

The Science of Espresso: How Variables like Temperature and Pressure Impact Flavor

Alok Satish Chaughule

Abstract

Espresso is a revered cornerstone of coffee culture, with a rich and complex flavor that has captivated coffee enthusiasts worldwide. Unlike other coffee preparations, espresso involves a scientific precision that influences every cup. The process hinges on specific variables—temperature, pressure, grind size, water quality, and extraction time—that must be fine-tuned to achieve the perfect balance of flavor, body, and aroma. Understanding how these variables interact is key to mastering the art of espresso. There are a large number of devices and methods to produce espresso coffee (EC). EC is defined as “a brew obtained by percolation of hot water under pressure through compacted cake of roasted ground coffee, where the energy of the water pressure is spent within the cake” (Illy et al., 2005). In this process flavors are extracted from the coffee by means of hot water. EC consists of about 35 ml of dark beverage, usually served in a small cup with a brown foam layer called *crema* covering the liquid. *Crema* is a distinctive feature of EC, as it is absent in other coffee brews and is required for consumer acceptance. (1)

In this article, we'll explore the science behind espresso, focusing on the roles of temperature and pressure and how they shape the characteristics of the final cup. We'll break down each variable's effect on the extraction process and discuss how small adjustments can significantly impact flavor.

Keywords: Espresso Brewing, Pressure profiling, Coffee Extraction, Crema Formation, Barista Technique, Soluble Compounds, Coffee Oil and Lipids, PID controller.

Section 1: The Basics of Espresso Extraction

What is Espresso?

Espresso is a concentrated form of coffee, brewed by forcing hot water under high pressure through finely-ground coffee. This process extracts essential oils, sugars, and soluble compounds that form a complex, flavorful shot. Espresso is not only more concentrated than other brewing methods, but it also has a unique mouthfeel and crema—a golden foam layer—on top.

Extraction Science: Soluble Compounds and Flavor Profiles

The flavor of espresso results from the extraction of compounds like caffeine, lipids, acids, and sugars, each contributing distinct qualities:

1. **Acids** provide brightness and complexity.
2. **Sugars** contribute sweetness and balance.
3. **Lipids and oils** contribute body and mouthfeel.
4. **Caffeine** adds bitterness and intensity.

Proper extraction is key to achieving the right balance. Under-extraction (when not enough compounds are dissolved) results in a sour, weak espresso, while over-extraction (when too many compounds are dissolved) can taste bitter and harsh.

Section 2: Temperature and Its Impact on Espresso Flavor

Why Temperature Matters in Espresso Brewing

Temperature plays a critical role in the espresso brewing process, influencing how quickly and thoroughly flavors are extracted from the coffee grounds. Typically, espresso is brewed between 195°F to 205°F (90°C to 96°C), with slight variations depending on the bean type and desired flavor profile. Small changes in temperature can have a significant impact on the extraction rate and the resulting flavor.

Chemical Reactions during Brewing

Higher temperatures accelerate the chemical reactions that dissolve coffee compounds. For example:

- **Acidic compounds** dissolve quickly at lower temperatures, enhancing brightness and fruity notes.
- **Sweet and complex sugars** dissolve more readily at slightly higher temperatures, adding balance and sweetness.
- **Bitter compounds** like caffeine are extracted more easily at very high temperatures, which can overpower the coffee if not carefully managed.

Fine-Tuning Temperature for Flavor Control

The optimal temperature for espresso can vary depending on bean origin and roast profile:

1. **Lighter Roasts:** Tend to benefit from a higher temperature (around 200°F - 205°F) to fully extract sugars and balance acidity.
2. **Darker Roasts:** Perform better at lower temperatures (around 195°F - 198°F) to avoid excessive bitterness and bring out more nuanced flavors.

Temperature stability is equally important. Modern espresso machines often use advanced systems like PID controllers to maintain precise temperature, ensuring consistency in every shot.

Section 3: Pressure and Its Role in Espresso Brewing

The Role of Pressure in Espresso Extraction

Pressure is what distinguishes espresso from other brewing methods, creating a concentrated coffee by forcing water through the coffee grounds. Traditional espresso is brewed at around 9 bars (130 psi) of pressure, which is essential for extracting oils, flavors, and forming crema. It revealed that the barista's method of pumping the espresso was key to releasing the flavours and aromas of the ultimate espresso. (3)

How Pressure Affects Flavor

Pressure influences extraction in several ways:

- **Under High Pressure:** More compounds are extracted in a shorter amount of time, intensifying flavors and creating a thicker body.

- **Crema Formation:** Pressure emulsifies oils in the coffee, creating the characteristic crema layer, which affects mouthfeel and flavor perception.
- **Balancing Extraction:** Too much pressure can lead to over-extraction, resulting in a harsh, bitter taste, while too little pressure can cause under-extraction, leaving the espresso sour and thin.

Pressure Profiling

In recent years, baristas have experimented with pressure profiling—adjusting pressure throughout the extraction process. For example, starting with lower pressure during pre-infusion allows the coffee to “bloom,” helping to avoid channeling and promote even extraction. Gradually increasing pressure then brings out more flavors without overwhelming bitterness.

