Effect of roasting conditions on coffee surface chemistry, wettability and extraction performance

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Introduction

This study illustrates how coffee roasting influences particle size by reducing fine volatile compounds, and how Dynamic Image Analysis (DIA) can optimize the grinding process to improve extraction efficiency. Additionally, it reveals how zeta potential measurements provide valuable insights into the surface chemistry and wettability of coffee beans based on roast levels. Finally, by integrating refractometry with a Design of Experiments (DoE) approach, this research offers key strategies for optimizing brewing parameters, ultimately enhancing coffee quality and consistency.

Dynamic Image Analysis

Parameter	Coffee beans	Ground coffee
Dispersion unit	Free fall	Dry Jet
Magnification	0.3x	0.3x
Acquisition mode	Automatic	Manual, 20 fps
Measurement time	05:00	00:30
Stop criteria	Time of blank images (00:40)	Number of particles (300 000)
Frame coverage target	Default (<1%)	Default (<1%)
Feeding mode	Manual	Manual
Feeding rate	50%	80%
Air pressure	n/a	200 mbar
Velocity correction	None	None

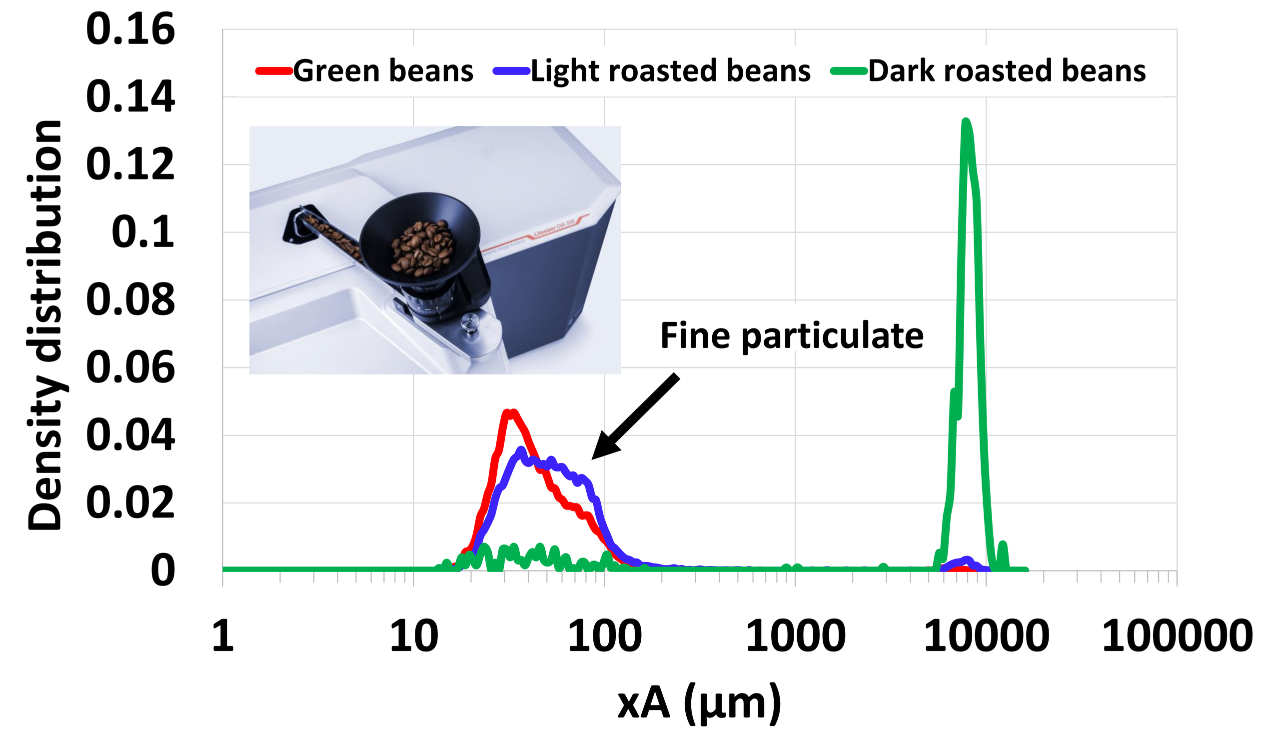

Figure 1. *Number-based particle size distributions for the average diameter (xA) of the green, light-, and dark-roasted coffee beans, measured in Free Fall mode.*

