Alchemy in the Roasting Lab

Discovering Organic Acids { Part 1 of 2 }

BY JOSEPH A. RIVERA

MENTION THE WORD "ALCHEMY" and most people will automatically think of long-bearded Medieval men mixing magical potions in their never-ending quest to convert lead to gold. Although the fruits of the early alchemists were never actually realized, the quest to instill greater value into something as common as lead continues to fascinates us.

Roasters are no different. Who else, on a daily basis, converts ordinary green beans into something consisting of more than one thousand complex compounds and an aroma "as sweet as honey?"

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But the idea of turning lead into gold is not so far-fetched, since, according to the First Law of Thermodynamics, *"matter is neither created nor destroyed, but simply changes form."* In this article, we'll explore the basics of coffee chemistry and discover some of the wonderful magic that occurs within those tiny beans and in the laboratories of thousands of roasters every day.

Raw Materials

Coffee plants, much like humans, produce hundreds of byproducts through their metabolic life, each terminating in the formation of organic acids and other intermediate compounds. (In layman's terms, "organic acids" are any acids that contain a carbon in their molecular structure.)

Coffee plants, via the Calvin cycle, produce more than a dozen different acid intermediates, all of which remain locked inside the bean at harvest. Variables such as genetics, varietals and species ultimately determine the sugar production that is "locked inside" the beans. For example, the species *Coffea arabica* contains almost twice the concentration of sucrose as its *Coffea robusta* counterpart. As we'll discuss later, these sugars play a critical role to the development of acidity in the cup. Sugars, being heat-labile, decompose during the roasting process to create more than 30 organic acids and hundreds of volatile compounds.

Though genetics play a key role in what sugars are ultimately produced, it would be premature to conclude that this is the only variable that affects quality. To fully explore the magic that occurs in the bean, one must look at altitude and microclimate, yet another example of the classic nature vs. nurture paradox.

On the physical level, altitude has the effect of increasing both bean size and bean density. With the help of a screen sorter, you can quickly confirm this, such that many countries rate coffee quality based on screen size. The effect makes sense, since at cooler temperatures reactions rates decrease and the plant effectively has more *"time"* to pack nutrients and sugars into the beans.

Altitude also has the effect of changing not only physical parameters, but of altering chemical composition as well. At higher altitudes we tend to produce coffees higher in perceived acidity. Such that for every 100 meters gained in altitude we can expect a 0.60° C drop in temperature, and for every 300 meters, a 10 percent increase sugar production, namely sucrose. What does all this mean? Higher acidity!

But the puzzle doesn't end here. For if altitude

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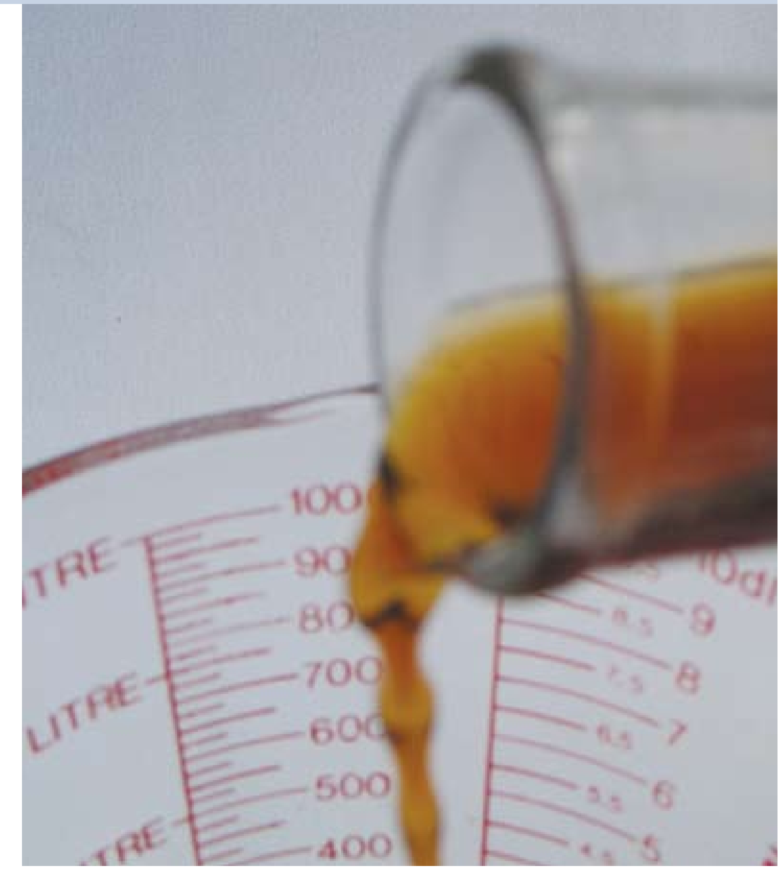

