9-2-2024

Strategies to Mitigate Electrostatic Charging During Coffee Grinding

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Citation Details

Harper, J. M., Bumbaugh, R. E., & Hendon, C. H. (2024). Strategies to mitigate electrostatic charging during coffee grinding. IScience, 27(9), 110639.

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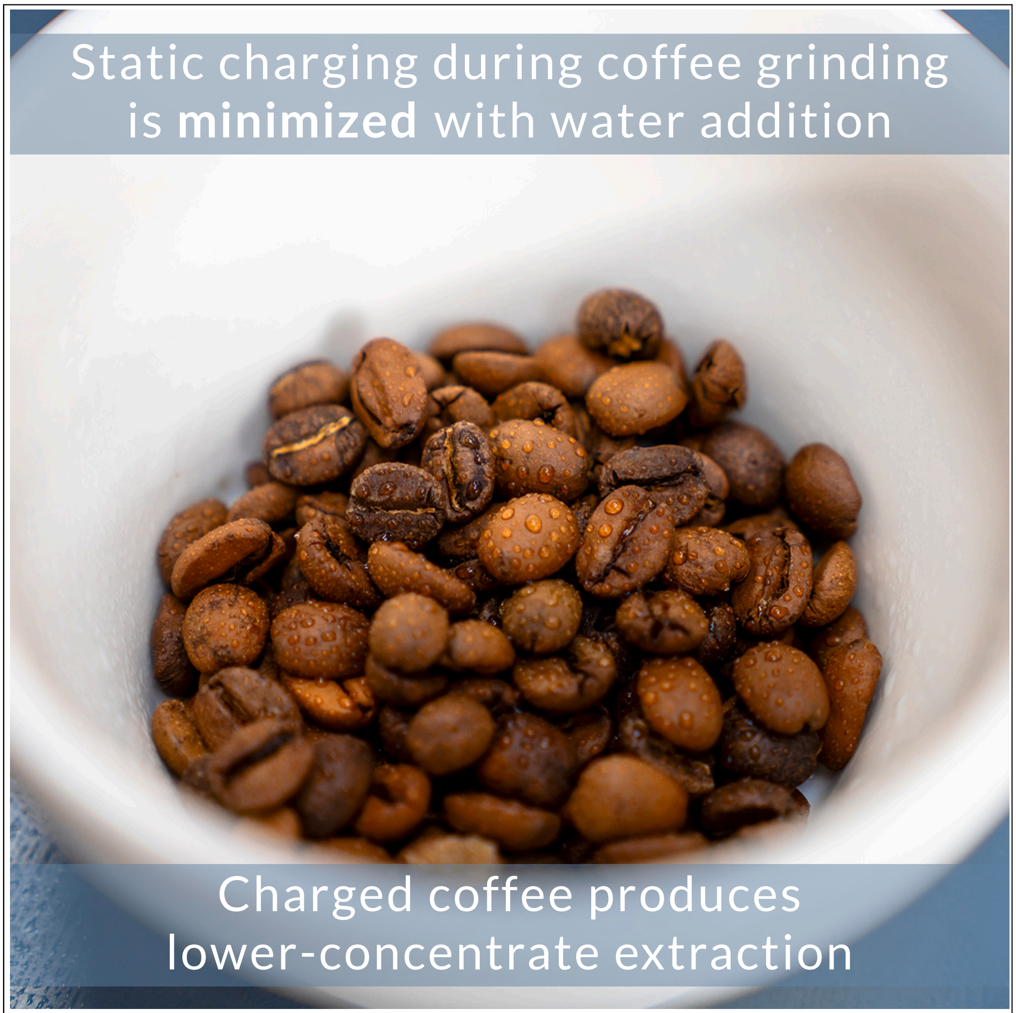

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Highlights

Coffee grinding generates static charge, with darker roasts charging more negatively

Ionizers can be effective in minimizing static charge but depends on interaction radius

Water addition to whole beans during grinding is most effective for static mitigation

Static reduction increases the surface area of the granular coffee bed

Harper et al., iScience 27, 110639
September 20, 2024
https://doi.org/10.1016/j.isci.2024.110639

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Strategies to mitigate electrostatic charging during coffee grinding

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SUMMARY

Coffee grinding generates electrostatically charged particles, causing clumping, spark discharge, and beyond. When brewing, the particle aggregates affect liquid-solid surface accessibility, leading to variable extraction quality. Here, we study four charge mitigation strategies. De-electrification is readily achieved by adding small amounts of water to whole beans or by bombarding the grounds with ions produced from a high-voltage ionizer. While these techniques helped reduce visible mess, only water inclusion was found to impact coffee extracts prepared as espresso. Wetting whole beans with less than 0.05 mL/g resulted in a marked shift in particle size distribution, by preventing clump formation and preventing fine particles from sticking to the grinder. This particle size shift results in at least a 15% higher coffee concentration for espresso extracts prepared from darker roasts. These findings encourage the widespread implementation of water use to de-electrify coffee during grinding with the benefit of increased coffee extraction efficiency.

INTRODUCTION

Grinding roasted coffee reduces whole beans into flows of highly electrified powders.[1,2] Charged granular materials can lead to electrostatic discharges,[3] jamming and sheeting (i.e., coating the interior walls of conduits),[4,5] spontaneous segregation,[6] and product nonuniformity.[7] Specific to coffee preparation, charging can produce erratic dispersal of grounds, making whole-bean grinders somewhat messy. More importantly, however, static charging during grinding results in particle-particle clumping.[1,2] These electrostatic agglomerates affect extraction quality when brewing by changing the packing of coffee particles and influencing solid surface area available to percolating water.[8,9] The elimination of these clumps should increase soluble availability, posing substantial financial and sustainability motivations to eliminate their formation.

