What Determines Coffee Aroma and Flavor?

By Jane Li

Many people start their day with a cup of coffee. As one of the few natural sources of caffeine—the most widely consumed psychoactive drug—coffee has become an essential part of modern daily life.[1] Although some people choose coffee as their first beverage of the day, due to its stimulating effects, others drink coffee for leisure and enjoy its odor or taste. Indeed, the price, quality, and uniqueness of coffee depend on the aroma obtained after processing raw beans; therefore, coffee aroma is of great commercial and consumer interest.[2] But how does coffee obtain its different flavors and aromas?

CHEMICALS —VOLATILE AND NON-VOLATILE COMPOUNDS OF COFFEE

A cup of coffee consists of over 1,000 chemicals which can produce various aromas and flavors.[3] Volatile organic compounds—compounds with a high vapor pressure at room temperature—and non-volatile organic compounds are produced in multiple phases of coffee production, from green (raw) beans to the brewed coffee we consume. Studies have shown that some volatile compounds determine the aroma while non-volatile compounds make up the taste or flavors.[3]

Some key non-volatile compounds include alkaloids (caffeine and trigonelline), chlorogenic acid (CGA), carbohydrates (sucrose), and lipids.[4,5] Both caffeine and CGA contribute to the bitter flavor, but CGA, which degrades rapidly and forms phenolic compounds,also produces astringent and acidic flavors.[5] Trigonelline, on the other hand, leads to an overall aromatic perception and has a weak, bitter taste, but it also degrades during roasting, producing volatile compounds such as pyridines or pyrroles. Lipids contribute to the texture and mouthfeel of coffee, while carbohydrates act as an aroma precursor and degrade quickly, leading to other volatile and non-volatile compounds that contribute to crucial flavors such as sweetness and acidity.[6]

Some key volatile compounds that influence aroma include pyrazines, pyrroles, furans, aldehydes, ketones, and phenolic compounds.[5] Pyrazines and pyrroles often lead to roasted, nutty, and burnt aromas. Furans contribute to malty and sweet roasted flavors. Aldehydes usually exhibit fruity notes, while ketones are associated with buttery flavor notes. Phenolic compounds often contribute to spicy aromas.[3,5,12,13]

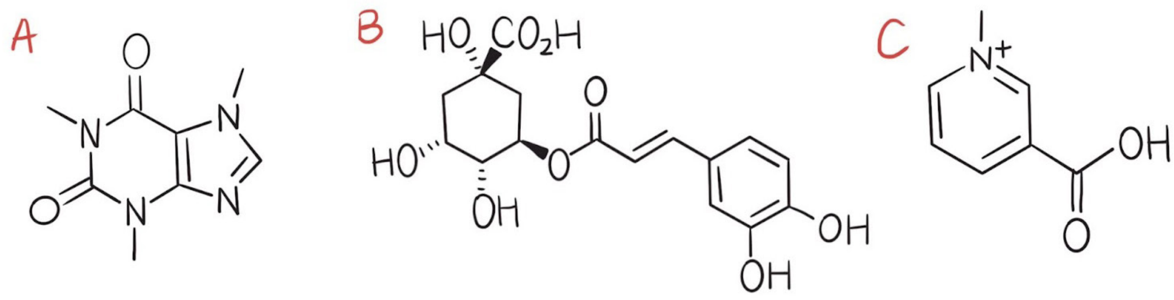

Figure 1. Non-volatile compounds: A) caffeine, B) chlorogenic acid, C) trigonelline

> "Some of the most known cultivars of Arabica—all of which have unique characteristics, flavors, and aromas—include Typica, Blue Mountain, Bourbon, and Yunnan Xiaoli."

As chemicals determine coffee's aroma, it is important to consider that a variety of variables influence the chemical composition of your morning brew.

COFFEE SPECIES AND CULTIVAR

One of the most apparent factors contributing to the wide variety of different chemicals is the species of coffee plant, a distinction dating back to coffee's Middle Eastern roots.

Several stories about the origin of coffee exist, but possibly the most well known version tells of a goat-herder named Kaldi. Around 850 CE, he noticed that his goats became more alert at night after eating the berries from bushes near the Red Sed. The beans, it seemed, had stimulating properties. Kaldi knew he had found something important and set about proclaiming his discovery to the world.

