FLAVOR DEVELOPMENT

The Relationship Between Time and Color in Coffee Roasting

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ABOVE AND PRECEDING PAGE
Coffee roasted to various levels of color.
Photos courtesy of CoffeeMind

WORLDWIDE, CONSUMER DEMAND for high-quality coffee is surging. While total coffee consumption grows each year, the specialty coffee segment has undergone the largest share of growth. This increased demand is coupled with greater consumer awareness that the sensory experience of drinking coffee is a culmination of the many links and processes along the value chain. From plant genetics, *terroir* and processing methods to transportation, storage, roasting and brewing, as well as the social environment in which coffee is consumed, quality can be regarded as the overall sensory enjoyment of all these aspects combined.

In this article, we will focus on one of the main transformative processes in the value chain that impacts coffee quality: roasting. The magnitude of importance that some of the key roast control parameters have on the sensory properties of our resulting brew are critical to product differentiation in the global marketplace.

However, a systematic approach to roast modulation can fully guide us only if we support these experiments with an evidence-based approach to sensory evaluation. For this reason, we have decided to share our findings from an extensive, newly published research study we conducted with the help of the wider coffee community. The study focuses on the end color of a coffee after roasting to ensure consistency and quality when creating roast profiles.

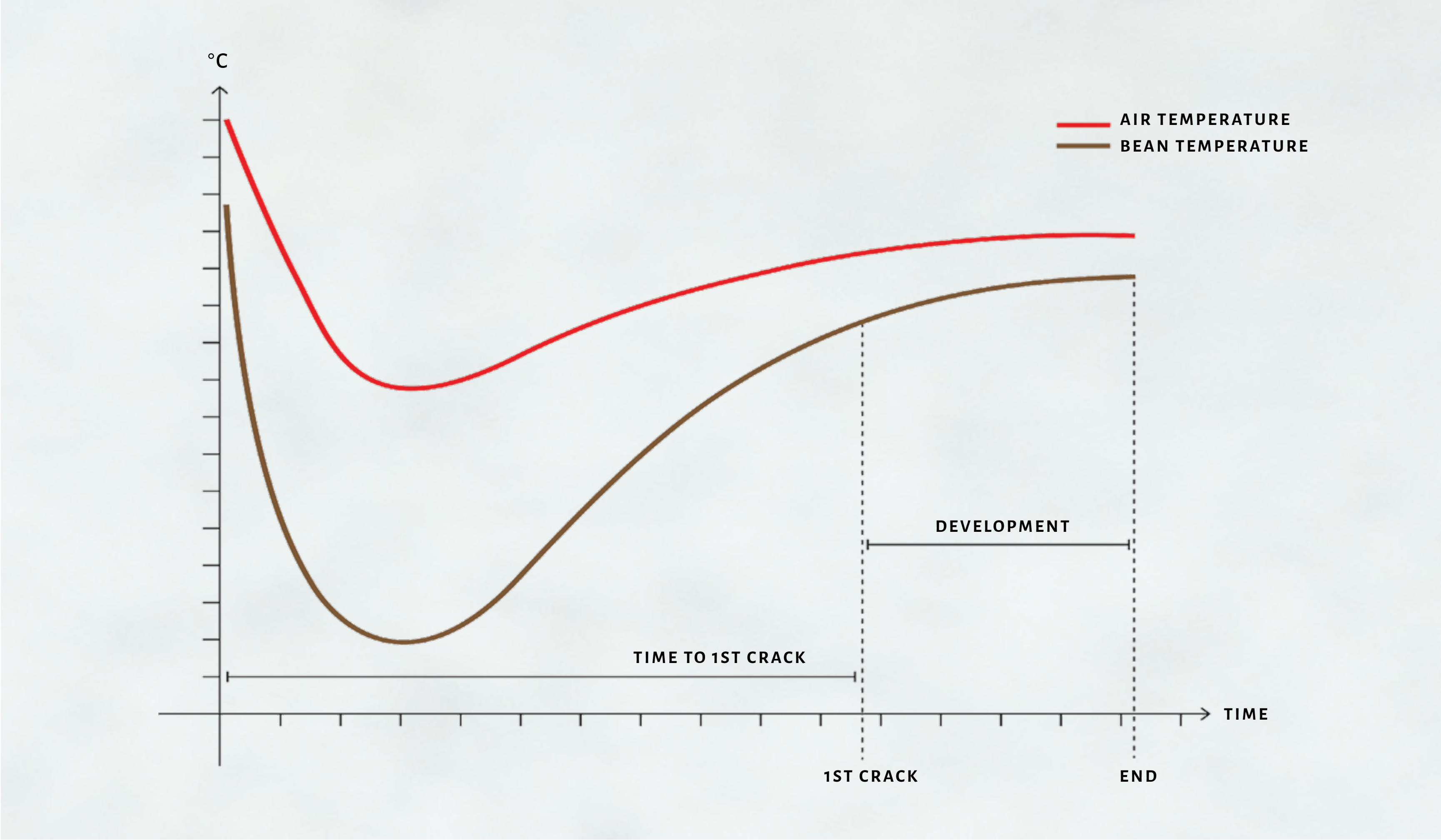
Broadly speaking, the difference in roasting styles between commercial and specialty coffee offers a fascinating glimpse into how the roasting community is still a long way from reaching consensus on the significance of certain roasting control parameters and which factors have the biggest impact on flavor. Of course, how these parameters are configured for each roaster reflects that machine's roast style—but knowing which variables to measure will allow for greater clarity in future research and education programs.

