary increase the momentum of the coffee as it approaches first crack, making sure there’s enough retained interior heat to power through and avoid flatlining temperatures as hot water vapor is released from the seeds as they pop. Jen is quick to caution that too much heat
application during this time is also dangerous, and can result in scorching, so care must be taken to navigate a tricky middle ground during this ultra-sensitive roasting phase.

Whether or not to back down from heat applications during first crack depends largely on the effectiveness of the two steps above. Sometimes the densest coffees simply need all the heat they can get during the initial seconds of first crack to prevent baking; sometimes they only require the bare minimum of added momentum and will quickly resume heat absorption.

What this means in terms of flavor is far more general, but because the sugars and acids in dense coffees are more protected from sudden changes in temperature during roasting, they might be better preserved in the roasted product. I tend to find that the densest coffees have brighter, more complex acids and rawer, more sucrose like sugar flavors than less dense counterparts. This is, of course, a very broad stroke of the brush, and shouldn't be taken as a hard and fast rule. It's also worth noting that coffees of low density due to higher moisture content tend to lose that moisture over time. This evaporation results in loss of weight, and also loss of cup quality related directly to vapor migration.

The point is this: density absolutely affects coffee across the entire supply chain. It is worth measuring and understanding whether you are a producer, a roaster, or anyone in between.