Historically, the wild coffee plant is indigenous to Ethiopia and was cultivated in the Arabian colony of Harar; thus, the earliest grown species is known as Arabica coffee (C. Arabica).[8] Arabica, along with another species Robusta (C.Robusta, also known as C. Canephora), are cultivated widely and compose most of the worldwide coffee market.

In the coffee industry, the words "variety", "cultivar", and "hybrid" are used interchangeably to describe different types of coffee beans. However, there are some differences. According to the Speciality Coffee Association of America (SCAA), a cultivar is a cultivated variety not generally found in natural populations.[9] Arabica coffee plants have been grown in different areas and this has resulted in many cultivars. Some of the most known cultivars of Arabica—all of which have unique characteristics, flavors, and aromas—include Typica, Blue Mountain, Bourbon, and Yunnan Xiaoli.[10]

On the other hand, Robusta is more noted for its resistance to diseases in the natural environment than its cultivars, varieties, or hybrids. Furthermore, Robusta, generally, is less vulnerable to adverse weather conditions than Arabica and is thus easier to grow and produces fruit more quickly. Robusta green beans are hard and have lower sucrose levels than Arabica green beans, which confers a stronger and harsher taste as well as a less acidic flavor after roasting. Since acidity is a crucial feature of high-quality beans, Arabica coffee is considered by coffee enthusiasts to possess superior flavor.[11]

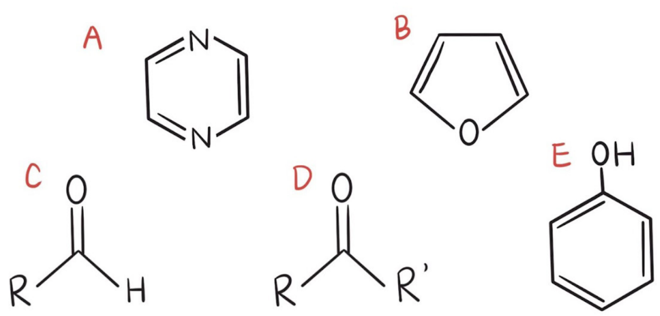

Figure 2. Volatile compounds: A) pyrazine, B) furan, C) aldehyde, D) ketone, E) phenol.

> "The most common three ways of processing coffee are natural processing (dry processing), washed processing (wet processing), and honey processing."

NATURAL IMPACTS

Environmental elements such as elevation and light exposure could also influence chemicals in coffee beans. Some studies have shown that altitude is correlated with glucose content in coffee beans. Coffee trees growing at higher altitudes typically have higher glucose content, thus improving the coffee's sensory attributes.[6] One of the most famous cultivars of coffee, known for its premium flavor, is Blue Mountain coffee, which is grown at an elevation of up to 2,350 metres above sea level and with regular rainfall and volcanic soil. Blue Mountain will not exhibit as good of a taste if it is not grown in its preferred mountainous environment.[12]

More often, bigger coffee beans are considered more flavorful, and consistency in size leads to a more even degree of roasting.[11] Shading, or avoiding direct sunshine, results in coffee beans with greater and more unified bean size and with higher levels of lipid content.[6] Therefore, shade-grown coffee beans have higher market prices.[11] In addition, high temperatures could cause faster ripening of the coffee cherries and thus immature, green coffee beans with higher sucrose, trigonelline, and chlorogenic acid concentrations, leading to more bitter and astringent tastes.[11]

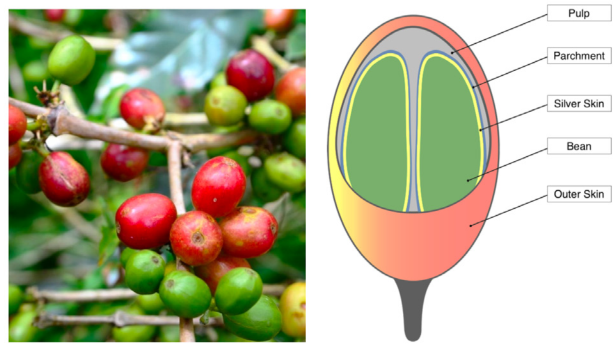

Figure 4: Coffee berry anatomy.

