Know Your Beans:
Quality Control of Coffee by Dynamic Image Analysis

Relevant for: Litesizer DIA, food powders, particle size, shape analysis, coffee beans, ground coffee

Roasting and grinding are major sources of variability for the quality of coffee. Particle size measurement of whole roasted coffee beans with the Litesizer DIA highlights contamination with fine particles, while particle shape analysis underscores the degree of breakage. On ground coffee, particle size analysis is essential to tailor the grinding process to the brewing method.

1 Introduction

With an estimated 2.2 billion cups drank each day, coffee is one of the most widely consumed beverages globally, and one of the most traded agricultural commodities. Its production is overwhelmingly concentrated in tropical regions, where it provides a key source of livelihood for an estimated 25 million farming households (1).

With such a variety of producers, coffee manufacturers need to perform strict quality control at all steps of the chain to ensure the continuity of their product's sensory profile.

While the main sources of variability for green beans are climate, soil type, topography and storage, the roasting and grinding steps are also major sources of variability for the finished product.

Establishing morphological quality control criteria is an essential tool to minimize the amount of tasting necessary, both for whole roasted beans and for ground coffee. Here, we demonstrate how Litesizer DIA 500, Anton Paar's Dynamic Image Analysis (DIA) instrument, can be used to perform this task.

2 Experimental Setup

2.1 Samples & Sample Treatment

Two commercial, whole bean coffee samples are used for this study. The first sample, hereafter referred to as “Arabica sample”, is a general-purpose coffee constituted at 100 % of roasted beans of the Arabica species. The second sample, hereafter referred to as “blend sample”, is a coffee destined for espresso machines and constituted of 80 % Arabica, and 20 % Robusta roasted beans.

A first set of measurements is conducted on the whole, unground samples. A second set of measurements is conducted on the samples ground with a household electrical burr grinder. For the latter set of measurements, independent, 10 g samples are ground for 30 seconds using the burr grinder at 4 different settings, for both coffee samples.

2.2 Litesizer DIA 500 Measurements

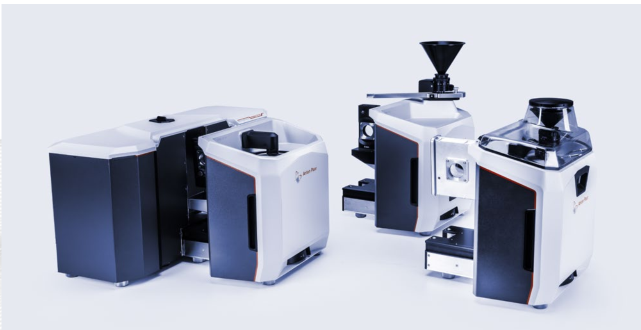


Figure 1: Litesizer DIA 500 with the Liquid Flow, Free Fall and Dry Jet dispersion units.

Litesizer DIA 500 is a modular dynamic image analysis instrument, where the main unit is coupled to one of 3 possible dispersion units (Figure 1).

Besides a dispersion unit dedicated to liquid samples (Liquid Flow) and another for dry powders using compressed air (Dry Jet), the instrument can analyze powders and free-flowing materials using the Free Fall dispersion. In this dispersion unit, the sample is mobilized from the hopper to the chute by a vibrator, and then flows in front of the camera simply by gravity (Figure 2). This dispersion method has the advantage of applying only minimal mechanical force to the sample, making it the dispersion of choice for fragile samples.

Litesizer DIA 500 is a single-camera, dual-objective instrument. The measuring range of the zoom objective is between 0.8 and 300 µm, while that of the standard objective is between 10 µm and 8 mm. For the broadest particle size distributions, an automatic switching between objectives and a merging of the results can be used.

Full measurement parameters used for the whole and ground coffee samples are detailed in Table 1 below:

Parameter	Whole coffee beans	Ground coffee beans
Dispersion unit	Free Fall	Dry Jet
Magnification mode	Standard objective	Standard objective
Acquisition mode	Automatic	Manual, 50 fps
Measurement time	03:00	01:00
Additional stop criteria	None	Number of particles = 300 000
Frame coverage target	Default	Default
Air pressure	n/a	200 mBar
Feeding mode	Manual	Manual
Feeding rate	70 %	60 - 70 %
Velocity correction	None	None

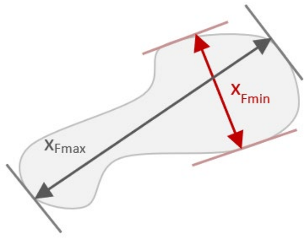
Table 1: Measurement parameters for whole and ground coffee measurements with Litesizer DIA 500.