For example, much research has been done on the physical and chemical impacts of roast speed from high temperature short time (HTST) and low temperature long time (LTLT) experiments in the commercial coffee industry. On the other hand, specialty coffee roasters have put emphasis on the timing of the roast phases and an event during the roasting process known as "first crack." First crack occurs when the accumulated pressure inside the bean causes it to expel steam, along with other volatile aromatic compounds, making an audible "crack" in the roasting machine. This step heralds the onset of a phase that we refer to as "development time." This final phase can be considered as a measure of time that the coffee spends in the primary aroma-formation phase.

CONSENSUS ON TIME AND TEMPERATURE

The most widely accepted reference point in the worldwide roasting community seems to be the

GRAPH 1 *Theoretical model illustrating a temperature development over time for the roasting profiles and the major phases investigated in this research (e.g. time to first crack, development time).*



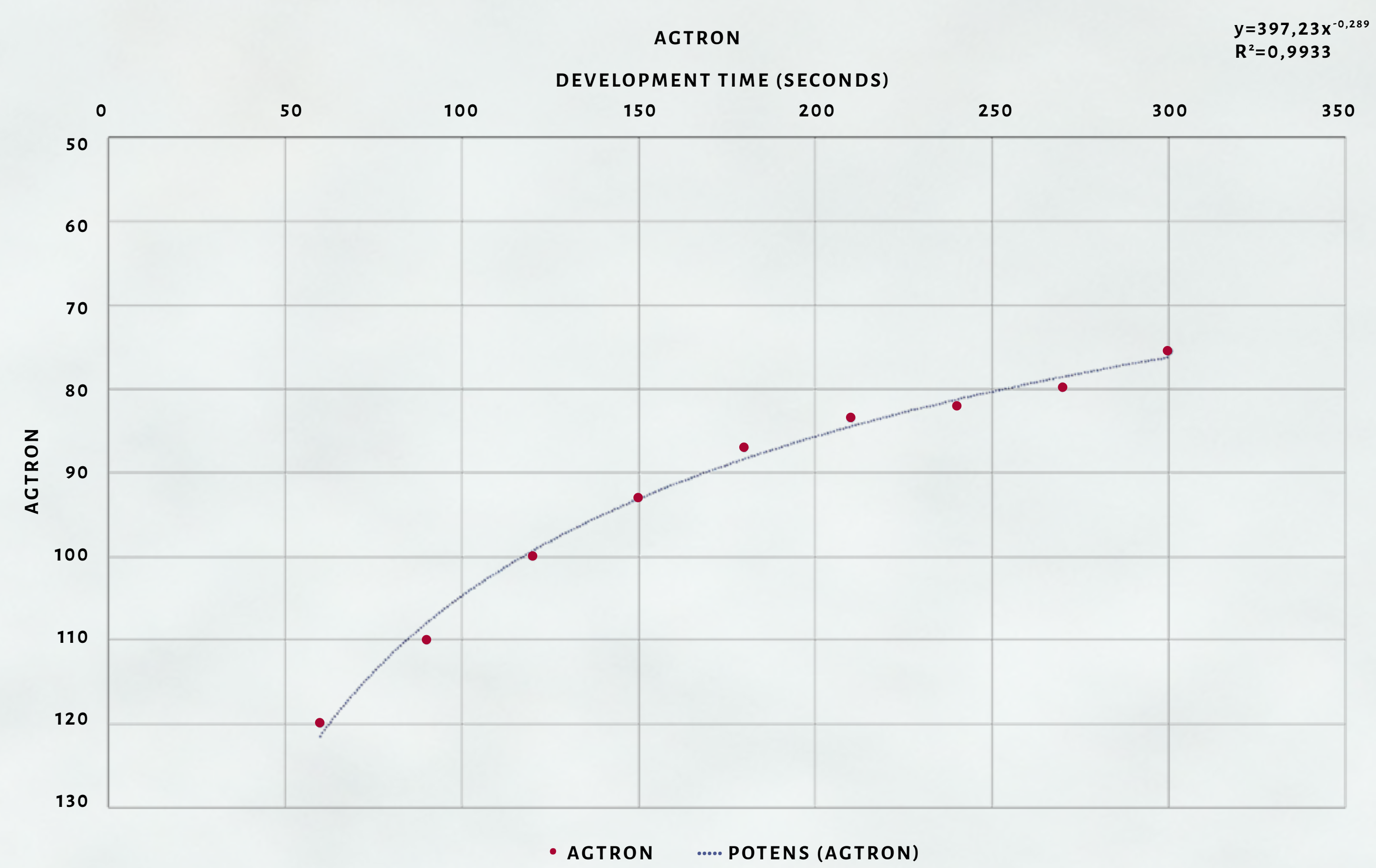
crucial relationship between time and temperature. This is, without doubt, a fundamental starting point for understanding the roast process. But it is also a point of departure from any common consensus when it comes to agreed control parameters regarding quality and consistency. Although roast color is still considered an important parameter in specialty coffee, there seem to be many conflicting opinions about the magnitude of its relevance as a diagnostic tool for quality control. In this context, generic labels such as "light," "medium" and "dark" roasts can be misleading because they are so vague. Indeed, the deeper our understanding of the complexities inherent in the roasting process at a chemical, physical and sensory level, the greater the likelihood of misinterpretation within the professional roasting community across cultures and continents. We need to start talking about roast degree in a more objective way.