Recently, we demonstrated parameters that control charging by grinding commercially sourced coffees and measuring the charge-to-mass (Q/m) ratio of the grounds using the process presented in Figure 1A.[2] As whole beans are fractured into small grains with broad size distributions (Figure 1B),[10] particles may acquire charge densities comparable to those of volcanic ash and thundercloud ice, through both fracto- and triboelectrification.[11,12] Generally, the polarity and magnitude of charge loosely depends on the roast level or color of a coffee, and we observed that dark roasts charge largely negative, and lighter roasts charge positively, Figure 1C. Residual moisture levels, a property typically inversely proportional to color, were found to be the primary determiner of charge polarity, where a positive-to-negative charging transition occurs at moisture contents less than $\sim$ 2%. Some coffees, especially dark coffees, can charge sufficiently to cause gaseous breakdown in the form of millimeter-long spark discharges, Figure 1D.

The coffee industry has long maintained an intuitive understanding that water can significantly modulate grinding-associated electrostatics. A small amount of water added to whole beans before grinding—the so-called Ross droplet technique (RDT)—is known to prevent static accumulation and causes the grinder to retain less grounds within its chamber.[2,13] However, the inclusion of too much water may result in caking or corrosion in the grinder, the limit of which will depend on the coffee and grinder. Concurrently, there is interest in the industry in developing water-free charge mitigation strategies, but their utility and impact on achieving high extraction yields remain unknown. In this paper, we examine the effectiveness of various electrochemical techniques to suppress electrostatic buildup—grinding and waiting, adding external water, and alternate ionization methods. We show that de-electrification techniques that introduce charges after the agglomerates have formed (i.e., simply waiting or ionization methods) do not improve the particle availability in espresso brewing, resulting in variable extractions and no improvement in total dissolved solids (%TDS). The addition of water mitigates charging during the grinding process and results in extraction increase of beyond 15%.

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https://doi.org/10.1016/j.isci.2024.110639

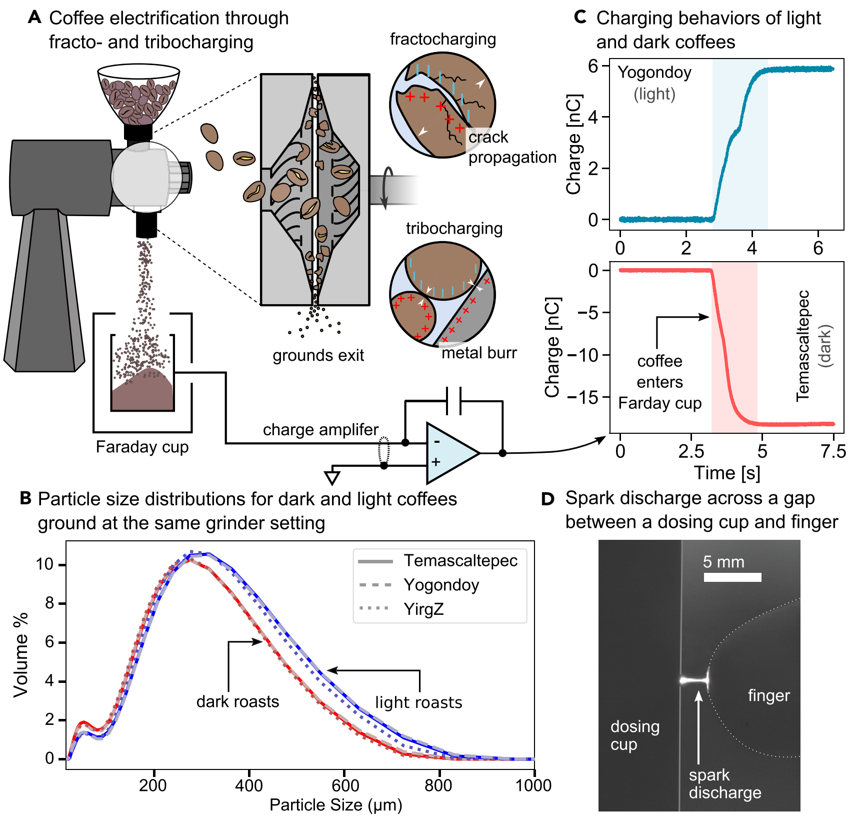

Figure 1. Electrification of coffee during grinding

(A) Schematic of the setup used to assess the electrification of coffee during grinding. During fracture, coffee particles accumulate charge from the burr-coffee and coffee-coffee interfaces (tribocharging), as well as fracture points (fractocharging). Charge-to-mass ratios can be measured with a Faraday cup and scale.

(B) Particle size distributions for our in-house roasted coffees ground at setting 2.0 on our Mahlkönig EK43.

(C) Example charging curves (raw data from Faraday cup) for lighter/wetter and darker/dryer coffees.

(D) Photograph of a spark discharge spanning the gap between a metal cup containing freshly ground coffee and the lead author's finger. Assuming a breakdown field of 3 MV m^{-1} (air at 101 kPa), the potential difference between the two surfaces is $\sim$ 7.5 kV.