2.3 Expressing Particle Size and Shape in Dynamic Image Analysis

In dynamic image analysis, the particle size is calculated from the particle's 2-dimentional projection, as seen and captured by the camera. Commonly used methods for calculating the equivalent spherical diameter from the particle's projection are the Feret diameter (x_F) and the area-equivalent diameter (x_A).

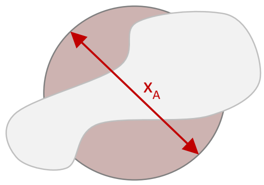
The Feret diameter x_F (Schematic 1) corresponds to the distance between two parallel planes tangent to the outline of the particle.

The minimum and maximum distances between these planes are named minimum and maximum Feret diameter (x_{Fmin} and x_{Fmax}), respectively.



Schematic 1: Minimum (x_{Fmin}) and maximum (x_{Fmax}) Feret diameters

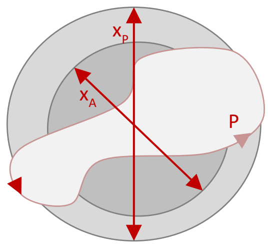
The area-equivalent diameter x_A (Schematic 2) represents the diameter of a sphere with the same projected area (A) as the particle's projection.



Schematic 2: Area-equivalent diameter (x_A)

Particle shape analysis is also derived from the particle's projected outline. The Litesizer DIA 500 automatically calculates 10 different particle shape parameters, from aspect ratio, to elongation, compactness, convexity, etc.

In this report we focus on the shape parameter termed circularity, which corresponds to the degree to which the particle's projected area is similar to a circle, considering the smoothness of the perimeter (Schematic 3).



Schematic 3: Circularity as shape parameter

Circularity is calculated as x_A/x_P, where x_A is the area-equivalent diameter, and x_P is the diameter of a circle having the same perimeter (P) as the particle's projection. The result is a dimentionless number between 0 and 1, with the value 1 representing perfectly smooth, spherical particles.

3 Results and Discussion

3.1 Whole Bean Measurements in Free Fall Mode

Because coffee flavors are volatile and easily oxidize when in contact with air, they are much better preserved when the beans are whole as opposed to ground. But since roasting makes the beans brittle, a certain level of breakage systematically occurs during processing, storage and transport, resulting in the splitting of beans and the production of fine particles. One can therefore expect that the least breakage and contamination with fine particles are present, the better the flavors will be preserved.

Figure 2: Whole coffee beans can be analyzed thanks to the Free Fall dispersion's large-sized vibratory hopper and chute.

Whole coffee beans are analyzed using the Litesizer DIA 500 in Free Fall mode (Figure 2) in order to determine the level of contamination with fine particles as well as the level of breakage of the whole beans.

3.1.1 Identifying Fine Particle Contamination with Particle Size Analysis

In order to better identify the samples' fine particle fraction, particle size distribution results are expressed using the number-based weighting model, and the minimal Feret diameter (x_{Fmin}) as size model.

As shown in Figure 3, the particle size distributions for both coffee samples are dominated by peaks culminating at or above 8 mm, corresponding to the whole beans. However, an ultra-fine fraction (ca. 10 to 60 µm) is clearly identifiable, together with a fine fraction (ca. 60 to 1000 µm).

Interestingly, this fine fraction (60 – 1000 µm) is much more prominent in the Arabica as in the blend sample. This is confirmed by analysis of the Q-values for the number-based x_{Fmin} (Table 2). Indeed, while the differences between the 2 samples' Q_{10} and Q_{90} are minimal, the values for Q_{50} (median size) are starkly different, at ca. 280 µm for the Arabica and ca. 6520 µm for the blend sample.