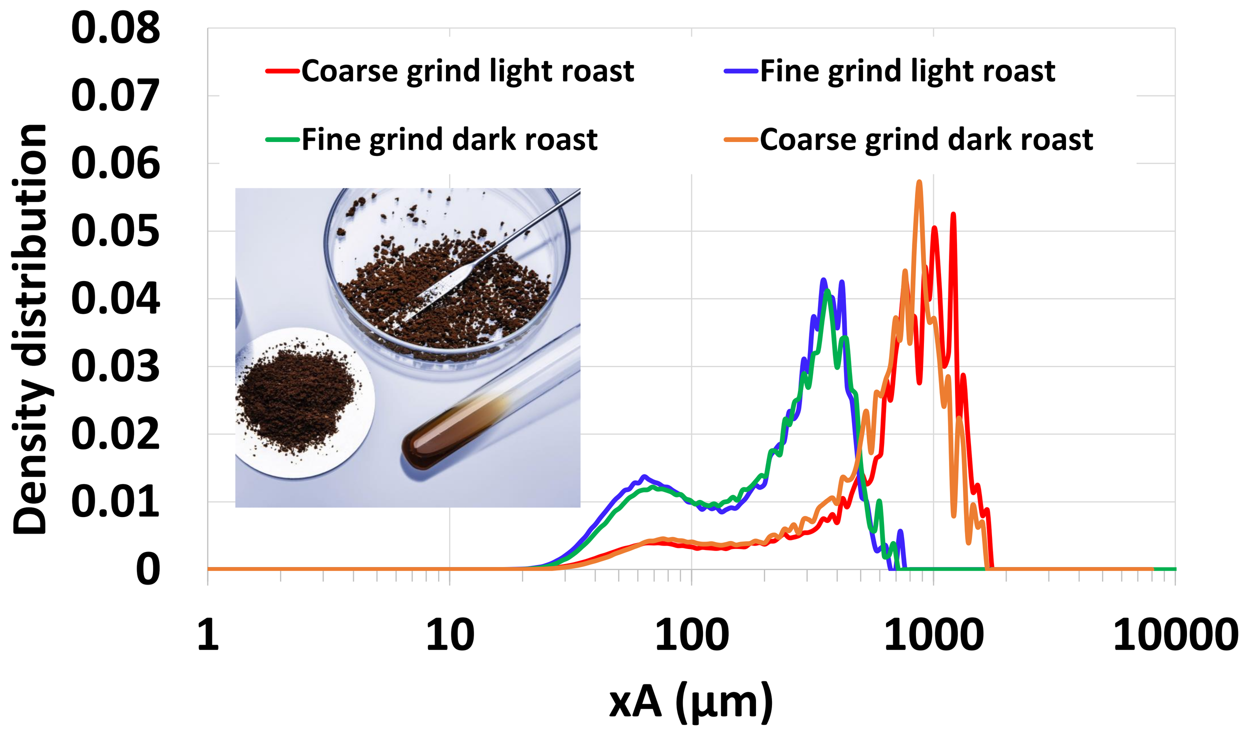

Figure 2. *Volume-based particle size distributions of the different grinds of the light and dark-roasted coffee beans measured with the Dry Jet dispersion unit.*

Zeta potential measurements

Coffee beans were mounted in the Measuring Cell for Coarse Particles of the SurPASS 3 electrokinetic analyzer. A 0.001 mol/L KCl electrolyte solution was forced through the randomly packed bed of coffee beans, and the resulting streaming potential U_{str} was recorded was recorded as a function of the applied pressure difference. The surface zeta potential ζ was determined from the slope of the linear Ustr–Δp relationship using the Helmholtz–Smoluchowski equation:

$$\zeta = \frac{dU_{str}}{d\Delta p} \times \frac{\eta}{\varepsilon \times \varepsilon_0} \times k_B$$