RESULTS AND DISCUSSION

Canvasing charge passivation strategies

Time-resolved discharge

Perhaps the simplest discharge method is to let the ground coffee sit for a period of time after grinding. This respite permits discharge through volumetric or surface conduction or, in the case of exceedingly high charges, gaseous breakdown.[14–16] To a zeroth order, Jones and Tang[17] have described the relaxation of the volumetric charge density $\rho(t)$ in a powder by

$$\rho(t) = \rho_0 e^{[-t/(\kappa\epsilon_0\gamma)]} \quad \text{(Equation 1)}$$

where ρ_0 is the initial charge density, t is time, κ is the dielectric constant of the material, ϵ_0 is the permittivity of free space, and γ is the effective resistivity. The denominator in the exponent defines a time constant, τ. This exponential behavior of charge decay can be readily observed using a non-contact electrostatic voltmeter probe (Trek 541A-2) placed 5 mm over 10 g of freshly ground coffee (collected in a metal cup, resting on an insulating surface), Figure 2A. Charge relaxation curves for both light and dark roasts of the same Ethiopian coffee (a washed Yirgacheffe, details in Table 1) are rendered in Figure 2B. There, the light roast (2.8% residual water) loses its charge faster ($\tau \sim$ 15 s) than its darker, drier counterpart (1.0% residual water, $\tau \sim 65$ s). Overall, however, the charge appears to dissipate on timescales of minutes but exceeds the average time between preparing shots in a busy cafe. Also, grinding and waiting poses problems for volatile loss and quality degradation, which occurs over similar timeframes.[18]

De-electrification through external water inclusion

While time-resolved de-electrification is both cost-effective and predictable, it does not prevent the formation of aggregates during grinding and also provides the particles with prolonged off-gassing time, resulting in a significant loss of volatiles.[19] Thus, a number of active strategies

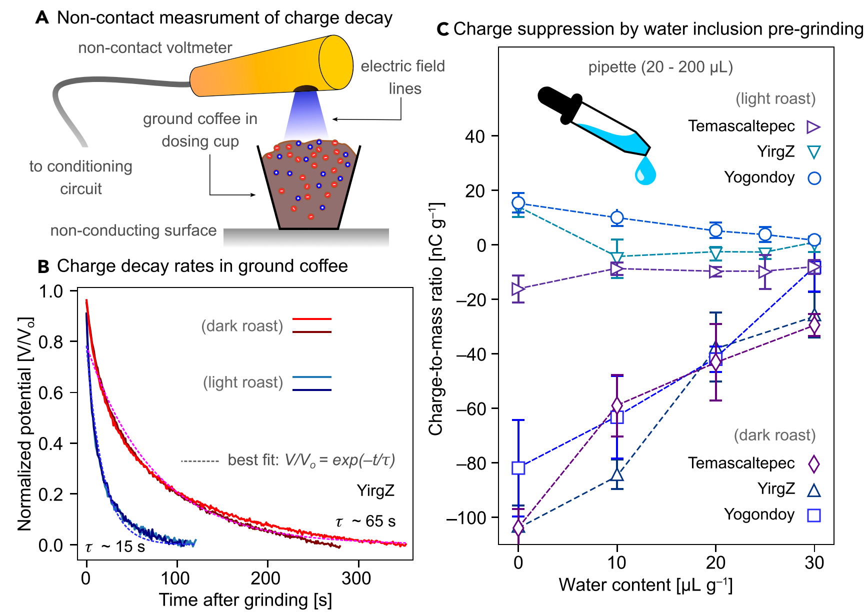

Figure 2. Time-resolved and water-mediated charge reduction strategies

(A) Schematic of setup used to measure the charge decay in freshly ground coffee. A non-contact voltmeter was placed 5 mm above 10 g of ground coffee and its potential was measured every 0.5 s.

(B) Charging dissipates with time as charge carriers recombine with each other through surface and bulk conduction. Some charge may also be lost directly to the atmosphere. Charge in lighter roasts decays faster than in dark coffee.

(C) During the grinding process, charge accumulation is hindered by the addition of small amounts of water (0–30 μL g^{-1}) to the whole beans prior to grinding.

have been devised to address charging during the act of grinding. We recently demonstrated that the addition of extrinsic water mitigated fractocharging in both positive and negative charging coffees.[2] By incorporating up to 30 μL of water per gram of whole coffee beans, our in-house roasts behave similarly to other literature's coffee samples, with the Q/m ratio decreasing with increasing water content, Figure 2C. Although, in many cases, charging was not completely eradicated, we find that 20–30 μL g^{-1} reduced the charge by a minimum of 50%–60%. In practice, this reduction appears to sufficiently mute electrostatic forces, precluding dispersal of grains, clumping, and other effects. Videos of the behavior are presented in the supplemental information (Videos S1, S2, and S3). We also note that it is difficult to ensure that all of the added water ends up on the beans in the grinder, and this likely contributes to the variability in each data point in Figure 2C.

Although we have not observed it in our hands, the addition of water could lead to residual water accumulation within the grinder. This could pose problems for bacterial growth within the chamber, corrosion of the burrs, or other effects. By placing a small humidity sensor (Honeywell HIH-4030) within the grinding volume of the EK43, we measured the buildup of moisture associated with the RDT. For additive water in the range of 0–50 μL g^{-1} and a base RH of 40%, we find that the relative humidity (%RH) within the grinder may increase up to 75% for a few tens of seconds (see Figure S2), but returns back to ambient within minutes. The water is presumably consumed in electrochemical reactions, or boiled off. We did not detect condensation. Grinding 10–20 dry beans after grinding the wetted ones returns the grinder to equilibrium %RH instantaneously.