POPULAR WISDOM VERSUS SCIENTIFIC STUDY

As partners in a coffee education and scientific research consultancy who deliver accredited courses on sensory and roasting for the Specialty Coffee Association (SCA), we encounter a great deal of confusion within the specialty coffee community when it comes to roast profiling and its impact on quality control. Competing opinions about roasting are often amplified in the global echo chamber of social media, which is both inevitable and perfectly understandable.

For this reason we partnered with the Department of Food Science at the University of Copenhagen and the SCA to investigate how different roasting conditions can crucially impact coffee flavor. We designed the research to encompass both commercial and specialty coffee markets—and the fuzzy "gray zone" in between. By freely sharing the research with the coffee roasting community, it is our hope that we can help establish solid ground in the heated debate about which roast control measures are of most importance for the sensory quality of the final roasted product.

By sharing some key findings from this research, we hope to reassure professional coffee roasters who are struggling to navigate the maze of conflicting quality control parameters. Far from downplaying the enormous contribution that a technical-driven approach to roast profiling has given to our collective understanding of coffee roasting in recent years, our objective is to distinguish which roast modulations can have the most impact in the cup from a sensory perspective. Fortunately, empirical



GRAPH 2
Samples roasted to a fixed end temperature but with differing development times. You can see the relationship between a longer development time and lower Agtron value (i.e. darker roast color).

scientific studies help to bring clarity to a world often blurred by complexity and popular opinion.

CONCEPT OF ROAST DEGREE

First, let's look at the concept of roast degree (i.e. color) in coffee. One can determine the roast degree either by eye or, preferably, by using a precise instrument such as a roast color spectrometer analyzer to objectively measure the degree of roast. Simply put, we will not deliver the same roasted product to our clients and customers if we do not achieve a consistent final roast degree. Although there may be some minor deviations due to changing environmental conditions in the roastery, deliveries to coffee shops or offices are at risk of being rejected if the final product is too far from standard expectations—sometimes with highly inconvenient and wasteful consequences for coffee roasting businesses.

Second, the concept of roast degree has a high correlation to end temperature. This means that end temperature can be used as a strong indicator of when to terminate the roast. However, we must assume that all other roast control parameters including charge temperature, airflow, energy input, batch size and ambient conditions such as relative humidity remain constant if we are to use this as a practical guide. Let's now consider that roast color is an effect of the non-enzymatic browning reactions that occur during the roasting process. These Maillard reactions are a result of molecules bumping into each other and setting off further chains of chemical reactions between the amino acids and sugars. During this process, new compounds such as melanoidins add color to the roasting coffee. Thus, the speed of these reactions increases with higher temperatures. This explains why temperature is a good estimate of color and is an indicator of how many browning reactions we can expect to occur—assuming that everything else remains constant.