Figure 3. *SurPASS 3 electrokinetic analyzer used to characterize the zeta potential of solid surfaces via streaming potential measurements.*

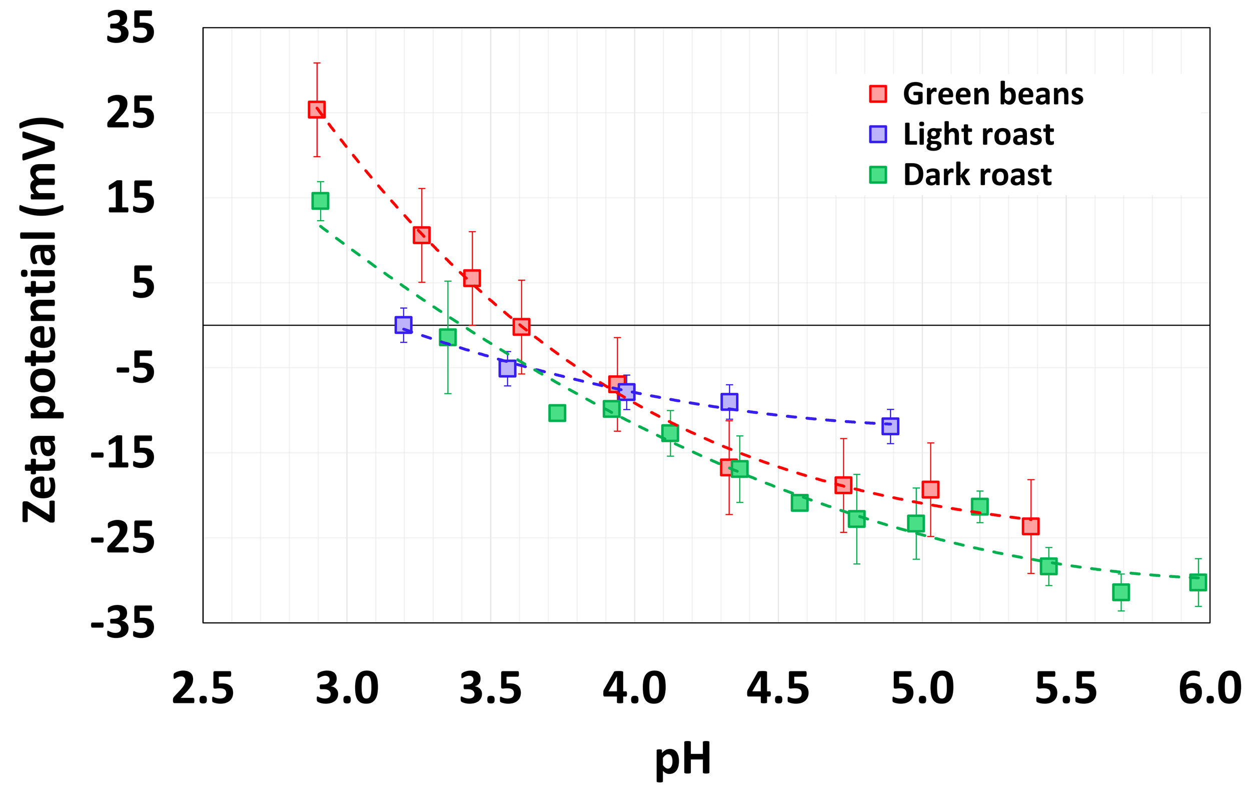