Environmental factors have a significant effect on coffee's final flavor profile. Farmers thus grow specific cultivars in preferred environments that could potentially cultivate higher quality coffee.

PROCESSING AND ROASTING IMPACTS

Once coffee cherries are harvested, the seeds (which we call beans) are fermented and dried via one of the many processing methods that influence the aromas and flavors of coffee. The most common three ways of processing coffee are natural processing (dry processing), washed processing (wet processing), and honey processing.

Dry processing coffee is the most traditional process and involves drying coffee cherries in the sun, allowing them to ferment. In this process, all the layers usually remain intact, leading to a deeper-tasting coffee with fruity and syrupy notes. Wet processed coffee requires depulpers to remove the skin, pulp, and mucilage from the seeds before drying. Once this is done, the seeds are washed in water and then finally dried out in the sun. These coffee beans are typically more acidic and cleaner. This process is efficient but usually considered environmentally unfriendly due to the amount of wastewater produced as a byproduct. Honey processed coffee combines wet and dry methods, producing coffee with flavors similar to both of the previously described methods, but that is sweeter and more complex. The mucilage—a layer of sugary substance surrounding the seed—is what the "honey" refers to. After the depulper removes the seed from the cherry, the mucilage stays on the seed as it dries in the sun.[13]

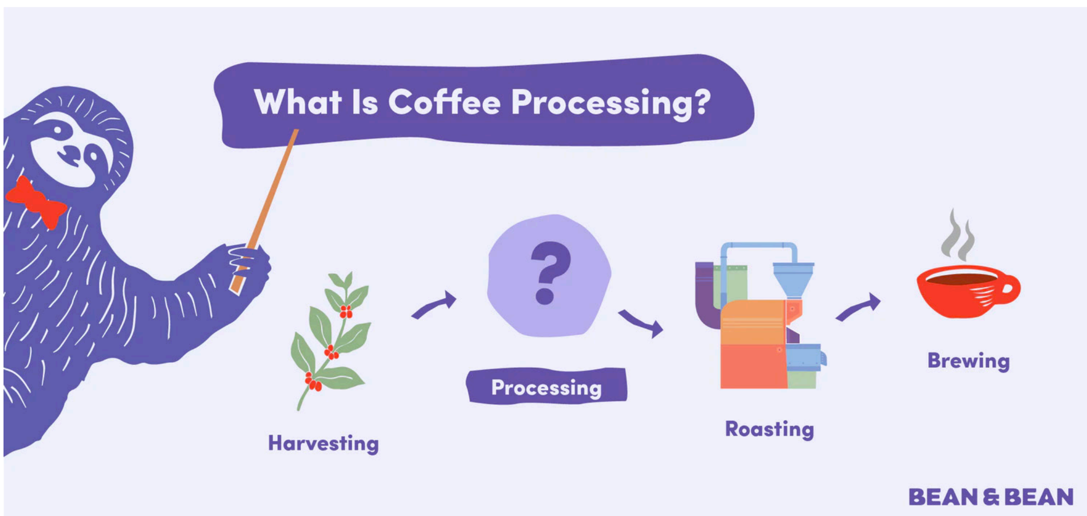

Figure 3: Coffee processing process.