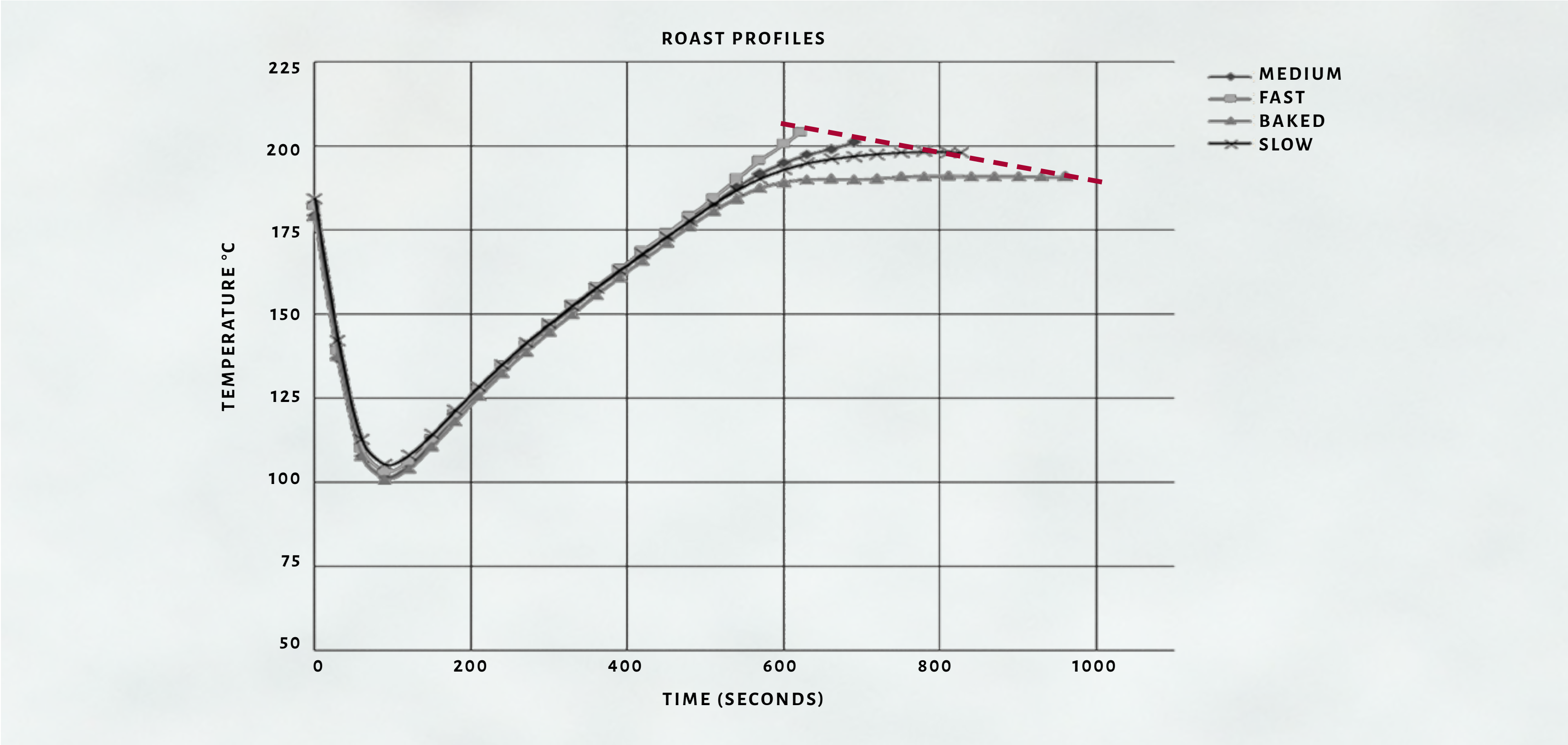
The other important factor that we need to consider is time. The more time we allow coffee to roast, the more we can expect chemical browning reactions to occur. To illustrate this, we roasted nine samples on an IKAWA roaster. Keeping the time to first crack the same, the samples were roasted to the same end temperature but with different development times ranging from one to three minutes. The roast degree was then measured using an Agtron Gourmet roast color spectrometer analyzer. Graph 2 on page 40 shows the effect that time has on color with a consistent, fixed end temperature.

We can conclude that temperature and time regulate the amount and speed of browning reactions during the coffee roasting process. This means that if we increase one parameter (e.g. time), we must decrease the other (e.g. temperature), or vice versa, to reach the same roast color.

Graph 3 on the opposite page is from one of our studies where roast color was kept the same with four consecutive roasts. The difference between the roast profiles was the time it took to reach that color after first crack. If we apply this principle, it is clear that as development time increases, the end temperature needs to be lowered in order to achieve the same end roast color.