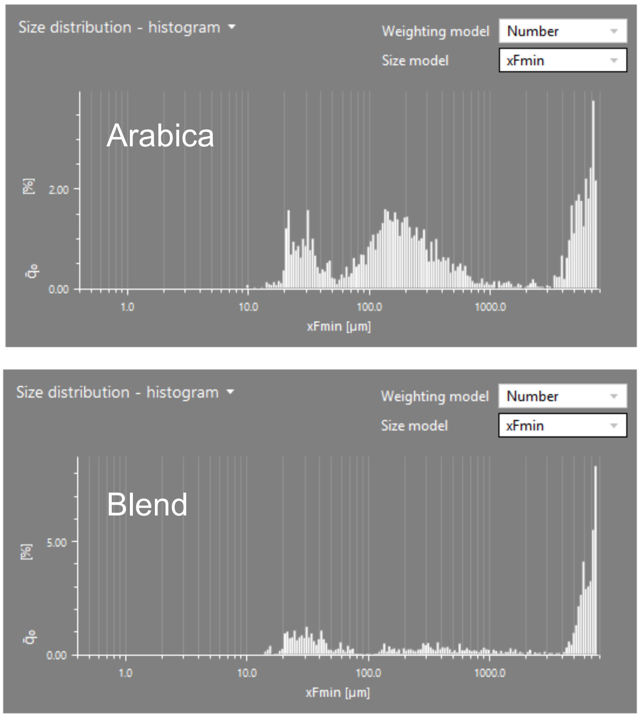


Figure 3: Number-based particle size distributions for the minimal Ferret diameter (X_{Fmin}) of whole coffee bean samples, measured in Free Fall mode. Top: Arabica sample; bottom: blend sample.

Sample	Q_{10} (X_{Fmin}) [µm]	Q_{50} (X_{Fmin}) [µm]	Q_{90} (X_{Fmin}) [µm]
Arabica	30.5	**279.7**	7769.6
Blend	32.0	**6522.3**	7986.1

Table 2: Number-based Q-values for the minimal Feret diameter (x_{Fmin}) of the 2 whole coffee bean samples, measured in Free Fall mode.

This indicates that the Arabica sample is significantly more contaminated with fine particles than the blend sample.

3.1.2 Identifying Whole Bean Breakage with Particle Shape Analysis

In order to evaluate the level of breakage of the whole beans, a particle shape analysis is conducted on the same set of results.

For this analysis, a filtering of the results is conducted to only consider the sample's fraction representing the whole beans, and not the contaminating fine fraction.

This filtering function is made possible in the Litesizer DIA software by the fact that every particle is analyzed individually, and that all the particle's attributes are stored in a database together with the particle's image (Figure 4).

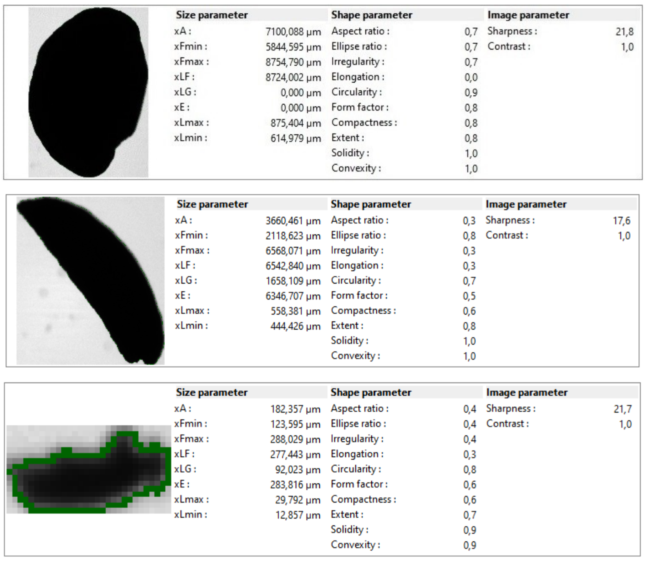


Figure 4: Individual datasets from representative Arabica sample particles, as viewed from the particle database when performing data filtering.

Filtering was performed on the datasets to eliminate particles with a number-based x_{Fmin} below 3 mm, considered to be contaminating debris. Of the 10 different shape parameters available in the software, circularity was considered the one best describing potential bean breakage.

As shown in Figure 5 below, the blend sample displays higher overall circularity than the Arabica sample. Additionally, the span of the circularity distribution (broadness of the curve) is significantly higher in the Arabica sample than in the blend sample (see Table 3), indicating a more diverse circularity profile.

Taken together, these observations suggest that the Arabica sample has suffered more bean breakage than the blend sample.

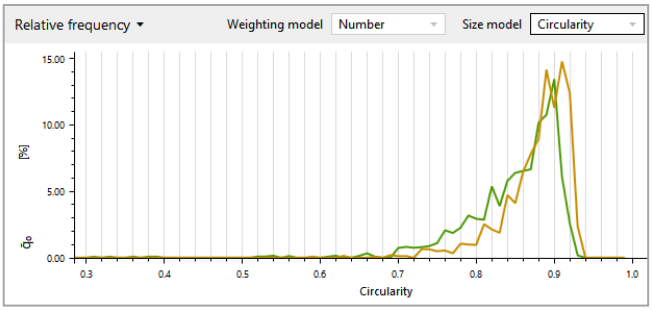


Figure 5: Number-based circularity distribution, for the Arabica sample (green curve) and the blend sample (yellow curve). Results filtered for particles with number-based $x_{Fmin} \geq 3$ mm.