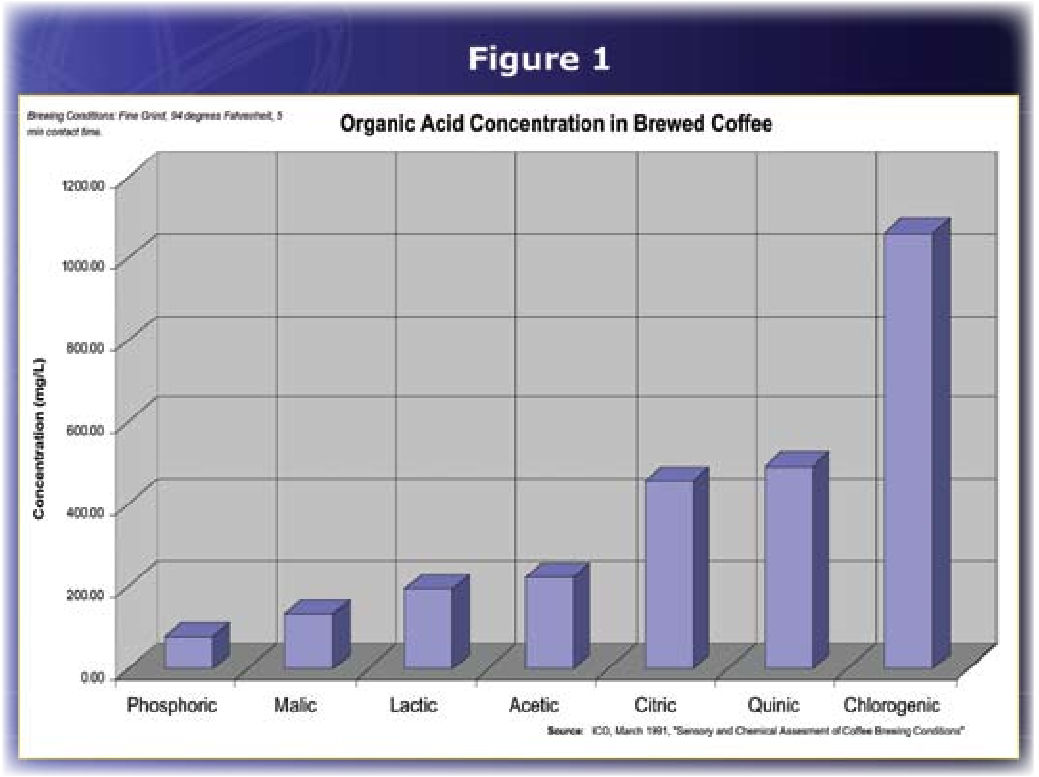

determines *how much* acidity is produced, then regional humidity determines the *type* of acid produced. It is not just how much acid is produced, but what type, that effectively defines the acidity profile of a certain coffee. This is easy to see when cupping any one of the seven regional coffees in Guatemala. Anyone who has ever cupped an Antigua or Huhuetenango alongside a Coban can attest to a pronounced difference. To those not familiar with Coban, it is one of the most humid regions in Guatemala, at times resembling a rainforest. In the cup, many would say the Coban cups with a delicate fruitiness or wineyness as compared to the other regions in Guatemala. As it turns out, the regional humidity has the effect of increasing the "fruity acids" in the bean, much like the fruitiness of chardonnay wines. This would suggest that humidity increases the level of malic acid, though I have not seen published studies on this.