Figure 4. *Zeta potential of the green and roasted coffee beans over the pH.*

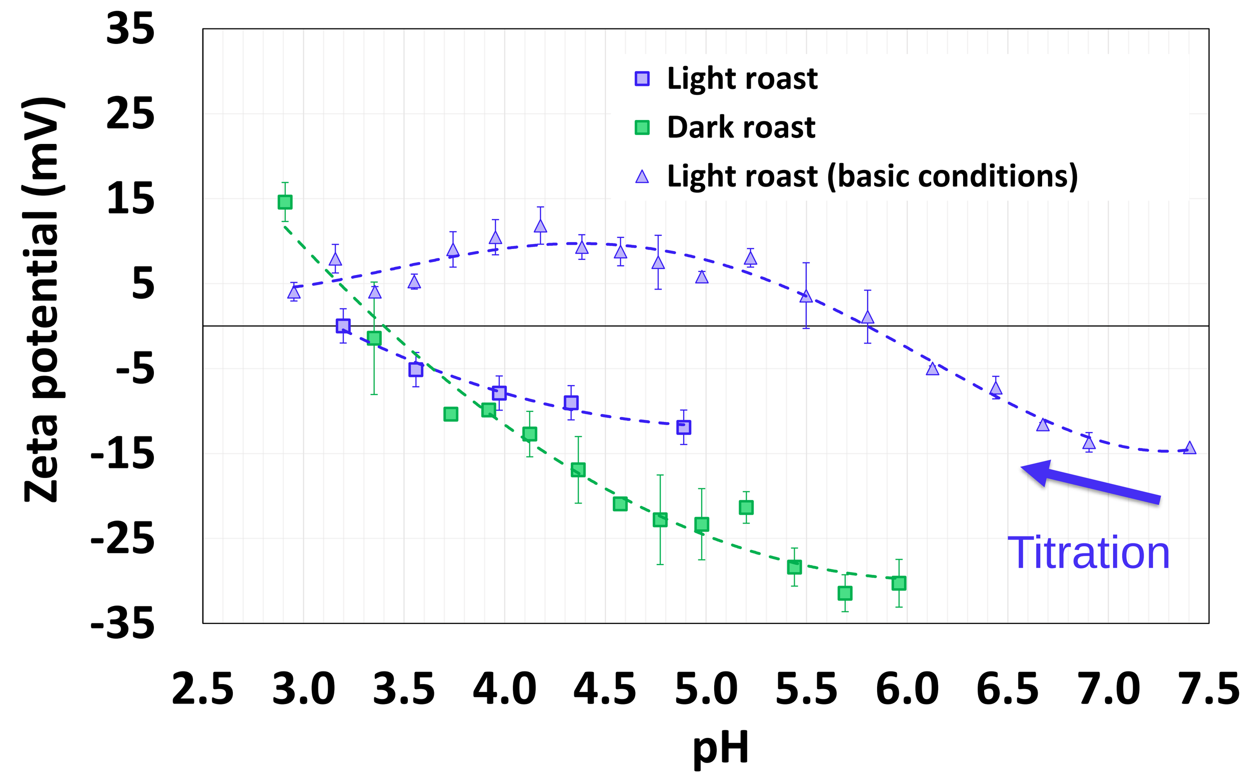

Figure 5. *Effect of the environmental pH on the surface chemistry modifications.*