The findings show that the roast degree of a coffee can be greatly impacted by large variations in time (ranging from 1 minute, 31 seconds to 6 minutes, 30 seconds in development time, or around a five-minute difference from fastest development time to slowest development time) or end temperature ("fast" was 205 degrees C/401 degrees F and "slow" was around 190 degrees C/374 degrees F, or a difference of 15 degrees C/27 degrees F between the slowest and the fastest sample). Introducing in-between batch roast protocols and being aware of the changing environment outside and inside the roaster will also help lower the deviations in time or temperature outcomes. Making necessary adjustments to help compensate for the changing environmental conditions throughout the day will further ensure a

GRAPH 3 *Overview of roast profiles included in the study. The red dotted line indicates the relationship between end temperature, time and the roast degree achieved. These examples illustrate roast profiles with increasingly longer development time (the time from first crack to target color).*



more consistent final roasted product. Taking precise roast color measurements into consideration as part of product development or quality control protocols is a major factor in meeting the high expectations of clients and customers in specialty coffee.

To illustrate this concept, you could try roasting with the same bean temperature for one day and measure the color of the coffee coming out. This way you can see whether the color of the final, roasted product shifts throughout the day, even if the bean temperature is kept the same. It might be an expensive experiment, but it would be the correct way to approach this from a scientific perspective. Another way to explore this concept would be to take a coffee requiring many batches for the day's roasting, and use your eyes to discharge the coffee at the same color each time—you'll notice how the bean temperature shifts throughout the day. This requires you to be consistent in making color decisions visually—an ability expected from a skilled roastmaster.

SENSORY IMPACT ON FLAVOR

Drawn from extensive qualitative sensory data gathered by CoffeeMind from across eight studies and totaling nearly 18,500 data points collected over six years, our research aims to better understand the relationship between the technical inputs in coffee roasting and the resulting sensory properties. Using descriptive sensory analysis, our investigation shows the relative importance of two key roasting parameters on the sensory properties of coffee: color and time. In fact, we found that roast degree accounted for more than 80 percent of the total variation in the sensory properties of coffee. Furthermore, we found that while both parameters significantly affected coffee

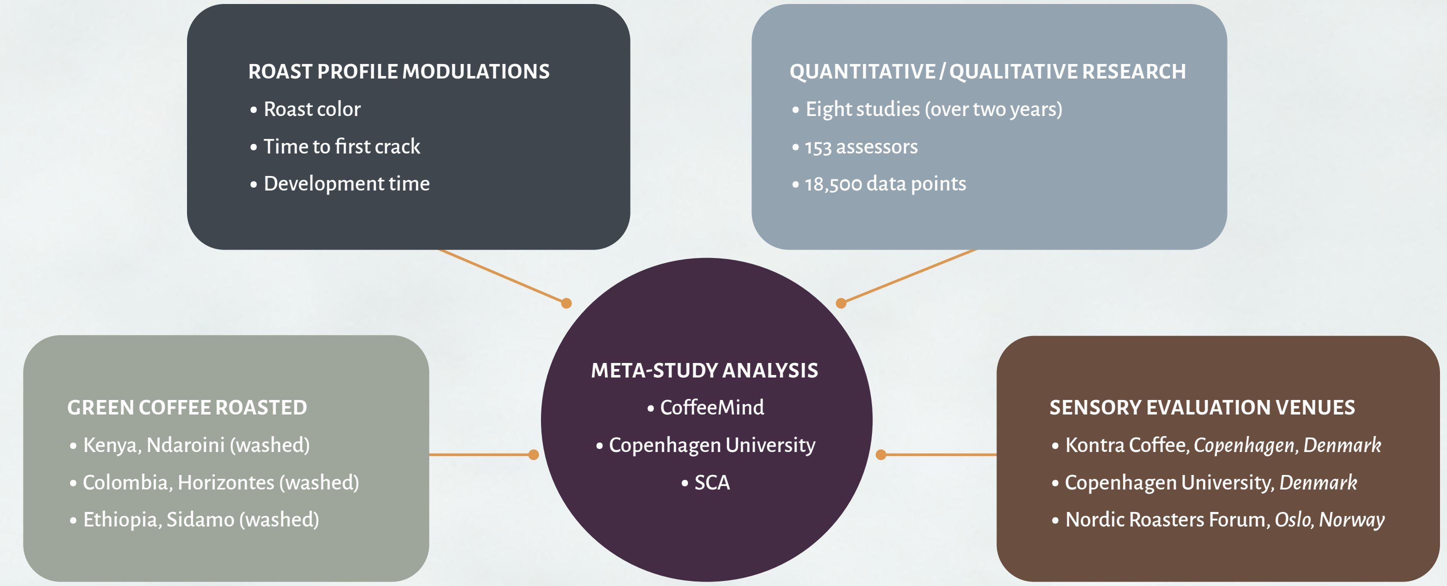


ILLUSTRATION 1 *Summary overview of the studies conducted for the meta-analysis (see Annex Table 1 on page 50).*

flavor, color was the stronger predictor of the two. The results also indicate that under the same roast color outcome, time variation also greatly influences flavor—specifically, development time after first crack, rather than time to first crack.