For countries that lack the topographical elevation necessary to maximize the beans' potential, shade plays an ever-important role. For what is not achieved through altitude can be made up, within reasonable limits, by proper shading. The goal is to slow down the metabolic rate of the plant, increase sugar production and, ultimately, improve cup quality.

Although there are more than one thousand compounds produced during roasting, by far the most important when dealing with cup profile are the organic acids. As we embark on this brief journey, we'll explore the science behind the scenes.

Let's begin the journey…

Chlorogenic Acids (CGA)

No explanation of organic acids would be complete without a thorough discussion of chlorogenic acids (CGA). As seen from Figure 1, CGA accounts for the majority of the organic acid concentration in coffee, accounting for six to seven percent for arabica and up to 10 percent in robusta on a dry basis. Although it may not appear to be much, the relative content of CGA compared to that of caffeine is seven to eight times higher. And in a typical eight-ounce cup of coffee, CGA represents roughly two ounces, or an estimated 30 percent by volume.

During roasting, CGA plays an important role in the development of coffee flavors. Almost half of the CGA content is decomposed in a medium roast, whereas French roasts can exhibit up to an 80 percent loss. The portion that does decompose is used in the production of quinic acid and flavor precursors.

It should be mentioned that chlorogenic acid does not refer to a single compound, but rather a family of more than six different isomers of the acids, each with different flavor attributes. Without getting too technical, there are basically two families of these acids; mono-caffeoyl and di-caffeoyl. While mono-caffeoyl acids readily decompose during roasting, those of the di-caffeoyl family remain almost unchanged and have been reported to impart a metallic-bitter taste. It's no surprise then that robustas, which exhibit a similar metallic taste, contain a larger concentration of these acids than their arabica counterparts. It has even been suggested that due to their undesirable taste, CGAs have effectively been used by plants for protection from animal and insect infestation. Perhaps those pesty bugs do know a thing or two about specialty-grade coffee!

At just past the second crack, these di-caffeoyl acids decompose and the metallic-bitter taste slowly diminishes, though a few savvy chemists at soluble factories have effectively been able to slightly alter the levels of these acids through steam treatment of lower quality green beans. Who would have ever thought of such a thing? I guess necessity is truly the mother of invention.

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Decomposition of CGA leads to the production of two very important components. As seen in Figure 2, the decomposition of CGA causes a steady increase in caffeic and quinic acid, both of which are classified as phenolic compounds. Such compounds are often astringent in nature, thus darker roasts tend to produce coffees higher in astringency and body. The same principle is seen when we compare the body and astringency of a red wine, such as a cabernet, to that of a chardonnay. As a rule of thumb, any naturally occurring substance that exhibits color will always contain a large concentration of chromophores, a class of colored phenolic compounds.