Static reduction using ion beams

To move away from adding water, charge may also be neutralized by recombination with extrinsically generated negative and positive ions. Such techniques draw from an extensive heritage in other settings[20–22] and generally employ one of two methods: (1) corona discharge, which uses high voltages at sharp, conducting tips to accelerate naturally occurring free ions and also cause collisions with neutrals[21,23,24]; and (2) ionizing radiation, involving a radioactive or X-ray source to generate similar numbers of positive and negative ions.[25] Toward the former, high-voltage ionizers may be unipolar, involving net negative or positive ions, or balanced, where the production of negative and positive charges is equal. Some manufacturers have begun to include these devices in grinders or sell them as accessories to reduce charging.[26,27] Toward the (2), we examined a de-electrification using a helium nuclei source, Figure S4. However, given the results are largely similar to the effects produced by the balanced ionizer, but balanced ionizer present significantly less risk than using radioactive sources,[25] we have elected to not present those data in the manuscript and do not recommend the reader attempt that experiment.

Unipolar ionization. The efficacy of unipolar ionization on charge reduction can be tested using a high-voltage ionizer. The device consists of a bundle of fine carbon needles fed by a high-voltage source that can generate either 12 or −12 kV. The tip of the ionizer was placed at a

Table 1. Characteristics of in-house roasted coffee used in this work

	Yirgacheffe zero defect	Temascaltepec	Yogondoy
Origin	Ethiopia	México	México
Producer	Tamrat Alemayehu	Federico Barrueta	García Luna
Process	washed	washed	washed
Mass percentage of H_2O (initial)	12.0	8.9	9.3
Mass percentage of H_2O (dark)	1.0	1.3	1.1
Mass percentage of H_2O (light)	2.8	3.0	3.0
Agtron (dark)	62.1	58.4	60.2
Agtron (light)	88.7	70.1	93.1

controlled distance (30–120 mm) from the coffee grinder chute (see schematic in Figure 3A). Using a Gerdien condenser (AIC, AlphaLabs Inc.), we estimate the negative and positive ion densities to be 1.5 and 1.2 × 10^6 cm^{-3} at a distance of 0.3 m, respectively. These densities can be augmented by moving the bundle closer to the chute. To shield the Faraday cup from the direct influence of generated ions, we placed a coarse, grounded copper mesh over the cup's aperture.

The plots in Figure 3A show the Q/m ratios gained by dark and light roasts of the YirgZ and Yogondoy during grinding as a function of ion density, as measured by the Faraday cup. With the ionizer off, the dark roasts nominally charge negatively, whereas the light roasts gain positive charge. Systematically increasing the positive ion density reduces the negative Q/m of the dark roasts toward 0 nC g^{-1} (middle panel of Figure 3B). However, bringing the positive ion source too close to the chute causes a polarity flip and the dark roasts end up depositing positive charge into the Faraday cup. A similar effect is true for light roasts (rightmost panel of Figure 3B); low degrees of negative ionization reduce positive charge, but moderate-to-high ion densities result in negative charging.

These experiments demonstrate that corona discharge is highly effective at neutralizing charge and minimizing dispersal effects (i.e., mess, see Video S3), but only if the characteristics of the ion source are tuned to the charging behavior of a particular coffee. Despite originating from the same green coffee, the light and dark Yogondoy samples require vastly different ion densities and polarity to achieve a reduction in Q/m ratio comparable to that produced by the water addition technique. The dark roast necessitates ion densities around 6–7.5 × 10^6 cm^{-3}, whereas charge on the light roast is minimized between −5 and −2.5 × 10^6 cm^{-3}. While these ranges can be achieved by adjusting the distance between coffee and ion source, ion densities outside of these ranges compound existing problems (*increase* charge) and create new problems (such as scattering fine particles via an ionic wind). Because the behavior will depend on environmental variables such as humidity, coffee moisture, roast color, and other parameters, implementing unipolar ionization discharge necessitates trial and error.

Balanced ionization. If the charge behavior of a granular material is not known beforehand, implementing electrostatic reduction using ionizing devices that produce an equal number of positive and negative charge carriers may be effective. In general, these bipolar static eliminators concurrently produce positive and negative ions as well as electrons at atmospheric pressure in air. Here, we test a commercially available bipolar static eliminator (Shopcorp 12M). Like the unipolar setup, the bipolar systems generate ions from bundles of fine carbon needles. The positive and negative outputs were placed facing each other just below the chute of the EK43 grinder with a separation of 10 cm, Figure 3C. In the space between the outputs, we measured positive and negative ion densities in the range of ± 9.8 × 10^6 cm^{-3} (for a net ion density of ∼0 cm^{-3}).