All the studies adopted the same strict methodological approach, using the same set of sensory attributes, to provide a solid basis for quantifying the magnitude of influence that each roast control parameter has on the sensory properties of the resulting coffees. These scientific protocols are used in sensory labs around the world to generate reliable scientific data. The illustration on page 45 shows an overview of the studies undertaken.

All the sensory attributes detailed on page 47 were rated on a line scale with points of intensity. The assessors evaluated the coffee using the standard cupping method in which the coffee is aspirated into the mouth with a spoon. Samples were evaluated in three replicates, and the sample order was randomized between each of the panelists to avoid bias. The illustration on page 47 lists the descriptive sensory attributes evaluated by assessors in each of the studies.

RESULTS AND CONCLUSIONS

Following statistical analysis, some surprising results emerged from this research, which was published in an open-access journal and is available to read in full at *mdpi.com/journal/beverages*. First, the mouthfeel attribute *body* was not significantly affected by modulating the roast phase from time to first crack, or development time. This is interesting, as it challenges the popular wisdom that links the Maillard reaction with increased *body*. Indeed, the concept of *body*, or mouthfeel, is an elusive concept to most people and

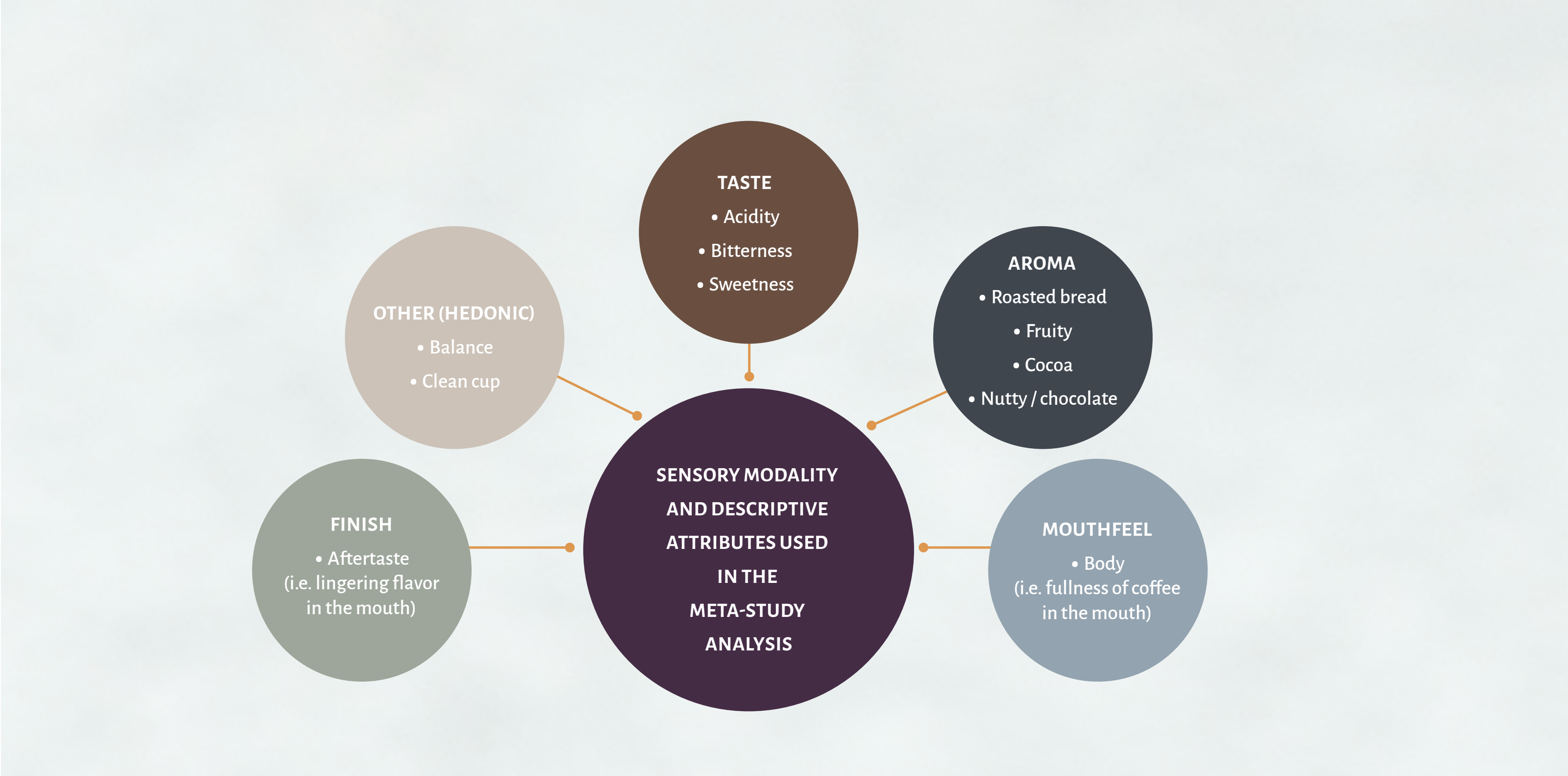


ILLUSTRATION 2 *Sensory attributes and descriptors used by the assessors across all studies (see Annex Table 2 on page 52).*