Section 4: Grind Size and Its Interaction with Temperature and Pressure

Grind Size and Extraction Rate

Grind size is a critical factor that works in tandem with temperature and pressure. Espresso requires a fine grind, increasing the surface area for extraction. The grind size affects how quickly water passes through the coffee bed, impacting the balance of flavor:

1. **Finer Grinds:** Increase resistance to water flow, often requiring higher pressure and slightly lower temperatures to avoid over-extraction.
2. **Coarser Grinds:** Allow faster water flow, often resulting in a weak or sour shot if pressure and temperature are not adjusted accordingly.

Balancing Grind with Temperature and Pressure

Baristas must adjust grind size alongside temperature and pressure to achieve ideal extraction. For instance, a coarser grind might pair well with higher pressure or temperature to compensate for faster water flow, while a finer grind may require lower pressure or temperature to avoid bitterness.

Section 5: Other Influential Variables – Water Quality and Extraction Time

The optimisation of other technical parameters in previous studies seemed to minimise the influence of an increase in the coffee/water ratio on the extraction of soluble and solid compounds. In fact, only some sensory attributes, such as bitterness, astringency and burnt, acrid and earthy/musty flavours were proposed as relevant to the selection of 6.5 g 40 mL⁻¹ or 7.5 g 40 mL⁻¹ in conventional roasted coffees (Arabica 100% and Robusta blend), and 6.5 g 40 mL⁻¹ in torrefacto roasted coffees. (2)

Water Quality

Water quality directly influences extraction and flavor. The ideal water for espresso should have a balanced mineral content—too hard or too soft water can impact the taste and extraction efficiency. Water quality also affects crema formation and can influence the acidity and sweetness of the espresso.

Extraction Time

Extraction time is the duration that water is in contact with the coffee grounds, usually between 25 to 30 seconds for a typical espresso shot. Longer extraction times lead to over-extraction, while shorter times can result in under-extraction. Baristas fine-tune extraction time in combination with grind size, temperature, and pressure to ensure optimal flavor.

Section 6: Common Challenges and Adjustments for Consistent Espresso

Challenge: Sour or Bitter Shots

When espresso is sour, it often indicates under-extraction due to low temperature, low pressure, or coarse grind. In contrast, bitterness generally signals over-extraction, which could result from excessive temperature, high pressure, or an overly fine grind. Adjustments can be made to correct these issues, such as:

- **Lowering Temperature:** To reduce bitterness.
- **Reducing Pressure:** To soften the harshness of the shot.
- **Fine-Tuning Grind Size:** To control extraction rate.

Challenge: Inconsistent Crema

Crema is affected by factors like water pressure, temperature, and coffee freshness. Adjusting pressure profiling, maintaining consistent temperature, and using freshly roasted coffee can help produce stable crema.

Challenge: Machine Calibration

Professional espresso machines require regular calibration to maintain accuracy in temperature and pressure. Baristas calibrate their machines daily, adjusting variables as needed based on factors like bean freshness, humidity, and other environmental conditions.

Section 7: Innovations in Espresso Technology and Future Trends

Advanced Temperature and Pressure Control

Espresso machine manufacturers continue to innovate, creating machines with PID controllers and advanced pressure profiling systems that allow baristas to experiment and achieve precise flavor control. These machines enable consistency and open doors to creative brewing methods.

Data-Driven Espresso

With the use of data tracking and sensor-based technologies, baristas can monitor variables like temperature, pressure, and extraction time, refining recipes for consistent quality. Data-driven insights are paving the way for further understanding of the science behind espresso and how to manipulate it for optimal results.

Emerging Coffee Science and Research

As espresso becomes a central subject in coffee research, scientists and baristas are studying chemical reactions and extraction at a microscopic level. This research aims to improve flavor control, explore new extraction techniques, and create a more sustainable coffee experience. Further the consumption of Italian-style espresso-based beverages outside the home is widespread, and many of these beverages are drunk in branded coffee shop outlets, based on a format popularized in the United States. (4)

Conclusion

Espresso is more than just a coffee preparation; it is an intricate dance of science and art where variables like temperature, pressure, grind size, and water quality converge to create a unique sensory experience. Understanding the impacts of temperature and pressure on extraction allows baristas and enthusiasts to fine-tune each shot for optimal flavor. Temperature affects the extraction speed of acids, sugars, and bitters,

while pressure dictates how flavors are concentrated and how crema forms. Together with grind size and water quality, these factors must be balanced for a well-extracted espresso that showcases sweetness, body, and complexity.

Advances in espresso technology, such as precision temperature control and pressure profiling, empower baristas to experiment and innovate. These developments, paired with a deeper understanding of chemical processes during extraction, continue to elevate the craft of espresso. As research into coffee science expands, so does the potential for more sustainable and flavor-rich espresso experiences, ensuring that this cornerstone of coffee culture continues to evolve.

References:

1. Comparison of espresso coffee brewing techniques, Journal of Food Engineering, Volume 121, January 2014, 112-117, <https://doi.org/10.1016/j.jfoodeng.2013.08.031>.
2. Journal of the Science of Food and Agriculture, Issued 2007, <https://doi.org/10.1002/jsfa.2720>.
3. Your Good Mood is sponsored by Presso Coffee, International Journal of Development Research, Vol 13, Issue 13, pp. 62220-62224, March 2023, ISSN 2230-9926.
4. Bringing gourmet coffee to India: Lessons of an Italian firm in an emerging market, Journal of Business Strategy, August 2012, <http://dx.doi.org/10.1108/02756661211282777>, ISSN 0275-6668