Sample	Q_{10} (Circularity)	Q_{50} (Circularity)	Q_{10} (Circularity)	Span
Arabica	0.775	0.870	0.909	**0.154**
Blend	0.825	0.893	0.924	**0.111**

Table 3: Number-weighted circularity Q-values for the whole coffee bean samples measured in Free Fall mode – data filtered for particles with number-based $x_{Fmin} \geq 3$ mm.

3.2 Ground Coffee Measurements in Dry Jet Mode

The particle size of ground coffee, together with the brewing method, crucially influences the final taste of the infusion. During brewing, the different coffee flavors are not extracted at the same time. Acidic and fruity notes are released first, followed by sweetness, and, last, bitterness. A grind that is too coarse for the brewing method will result in an under-extracted brew, which will have too little sweetness and bitterness to counter the acidity, and will therefore taste sour. In contrast, a grind that is too fine for the brewing method will lead to an over-extracted brew, in which the bitterness will overwhelm the finer sweet and sour notes (2).

Hence, grinding must be perfectly adapted to each brewing method (Table 4) and, for industrially ground coffee, the size of particles must be tightly monitored.

Grind type	Mean Particle Size	Best adapted for...
Very coarse	1.8 – 3.0 mm	Cold brew coffee
Coarse	1.4 – 1.8 mm	French press coffee
Medium	0.8 – 1.4 mm	Filter coffee
Medium fine	0.5 – 0.8 mm	AeroPress coffee
Fine	0.2 – 0.5 mm	Espresso, moka coffee
Very fine	0.05 – 0.2 mm	Turkish coffee

Table 4: Coffee grinds and corresponding average particle size best adapted for the different brewing methods (3)

Here we study four different grinds for both the Arabica and the blend sample: coarse, medium, medium-fine, and fine – hereafter referred to as "espresso" grind.

The samples are then analyzed for particle size using the Litesizer DIA 500 equipped with the Dry Jet dispersion. The Dry Jet dispersion is chosen over the Free Fall dispersion because ground coffee is a relatively cohesive powder, and therefore needs the application of compressed air to perfectly disperse the particles. A low compressed air pressure of 200 mBars proves enough to perfectly disperse the sample, while minimizing the applied mechanical stress.

In order to best represent the grinding efficiency, particle size results are here expressed as volume-weighted area-equivalent diameter.

As shown in Figure 6 and Table 5, the median particle size for the ground Arabica samples ranges from 1.9 mm for the coarse grind, 1.2 mm for the medium grind, 0.6 mm for the medium-find grind, and finally 0.24 mm for the espresso grind.

These values correspond well to the particle sizes recommended for, respectively, the French press, the filter coffee, the AeroPress and the espresso brewing methods (see Table 4).

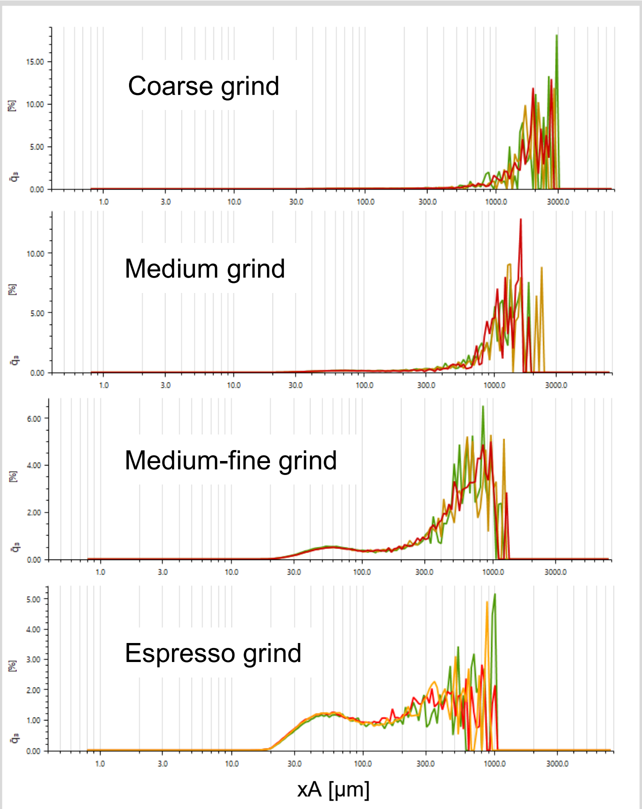


Figure 6: Volume-weighted particle size distribution of different grinds of the Arabica sample, expressed as area-equivalent diameter (xA). Overlay of 3 consecutive Dry Jet measurements.