During an experiment, ground coffee was allowed to fall through the volume of ionized air generated by the balanced ionizer. The bar graphs in Figure 3D show the Q/m ratios measured on dark and light roasts of all three coffees in the absence (gray bars) and presence (purple bars) of the balanced ionizer. For dark roasts (left panel), we observe a minimum reduction in Q/m ratio of ∼50%, comparable to that imparted by the RDT (at the highest water contents of 20–30 μL g^{-1}). For light roasts, we also see up to 90% reduction in electrification. Interestingly, light-roasted samples that nominally charge positively (YirgZ and Yogondoy) may occasionally acquire small negative charges in the presence of the balanced ionization. We suspect that this polarity flip reflects the higher mobility of electrons relative to that of much more massive positive ions, but it could also depend on the composition of the coffee itself. Note also that the balanced ionizer is overall less efficient than a properly tuned unipolar corona ionizer in its capacity to reduce charge. This observation is aligned with experiments in silos, which show that the most effective neutralization of negatively charged powders occurs not under balanced ionization but when the positive ion density is higher than the negative one by a factor of 2–3.[28]

Aggregate formation

For ionizing strategies, charge mitigation occurs at the chute exit, not in the grinder itself. Conversely, the water addition evidently passivates charging throughout the grinding process. These differences may have important effects on particle-wall adhesion, material loss, and clump formation, especially since previous work has shown that particles adhered to the wall can have Q/m ratios several dozen times larger than those forming the bulk.[29]

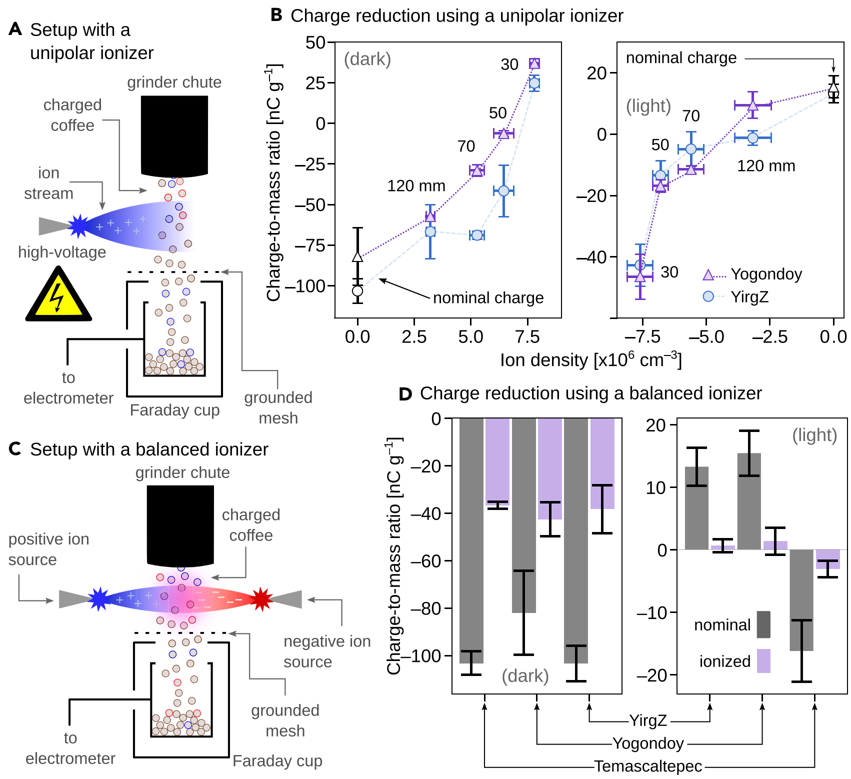

Figure 3. Ion beam charge reduction strategies

Charging may be counteracted by ionizing the air around the coffee grounds as these exit the grinder. Free negative and/or positive ions adhere to solid particle surfaces, tuning their charge.

(A) Ionization may be accomplished via high-voltage gaseous breakdown.

(B) While potentially effective, the number of positive and negative ions generated must be adjusted to balance the charging characteristics of a coffee. The nominal charging behavior of coffee with no de-electrification is presented in white. Dark coffees generally natively charge negatively, while light coffees charge positively. The distance between the ionizer and coffee is presented in mm.

(C) Negative and positive ions may also be generated via a bipolar high-voltage source.

(D) Exposing negatively charging coffee to a balanced ionizer reduces its charge by at least 50%.

Whether a particle of radius r with charge q will electrostatically adhere to a surface depends in part on its electrostatic-to-gravitational force ratio (EGR),

$$EGR = \frac{F_e}{F_g} = \frac{3}{4}\frac{kq^2}{\pi g \rho_p r^5}. \qquad \text{(Equation 2)}$$

where k is Coulomb's constant, ρ_p is the particle's density, and g is the acceleration due to gravity. Because $EGR \propto 1/r^5$, smaller particles are much more likely to adhere to surfaces than larger ones (for a given q). Thus, dry, charged coffee exiting the grinder tends to be depleted in small particles. Retained fines within the grinder must be knocked out mechanically. This segregation can be observed in Figure 4A, where we plot the size distribution of grounds directly expelled by the grinder (solid, brown curve) and that of grounds retained within the grinding cavity (dotted, brown curve) when 10 g of whole coffee is ground with no charge mitigation technique.

From Figure 2C, our data show that adding moisture to whole coffee reduces charging by at least 50%. This reduction would result in a 4-fold decrease in the EGR, possibly allowing small particles to overcome electrostatic adhesion and become reincorporated into the bulk. The effect is reflected in our data where the addition of 100 μL of water added to 10 g of whole beans produces an appreciable shift in particle size distribution toward smaller diameters, Figure 4A (dashed, blue curves). In fact, we observe a decrease in the mean particle size of expelled grounds up to water contents of 50 μL g^{-1} (see Figure 4B). However, at higher extrinsic moisture levels, the mean particle size again moves toward larger diameters due to the formation of moisture-promoted aggregation driven by capillary forces, rather than electrostatic ones.[30]

For the high-voltage ionization system, we do not see an analogous shift toward smaller particles sizes with increasing ion density (see Figure 4C). Comparing the masses of coffee retained under high-voltage ionization and the water addition technique, Figure 4D, even a modest 10 μL g^{-1} reduces retention to ~2.5%, whereas the high-voltage ionization method has retention percentages indistinguishable from those of no-treatment grinding (~12%).