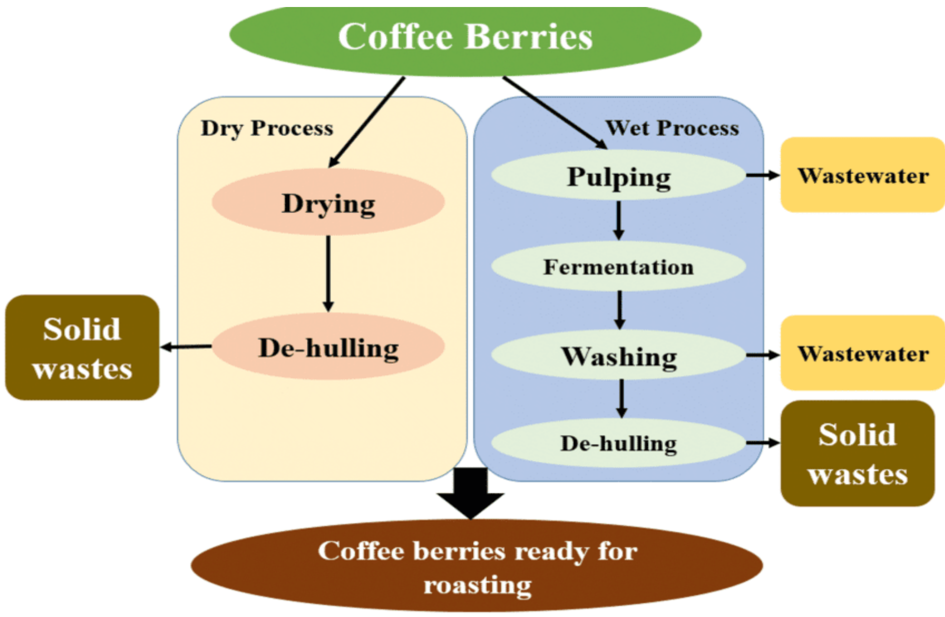

Figure 5. Wet and Dry coffee processing.

These processes get us from coffee cherries to green coffee beans. However, green bean coffees are typically odorless. It is not until roasting triggers certain chemical processes that coffee develops its distinctive aromas. Generally speaking, lightly roasted coffee contains more of the characteristics of green beans and generates more acidic and fruity flavors. When roasting time is increased and coffee beans are roasted more darkly, we obtain coffee with an oilier surface and less acidity, emphasizing a bolder and deeper aroma that is chocolaty and nutty.[11]

Other factors, such as level of grinding, water to coffee ratio, brewing method, temperature, and extraction process, could likely influence coffee's aroma as well. Many coffee shops also blend coffee beans from multiple origins to obtain a more balanced flavor. These factors could affect consumer preference and cause different tastes and mouthfeels of coffee.[11]

Figure 6. The coffee taster's flavor wheel: Taste descriptors near the center are the most broad and get more specific towards the outside.

THE COFFEE TASTER'S FLAVOR WHEEL

Given a cup of coffee, people might perceive its taste and aroma differently, and a number of factors can explain this difference in perception and preference including genetics and environment. Studies have shown an association between taste receptor variants and bitter taste preference.[14] Genome-wide association studies (GWAS) have also indicated that genetic differences in the stimulating effects of caffeine result in different preferences for caffeine.[15] Environmental and social factors such as parents, peers, and food access may also affect individual choice.

In order to address these differences, the coffee taster's flavor wheel, initially published in 1995 and updated in 2016 as a collaboration between Specialty Coffee Association (SCA) and World Coffee Research (WCR), can help people characterize their cup of coffee. The wheel encompasses all the tastes and flavors of coffee and has served as the industry standard since it was published.

Coffee culture is growing while many people are starting to pursue unique flavoring. With some understanding of what contributes to the aromas and flavors of coffee, we can better choose our cup of coffee when entering a coffee shop. A cup of coffee is simple yet complex, with so many processes and factors influencing its taste, so we should appreciate every cup of coffee we drink.

REFERENCES

1. Nehlig, A. (1999). Are we dependent upon coffee and caffeine? A review on human and animal data. Neuroscience & Biobehavioral Reviews, 23(4), 563–576. https://doi.org/10.1016/S0149-7634(98)00050-5
2. Caporaso, N., Whitworth, M. B., & Fisk, I. D. (2022). Prediction of coffee aroma from single roasted coffee beans by hyperspectral imaging. Food Chemistry, 371, 131159. https://doi.org/10.1016/j.foodchem.2021.131159
3. Wood, J. (2019). Determination and correlation of volatile and nonvolatile