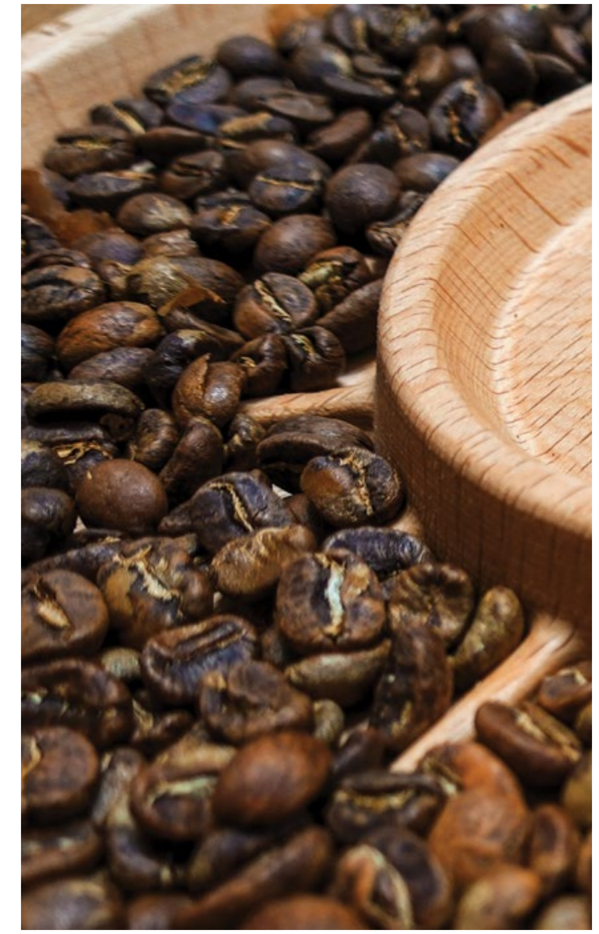
can lead to a range of individual definitions that can be problematic for objective sensory evaluation. Another surprising result was that unlike *bitterness*, *aftertaste* intensity decreased with longer roasting time in both roast phases.

The effect of roasting time on the remaining flavor attributes was less surprising. In particular, the intensity of *fruitiness* was found to decrease with both roasting phases, like *acidity*. The attribute *roasted bread* was significantly associated with a longer development time. This is in line with the formation of volatile aromatic compounds such as maltol (e.g. caramel-like), difurfuryl ether (e.g. roasted) and pyridine (e.g. roasted, burnt) during development time after first crack.

Following the SCA certification system for roasters, each study included a defect called *baked*, which can be defined as an overly extended development time and characterized by intense roasted or bready notes. The results of the meta-analysis allow us to conclude with greater confidence that it is development time, and not time to first crack, that is associated with this roast defect. Finally, roasting time was negatively associated with respect to *balance* and *clean cup* attributes, although only the effect of development time significantly impacted the assessors' perception of *balance*.

OUTLOOK

While these results may not be wholly surprising to many experienced coffee roasters or tasters, the interesting finding is that the variation in roast timing after first crack, while keeping color constant, has an important influence on coffee flavor. The research also provides a practical framework for the coffee industry to better understand how the relationship between roast color and time affects flavor. Our investigation sets out a solid scientific foundation for prioritizing color, closely followed by development time after first crack, over the roast phases that precede it. There is no magic bullet in identifying derivatives in the roast curve—however, factors such as rate of rise (ROR), while important, fall lower in the order of priority in



product development and quality control procedures than the end color of a roasted coffee.

In particular, our research serves to inform the development of future evidence-based certification systems and protocols in the product development and quality control aspect of coffee roasting. From a scientific and practical perspective, these findings help to provide an evidence-based compass to safely navigate our way out of the complexities of coffee roasting and sensory evaluation. If we focus on the primary roast-control parameters that have the greatest impact on sensory outcomes, rather than the secondary derivatives that may not, we allow ourselves more time for relevant activities such as exploring customer preferences to inspire product development. Moreover, if we follow where the science leads us and take a more simplified and systematic approach to coffee roasting, we can serve the coffee community with greater quality, consistency and, above all, confidence.