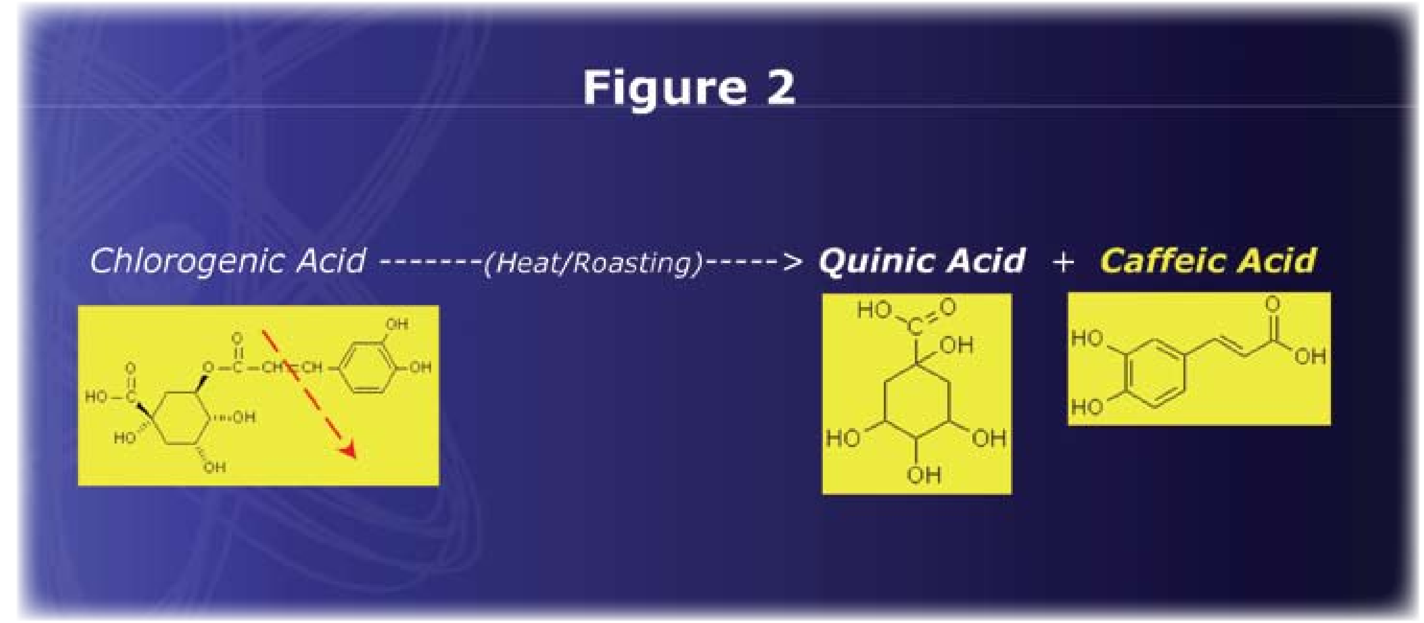
Recently, CGA has also been suggested as the main culprit for people suffering from acid reflux. It's been estimated that as little as 200 mg. of CGA can increase levels of HCl in the stomach. A typical cup of coffee yields anywhere between 15 and 325 mg. of CGA, well within the suggested range. Those drinking decaffeinated do benefit, as the decaffeination process results in a slight decrease of CGA content. But it should be noted that the initial increase in stomach acidity is due solely to CGA and not caffeine as many are lead to believe.

CGAs: Quinic and Caffeic

Before the first crack, CGA continues to decompose, while quinic acid progressively increases in concentration. Being a phenolic compound, quinic acid also proportionally increases body and astringency and forms colored compounds, namely *melanoidins*.

Interestingly, increases in quinic acid concentration have been documented in cases where green coffee is stored for an extended period of time in warehouses, at times up to 1.5 percent dry basis. Luckily, one does not need to wait months to see the immediate affects on acidity, as it can be demonstrated in any cupping lab. As most of us have experienced while cupping, the longer we leave out a coffee liqueur while cooling, the greater its perceived acidity. Why this happens is only one part of the fascinating chemistry that occurs in our morning cup of joe.

At roast levels exceeding 6.5 percent dry basis—roughly cinnamon roast—we begin to see the formation of *quinide*, the same compound commonly found in tonic water. As this compound remains in the hot infusion, it slowly hydrolyzes back to quinic acid and serves to increase the level of perceived sourness. Thus, with dozens of reactions invisibly taking place in the cup, it truly makes cupping an extremely difficult time-dependent exercise. Away from the cupping lab, the effect is also seen when coffee has been left sitting on a heating element for an extended period of time. This is all too common during long road trips, when we're welcomed at the nearest highway coffee shop with sour coffee, and when we hear stories of unscrupulous coffee shop managers leaving their coffee on the heating pan for up to eight hours on end, only to serve it "fresh" to you. Unfortunately, there is no magic potion to prevent this reaction, and we're once again reminded of the importance of coffee freshness.