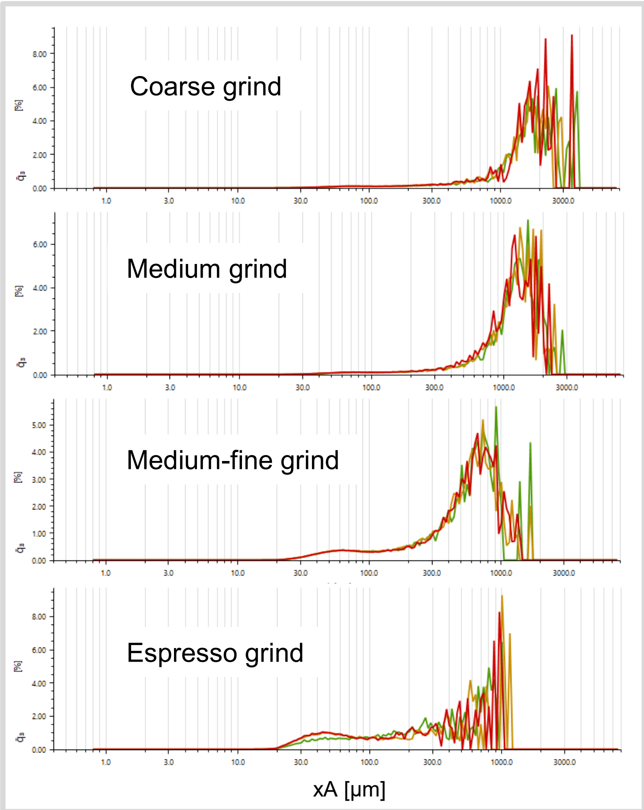


Figure 7: Volume-weighted particle size distribution of different grinds of the blend sample, expressed as area equivalent (xA). Overlay of 3 consecutive Dry Jet measurements.

Grind	Q_{10} (xA) [µm]	Q_{50} (xA) [µm]	Q_{90} (xA) [µm]
Coarse	991.4 ± 93.6	1949 ± 70.9	2791 ± 134.5
Medium	474.3 ± 45.1	1226 ± 55	1821 ± 284.3
Medium-fine	88.3 ± 5.9	601.8 ± 9.8	1005 ± 34.5
Espresso	42.7 ± 1	**242.5 ± 14.2**	794.4 ± 42.8

Table 5: Volume-weighted Q-values for the area-equivalent diameter (x_A), for different grindings of the Arabica sample. Mean ± standard deviation from 3 consecutive Dry Jet measurements.

Grind	Q_{10} (xA) [µm]	Q_{50} (xA) [µm]	Q_{90}(xA) [µm]
Coarse	688.1 ± 50	1759 ± 40.9	3007 ± 391.1
Medium	564.2 ± 33.9	1287 ± 58.5	1967 ± 37.7
Medium-fine	139.0 ± 3.3	621.1 ± 12.3	1029 ± 36.3
Espresso	48.4 ± 7.9	**374.3 ± 20.9**	983.2 ± 88.3

Table 6: Volume-weighted Q-values, for the area-equivalent diameter (x_A), for different grindings of the blend sample. Mean ± standard deviation from 3 consecutive Dry Jet measurements.

Results obtained on the ground blend sample (Figure 7, Table 6) are similar to that obtained on the Arabica sample for coarse, medium and medium-fine grinds. However, results obtained on the espresso grind display noticeable differences, with the fine fraction less prominent in the blend compared to the Arabica sample. This is also reflected in a statistically significative difference in the volume-based Q_{50} (x_A), with the blend sample displaying a median size of 374 µm against the Arabica's 243 µm.

Together, these observations suggest that the burr grinder is effective and produces similarly sized particles regardless of the coffee sample when used with the coarse, medium and medium-fine grind settings. However, the espresso grind results reveal differences between samples, suggesting that the burr grinder cannot ground the more robust, breakage-resistant blend sample as finely as the more brittle Arabica sample.

4 Conclusion

Litesizer DIA 500 can perform particle size and shape analysis on both whole and ground coffee samples in a fast and reproducible manner.

While the Free Fall dispersion unit is instrumental to the analysis of the free-flowing whole beans, ground coffee samples require analysis with the Dry Jet dispersion unit, which disperses cohesive powders with compressed air.

Results obtained on a 100 % Arabica sample and on a blended, 80 % Arabica and 20 % Robusta sample suggest that the pure Arabica is more subject to breakage and more contaminated with fine particles than the blend. The Arabica particles also reach a finer median size when processed in a burr grinder using the fine (espresso) setting, confirming the sample's increased brittleness.

5 References

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