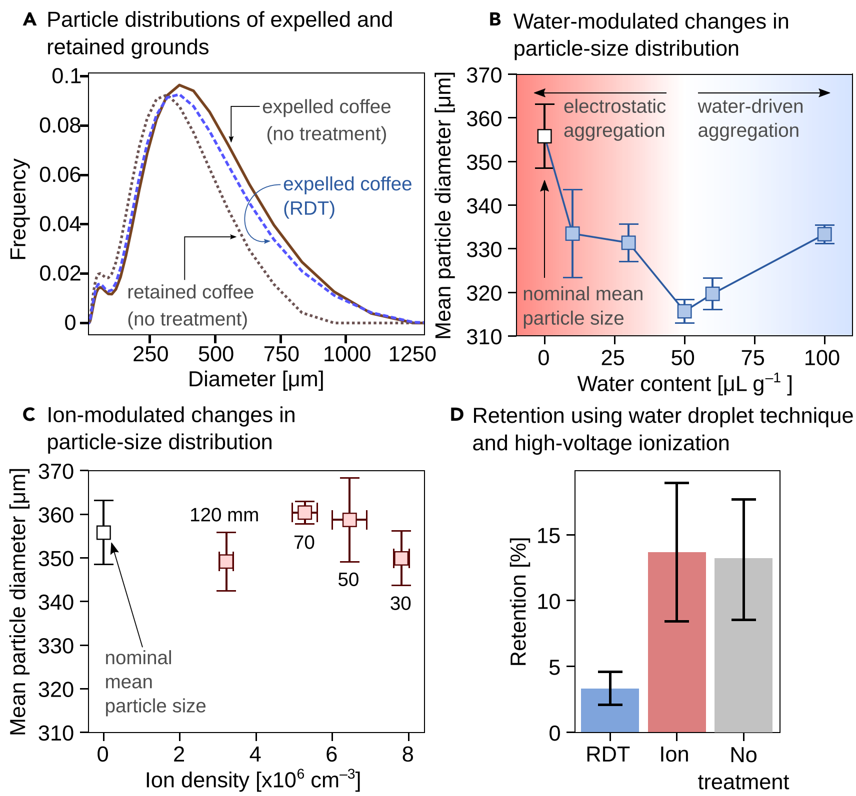

Figure 4. Particle aggregation and grinder retention

(A) For dry-ground coffee (Yogondoy [dark]), expelled grounds follow the particle size distribution that is presented in brown. Grounds retained within the grinding cavity concentrate fines (dotted, brown curve). Fines have higher electrostatic-to-gravitational ratios, meaning they are more likely to adhere to surfaces when charged. Adding even a small amount of water (10 μL g^{-1}) can significantly reduce electrostatic aggregation, reducing retention and shifting expelled ground particle sizes toward smaller diameters (dashed, blue curve).

(B) Water contents in the range of 0–50 μL g^{-1} continue to shift particle sizes toward smaller mean diameters. Water contents above 50 μL g^{-1} again increases the mean particle size, indicating the activation of wet (capillary) aggregation processes.

(C) A linear shift in mean particle size and ion density is not observed for coffee treated with a unipolar corona ionizer at different chute-ionizer distances. These data suggest that fine particles within the grinder are not included in the measurement sample (that is, they remain electrostatically adhered to the inner surfaces of the grinder), and the aggregates are formed before deionization, which is to be expected since the corona ionizer is placed after the chute.

(D) Because the water addition technique (RDT) hinders electrification throughout the grinder, the wet method (using 10 μL g^{-1}) has the ability to greatly reduce retention. Ionization (7.8 × 10^6 cm^{-3}), addressing static only at the grinder chute, involves retention masses similar to those of grinding with no static mitigation treatment. Grind data in A–C were collected in triplicate, and the averages are presented.

The effect of charge mitigation on espresso quality

In principle, charge mitigation during grinding should provide better control on the characteristics of the grounds used during coffee brewing. However, as evident from Figure 4, disparate charge reduction methods, while generally effective at reducing a material's Q/m ratio, do not necessarily generate granular materials with equatable properties. How do these differences influence brewing?

In our previous work,[2] we demonstrated that adding small amounts of water to beans prior to grinding changed the brewing behaviors when preparing espresso. Figure 5A exemplifies such behaviors. There, we plot the shot time (left panel) and flow rate for espresso brewed with and without added water, following the espresso preparation method discussed in the STAR Methods section. For these experiments, we employed the dark roasted Temascaltepec. Mitigating charge with extraneous water results in extended shot times, decreased flow rates, and increased percentages of total dissolved solids (%TDS) as compared to no charge mitigation. We interpreted these findings to reflect the breaking or rearrangement of electrostatically bound aggregates, resulting in a particle bed with smaller average grain size and, thus, reduced permeability. The data in Figures 4A and 4D suggest that an additional mechanism may also be operative: added water dislodges a large number of small particles that would otherwise remain trapped within the grinder.