Another one of CGA's byproduct is caffeic acid. It is also a phenolic compound and one that will contribute slightly to cup astringency. Recently, caffeic acid has been documented to be a

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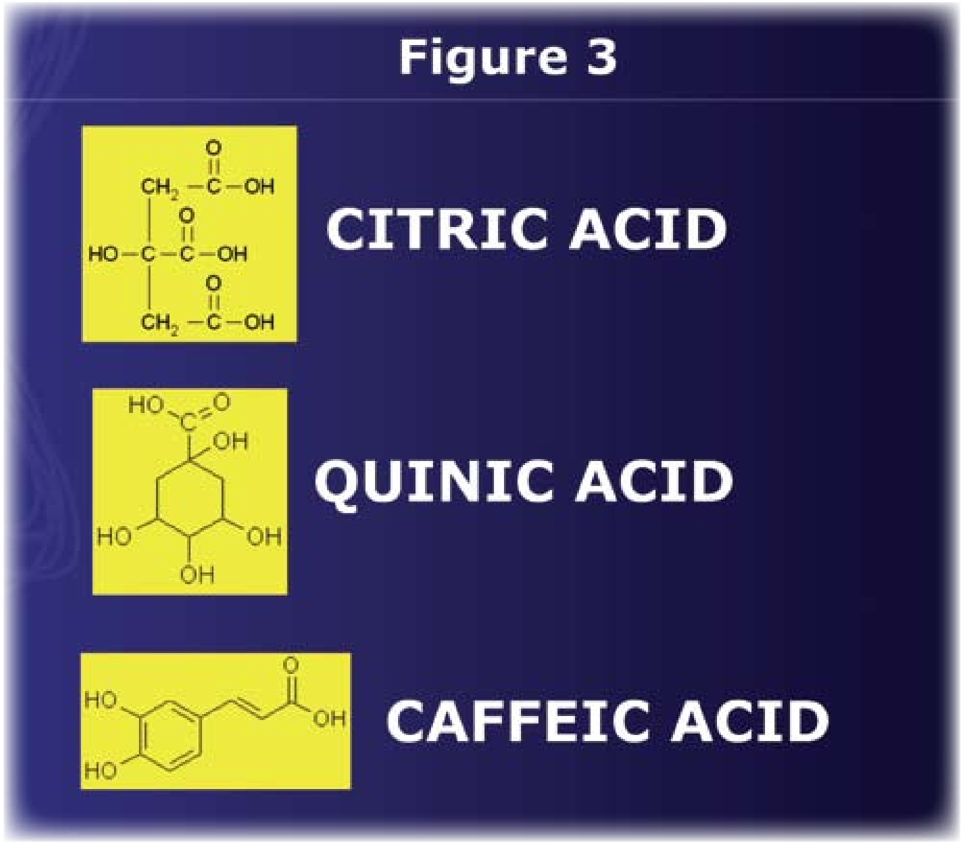

potent antioxidant and believed to prevent the onset of several human cancers.

Citric Acid

Second on our list is citric acid. Occurring naturally as part of the plant's metabolism, citric acid follows CGA in concentration levels. Unlike many other acids, citric acid is not produced during the roasting process, but it is slowly decomposed. At nine percent weight loss, we begin to see the concentration slowly diminish. A medium-roasted coffee will contain 50 percent less citric acid as compared to its green bean state. Citric acid's effect on perceived acidity is significant, as it is one of the major acids contributing to cup profile. However, citric acid is not an acid you would like to have in high concentrations, as most people describe its taste as acerbic and intensely sour. So intense is its characteristic sourness, that many candy manufacturers use it in the production of gelatin-based confections.

But one needs to look a little further to understand why this is so. Ever bitten into a unripe orange? Describe its taste? During early maturation, fruits tend to produce a large concentration of organic acids, but as maturation continues, these same acids are converted into sugars. Wait a couple days and that same unripe orange will taste significantly sweeter.

Any roaster who has ever received a shipment of green coffee only to find it cup sour has experienced this firsthand. Fortunately, roasters can use this bit of information to verify the quality of post-harvest separation at origin. Being a processed-controlled defect, poor separation of unripe beans will always elevate levels of this citric acid along with a corresponding sourness. So what should a roaster do if he's unable to return a sour lot of coffee? Quite simply… roast darker! This will drive off as much citric acid as possible.

While this article only offers a glimpse into the magic that occurs in the roasting lab, I hope it expanded your mind and introduced you to the wonderful world of chemistry that occurs within those tiny beans.

In Part 2, we'll look at the role of the rest of the important organic acids: acetic, malic and phosphoric acid. We'll discuss how these acids are formed, how they are affected by wet processing and how they ultimately change during roasting.

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