compounds with coffee quality . Southern Illinois University Honors Theses. https://opensiuc.lib.siu.edu/uhp_theses/456
4. Angeloni, S., Mustafa, A. M., Abouelenein, D., Alessandroni, L., Acquaticci, L., Nzekoue, F. K., Petrelli, R., Sagratini, G., Vittori, S., Torregiani, E., & Caprioli, G. (2021). Characterization of the aroma profile and main key odorants of espresso coffee. Molecules, 26(13), 3856. https://doi.org/10.3390/molecules26133856
5. Heo, J., Adhikari, K., Choi, K. S., & Lee, J. (2020). Analysis of caffeine, chlorogenic acid, trigonelline, and volatile cin crew coffee using high-performance liquid chromatography and solid-phase microextraction—gas chromatography-mass spectrometry. Foods, 9(12), 1746. https://doi.org/10.3390/foods9121746
6. Cheng, B., Furtado, A., Smyth, H. E., & Henry, R. J. (2016). Influence of genotype and environment on coffee quality. Trends in Food Science & Technology, 57, 20–30. https://doi.org/10.1016/j.tifs.2016.09.003
7. Caporaso, N., Whitworth, M. B., Grebby, S., & Fisk, I. D. (2018). Non-destructive analysis of sucrose, caffeine and trigonelline on single green coffee beans by hyperspectral imaging. Food Research International, 106, 193–203. https://doi.org/10.1016/j.foodres.2017.12.031
8. Smith, R. F. (1985). A history of coffee. In M. N. Clifford & K. C. Willson (Eds.), Coffee: Botany, Biochemistry and Production of Beans and Beverage (pp. 1–12). Springer US. https://doi.org/10.1007/978-1-4615-6657-1_1
9. Specialty Coffee Association of America. (n.d.). A botanist's guide to specialty coffee. Resources. Retrieved March 13, 2022, from http://scaa.org/index.php?goto=&page=resources&d=a-botanists-guide-to-specialty-coffee
10. Gibson, M., & Newsham, P. (2018). Chapter 18—Tea and Coffee. In M. Gibson & P. Newsham (Eds.), Food Science and the Culinary Arts (pp. 353–372). Academic Press. https://doi.org/10.1016/B978-0-12-811816-0.00018-X
11. Seninde, D. R., & Chambers, E. (2020). Coffeef: A review. Beverages, 6(3), 44. https://doi.org/10.3390/beverages6030044
12. Jamaica Blue Mountain Coffee. (n.d.). Location. Blue Mountain Coffee Group Ltd. Retrieved April 13, 2022, from https://www.bluemountaincoffeejamaica.com/en/location
13. Bean & Bean. (n.d.). Coffee processing methods. Blogs. Retrieved March 23, 2022, from https://beannbeancoffee.com/blogs/beansider/coffee-processing-methods
14. Diószegi, J., Llanaj, E., & Ádány, R. (2019). Genetic background of taste perception, taste preferences, and its nutritional implications: A systematic review. Frontiers in Genetics, 10, 1272. https://doi.org/10.3389/fgene.2019.01272
15. Cornelis, M. C., & van Dam, R. M. (2021). Genetic determinants of liking and intake of coffee and other bitter foods and beverages. Scientific Reports, 11(1), 23845. https://doi.org/10.1038/s41598-021-03153-7

IMAGE REFERENCES

1. Cover image: Designed by artist Yue Wu
2. Figures 1, 2: Created by author
3. Figure 3: Bean & Bean. (n.d.). Coffee processing methods. Blogs. Retrieved March 23, 2022, from https://beannbeancoffee.com/blogs/beansider/coffee-processing-methods
4. Figure 4: Lagrasta, F. P., Pontrandolfo, P., & Scozzi, B. (2021). Circular economy business models for the Tanzanian coffee sector: A teaching case study. Sustainability, 13(24), 13931. https://doi.org/10.3390/su132413931
5. Figure 5: Sengupta, B., Priyadarshinee, R., Roy, A., Banerjee, A., Malaviya, A., Singha, S., Mandal, T., & Kumar, A. (2020). Toward sustainable and eco-friendly production of coffee: Abatement of wastewater and evaluation of its potential valorization. Clean Technologies and Environmental Policy, 22. https://doi.org/10.1007/s10098-020-01841-y
6. Figure 6: Specialty Coffee Association of America. (n.d.). A botanist's guide to specialty coffee. Resources. Retrieved March 13, 2022, from http://scaa.org/index.php?goto=&page=resources&d=a-botanists-guide-to-specialty-coffee