The impact of shifting the distribution finer is enormous. Keeping all variables the same, a remarkable 16% increase in coffee concentration is achieved. Such increase in accessible coffee material in comparable brew times, Figure 5A, poses significant financial implications for the coffee industry, allowing for more efficient use of dry mass coffee, at the cost of adding less than 0.5 mL of water to the whole beans during grinding.

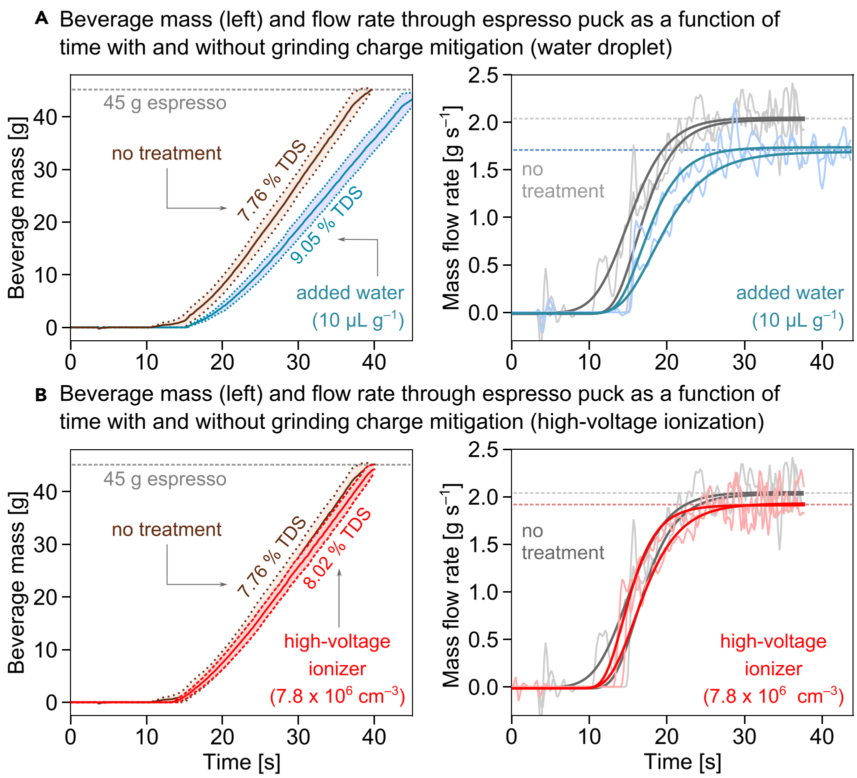

Figure 5. Espresso shot time and flow rate dependence with and without charge mitigation for a dark roast (Temascaltepec)

(A) Without changing any brewing parameters, coffee prepared using the addition of water to whole beans during grinding produces consistently longer shots (left) with reduced flow rates. The shot flow rate can be fit using a generalized logistic function such that the permeability of the bed approaches a constant (right). Note that the time it takes an espresso prepared with water to reach this plateau is significantly longer than that of an espresso brewed conventionally.

(B) Using a positive high-voltage ionizer, we do not observe an appreciable increase in shot time or a reduced flow rate. We do observe a modest increase in % TDS. The departure from the behavior observed with the RDT highlights the fact that ionization methods at the grinder chute do not address electrostatic effects within the grinder cavity and highlights the importance of de-electrification during grinding. Shots were run in triplicate and compared to the untreated samples. For a p value of 0.05, the ionization treatment is not significantly different from the native charging sample (t value of −1.625). However, the water addition treatment was found to be significantly different (t value of 6.059) at the same p value.

Conversely, charge reduction using an ionizing source at the grinder chute does not produce a reduction in the mean particle size, nor does it decrease grinder retention (see Figures 4C and 4D). As evident in Figure 5B, we observe nearly indistinguishable differences in espresso shots prepared with or without the ionizers. The modest increase in %TDS from 7.76% to 8.02% (average over five replicates) is still notable and can be attributed to some fine particles being liberated from boulders. These data suggest that ionization techniques perhaps do cause some aggregates to break up as these exit the chute, but the effect is limited. However, they do not propitiate the reincorporation of small particles bound electrostatically to the interior surfaces of the grinder and burrs. Thus, unlike the addition of water, discharging coffee at the nozzle produces limited changes to the physical characteristics of the grounds used to brew coffee compared to the untreated samples.

For dark coffees, added water prior to grinding can generate appreciable differences in espresso brew characteristics, Figure 5. Similar experiments with a lightly roasted sample of the same coffee (Temascaltepec) do not reveal significant changes to espresso brew characteristics, either with extrinsic water or ionization (Figure S3). As noted in our previous work,[2] darker roasted coffees not only charge negatively but also acquire the highest absolute Q/m ratios. Lighter roasts charge more ineffectively, with coffees with ∼2% residual water acquiring Q/m ratios near 0 nC g^{-1}. Consequently, electrostatic effects like clumping and sheeting are markedly less present when grinding lighter roasts. That the addition of extrinsic water or ionization does little to modify the properties of the bed is, thus, not surprising.