ANNEX

About the Study

FOCUS: Each study focused on coffee roasted with different time and temperature profiles with the aim of focusing on three clear research objectives:

- Compare the overall impact of roast color modulation versus roast timing modulation on the sensory profile of coffee;
- Assess the magnitude and effect of color modulations on individual sensory attributes;
- Assess the magnitude and direction of timing modulations on individual sensory attributes, with a focus on distinct phases of the roasting process.

Experimental Conditions

ROAST: The green coffee was roasted using a Probatino 1-kilo drum roaster in all studies apart from study six, in which a Loring 15-kilo Falcon was used. Overall roast times ranged from a fast roast speed (e.g. 7 minutes, 40 seconds) to a slow roast speed (e.g. 20 minutes, 20 seconds). Meanwhile, the end roast color measurement spanned from the lower (i.e. darker) Agtron Gourmet color range (e.g. 46) to a much lighter-colored roast (e.g. 117).

EVALUATION: Ground to a slightly coarse particle size, the coffee was brewed by adding 50 grams of coarse coffee to a French press brewer and then adding 900 milliliters of water at a temperature of 92 degrees C/197.6 degrees F. The coffee solution was gently stirred 10 times with a spoon, the foam was removed and after an extraction time of 3 minutes, 30

TABLE 1 *Overview of studies included in the paper. The third column indicates which part of the roasting process was varied in each individual study* (e.g. Col = Roast color, First crack = Time to first crack, Dev = Development time).*

Study ID and location	No. of assessors	Roast profile modulation*	Green coffee
1. Copenhagen University, *Denmark*	10	Col, First crack, Dev	Kenya, Ndaroini (washed)
2. Copenhagen University, *Denmark*	10	Col, Dev	Colombia, Horizontes (washed)
3. Kontra Coffee Roasters, *Denmark*	10	First crack, Dev	Colombia, Horizontes (washed)
4. Kontra Coffee Roasters, *Denmark*	7	Dev	Colombia, Horizontes (washed)
5. Kontra Coffee Roasters, *Denmark*	10	First crack, Dev	Ethiopia, Sidamo (washed)
6. Kontra Coffee Roasters, *Denmark*	11	Dev	Ethiopia, Sidamo (washed)
7. Nordic Roasters Forum, *Norway*	49	Dev	Colombia, Horizontes (washed)
8. Nordic Roasters Forum, *Norway*	46	Dev	Colombia, Horizontes (washed)

TABLE 2 *Sensory attributes, definitions and reference material used for assessor training across all studies.*

Sensory modality	Sensory attribute	Descriptive sensory definition	Reference material
BASIC TASTE	Acidity	Sour taste associated with citric acid solution	0.6 grams citric acid/liter water
	Bitterness	Bitter taste associated with caffeine solution	0.54 grams caffeine/liter water
	Sweetness	Sweet taste associated with sucrose solution	24 grams sucrose/liter water
AROMA	Roasted bread	Aroma associated with roasted bread	Roasted white bread
	Fruity	Aroma associated with mix of fruits	Mix of fruits
	Cocoa	Aroma associated with cocoa beans	
	Nutty/chocolate	Aroma associated with nuts and chocolate	
MOUTHFEEL	Body	Fullness of coffee in the mouth	Coffee with milk
AFTERTASTE	Aftertaste	The length of lingering flavor after spitting the sample	
OTHER	Balance	How well the flavors are balanced	
	Clean cup	No interfering negative impression, non-coffee-like tastes or aromas	

seconds, the plunger was pressed to the bottom. The extraction was terminated by decanting the coffee in thermal flasks and poured into 200-milliliter cupping bowls before being served to the sensory panel at a temperature of 55 degrees C/ 131 degrees F.

This evaluation protocol was developed by CoffeeMind in collaboration with the Department of Food Science at University of Copenhagen and has been used since 2014, when we started conducting these research projects. The use of French presses eliminates between-cup variations.

About the research

This research is freely available, and you can read the full findings of the research in the open-access scientific journal *Beverages* by visiting *mdpi.com/journal/beverages*.

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JESPER ALSTRUP *has a master's degree in sensory and consumer science from the Department of Food Science at the University of Copenhagen, and specialized in sensory evaluation of roast profile modulation in his master's thesis. He has been working with education, consultancy and research at CoffeeMind since 2016.*

ABOUT COFFEEMIND *CoffeeMind is a scientific research, taste and coffee-roasting academy based in Copenhagen, Denmark, with international venues. Its aim is to help students and coffee professionals in developing their careers through applied science in the coffee industry. Its goal is to deliver consumer satisfaction, which leads to more sustainable businesses and, ultimately, a stronger specialty coffee community. Learn more at* coffee-mind.com.