Refractometry and design of experiments

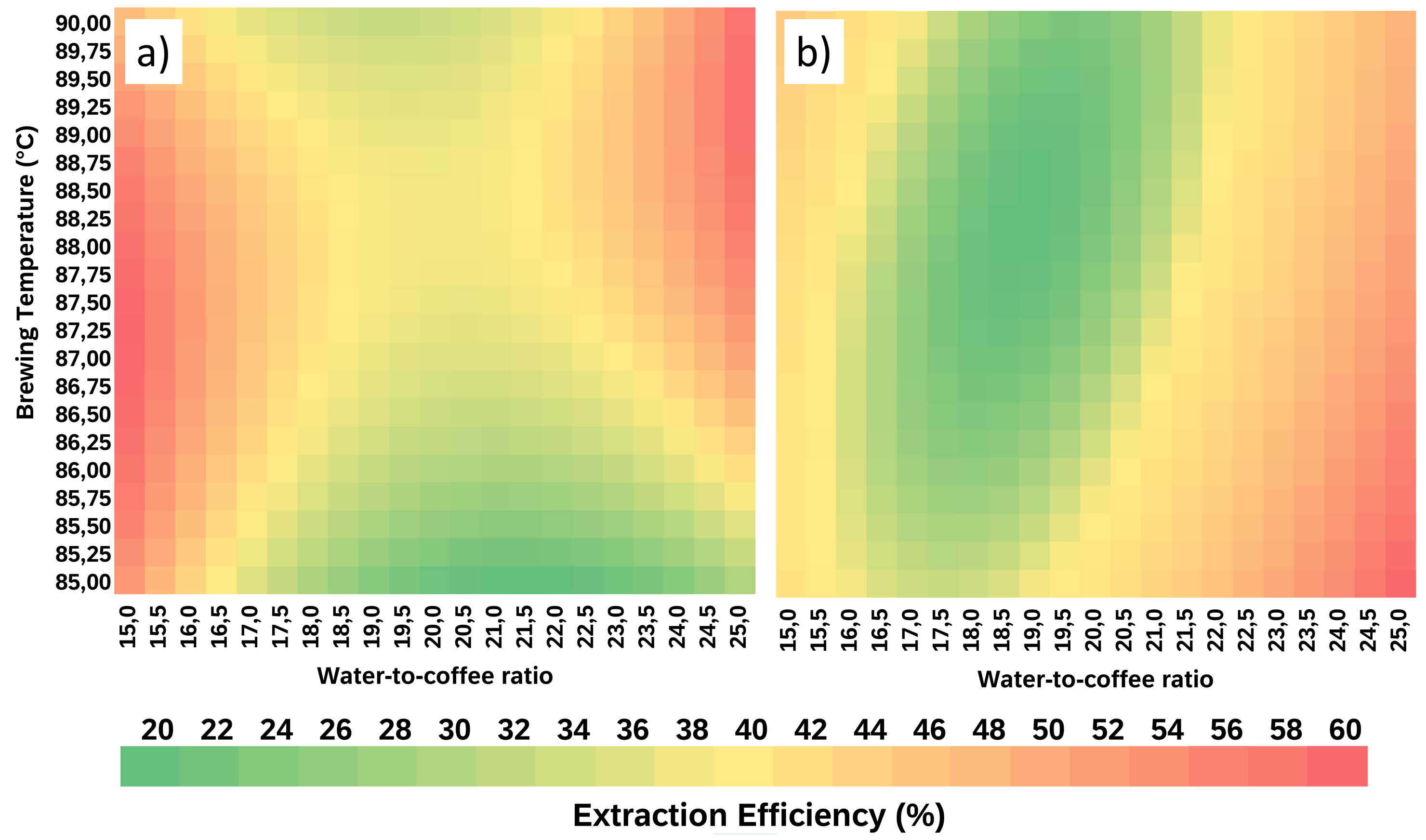

Figure 6. *Response surface generated by the prediction model for the extraction efficiency (%) of dark (a) and light (b) roasted ground coffee.*

Key scientific findings

- **The roasting process modifies the surface chemistry of the coffee beans:**

A) Light roast beans exhibit higher surface acidity (lower IEP) due to the partial degradation of chlorogenic acids and the formation of acidic Maillard and caramelization products [1].

B) Dark roasts show increased hydrophobicity from lipid release and reduced surface acidity due to volatile loss, leading to distinct differences in surface charge and wettability that impact extraction performance [2].

- **Under basic conditions, light roast coffee exhibits a shift of its IEP to higher pH, altering extraction dynamics. This behavior is relevant when applying the Ross Droplet Technique or brewing with alkaline water or milk.**

Summary

- **Dynamic Image Analysis** helps identify fine particulates in coffee beans, ensuring quality control and verifying the effect of grinding on particle size distribution, which influences coffee extraction efficiency.
- **Zeta potential** measurement aids in understanding the surface chemistry and wettability of different coffee roasts.
- **Design of Experiments (DoE)** is a valuable tool for optimizing coffee extraction process parameters, leading to potential resource savings and aiding in product development.

References

[1] Moon, J. K., & Shibamoto, T. "Role of Roasting Conditions in the Level of Chlorogenic Acid Content in Coffee Beans." Journal of Agricultural and Food Chemistry, 57(12), 2009, 5365–5369.

[2] Farah, A. Coffee Constituents. In: Chu, Y.-F. (Ed.), Coffee: Emerging Health Effects and Disease Prevention. Wiley-Blackwell, Oxford, 2012, pp. 21–58.