Conclusion

We have assessed the performance of a range of electrostatic reduction techniques in the context of coffee grinding. Added moisture and high-voltage ionization effectively counteract charging generated through fracto- and triboelectric charging. At minimum, both techniques have the potential to decrease the gravimetric charge by at least 50%. Unipolar ionization methods can reduce the Q/m ratios of expelled coffee to near zero if appropriately tuned to a given coffee. Bipolar or balanced ionization may be less effective than unipolar ionization but can produce charge reductions comparable to those afforded by water addition. However, ionization generally does not address electrification processes and adhesion dynamics within the grinder. As such, ionization methods at the grinder chute do not mitigate material loss (retention), which, for a grinder like the EK43, can be hundreds of milligrams of dry material. Conversely, the charge reduction afforded by water addition (volumes ranging from 0 to 50 $\mu L\ g^{-1}$ dry mass coffee) has the capacity to resolve aggregation effects across the entire grinding system, even if particles retain some charge. Because particle-wall aggregates comprise smaller grains, we find that reincorporating this material into the bulk significantly changes the espresso brewing behavior (slower shots and smaller flow rates) and resultant increase in coffee solubility. And while our experiments conclusively demonstrate the economic upside of water incorporation during grinding for espresso, we suspect a similar effect will be observed for all percolation brewing techniques, as liberation of fine particles will not only clog void space in the coffee bed but also fill voids in filter paper in pour-over embodiments.

Limitations of the study

Although the selected coffees do span a range of origins and processing methods, and were roasted to span colors commonly found in the specialty coffee sector, there may be coffee samples that fall outside the typical parameter space considered here (i.e., initial and post-roast moisture, bean color, origin, and even species). Furthermore, in our hands, we consistently observe the impact of reduced flow and increased extraction as a function of shift in particle size distribution. However, there may exist some parameter space where a coffee requires different volumes of water added to the coffee to observe the effect. Similarly, the rate of de-electrification achieved by grinding and waiting may be impacted by subtle variables such as grind size and humidity.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

- RESOURCE AVAILABILITY
  - Lead contact
  - Materials availability
  - Data and code availability
- METHOD DETAILS
- QUANTIFICATION AND STATISTICAL ANALYSIS

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2024.110639.

ACKNOWLEDGMENTS

J.M.H. acknowledges support from start-up funds at Portland State University. C.H.H. acknowledges support from the National Science Foundation under grant no. 2237345 and the Camille and Henry Dreyfus Foundation. This work was supported by the Coffee Science Foundation, underwritten by Nuova Simonelli. The work was enabled by donations of green coffee from Farmers Union and Finca La Ilusión. We are grateful to Ikawa for providing the roaster, Pentair for providing the reverse osmosis water filtration system, and Tailored Coffee, Eugene, OR for the use of the EK43.

AUTHOR CONTRIBUTIONS

J.M.H., R.E.B., and C.H.H. all partook in conceptualization, data collection and interpretation, and drafting of the manuscript. J.M.H. and C.H.H. acquired the funding and supervised the research.

DECLARATION OF INTERESTS

The authors declare no competing interests.

Received: February 27, 2024
Revised: June 11, 2024
Accepted: July 30, 2024
Published: August 5, 2024

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STAR★METHODS

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Prof. Christopher H. Hendon (chendon@uoregon.edu).

Materials availability

The study did not generate new unique materials. The readers can buy the chemicals to remake the materials as mentioned in the text.

Data and code availability

Data: All data reported in this paper can be accessed at https://doi.org/10.6084/m9.figshare.24737700.

Code: This paper does not report the original code. Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

METHOD DETAILS

We electrified coffee by grinding whole beans using a Mahlkönig EK43 grinder with stock 98mm burrs. Here we conducted experiments using three coffees (two Mexican coffees and one Ethiopian) roasted in-house on an Ikawa Pro100 roaster following two temperature profiles (see Figure S1), yielding dark and light colors. Salient characteristics of both green and roasted coffee are noted in Table 1. The coffee color/roast degree and internal water content were measured using The Dipper KN-201 and a RoastRite RM-800, respectively. The RoastRite uses capacitance to report moisture content, and is potentially susceptible to environmental convolution. To ensure quantitative moisture reporting, the device was calibrated to an Ohaus MB23. In our hands (at 35 %RH), the RoastRite factory software provided readings that were identical to the Ohaus device.

We assessed the performance of four techniques to reduce static generated during grinding: time-resolved discharge, the addition of external water, unipolar corona discharge, and balanced corona discharge. With the exception of the grind-and-wait technique, all experiments consisted in applying an electrostatic reduction technique during grinding and measuring the residual charges on particles exiting the grinder using a Faraday cup. Charge-to-mass (Q/m) ratios were then calculated, allowing comparative analysis between the various techniques. The particulars of each method are described in the sections that follow.

Roasted coffee was stored in sealed, evacuated bags and kept at -20°C. Prior to grinding the coffee was allowed to reach equilibrium temperature before unsealing. For all experiments, we used a grind setting of 2.0 (arbitrary units) on the EK43, producing particle size distributions comparable to those shown in Figure 1B. Particle size measurements were performed on a Malvern Mastersizer 2000 with the solid-particle feed system, Scirocco 2000. Experiments were conducted at 20 $\pm 3^{\circ}$ C and 35 $\pm$7% RH. Each Faraday cup experiment was conducted a minimum of 3 times. Surface charges were measured using a Keithley 614 electrometer.

Espresso was prepared using 18.0 g of dry mass coffee, with shots stopped at 45.0 g of liquid coffee extract. The coffee was ground to an arbitrary setting of 1.0 on our EK43, tamped at 196 N, and brewed using 94°C water, kept at 7 bar of static water pressure with a 2 second pre-infusion on a Victoria Arduino Black Eagle.

QUANTIFICATION AND STATISTICAL ANALYSIS

Statistic were obtained from the samples prepared per their description in the methods.