WORLD OF COFFEE
COPENHAGEN
JUNE 27–29 2024

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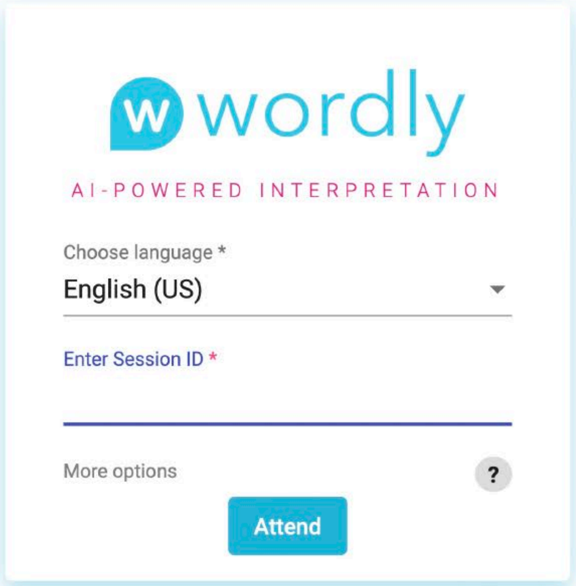

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The five drivers of extraction

Dr. Marco Wellinger – Coffee Excellence Center, ZHAW

29th July 2024

The five drivers of extraction

Almost infinite list of influences on extraction

We argue to focus on five main drivers:

- Extraction temperature
- Particle size / distribution
- Extraction time
- Concentration gradient
- Height of coffee bed

1 Extraction temperature

Typical ranges:

Espresso: 88-96 °C – optimum most closely related to roast level and beverage size

Temperature also impacts extraction dynamics (resistance)

Filter coffee: 85-96°C - some successful WBrC competitors have used temperatures as low as 80°C – especially towards the end of the extraction

Immersion: 80-96°C – lower (kettle) temperature is needed to achieve the same extraction tempearature (in the coffee bed) – due to less lower ratio of surface area to volume

0-100 °C - also at the extremes are used for cold brew or some rare older boiling methods (e.g. percolator or cowboy coffee)

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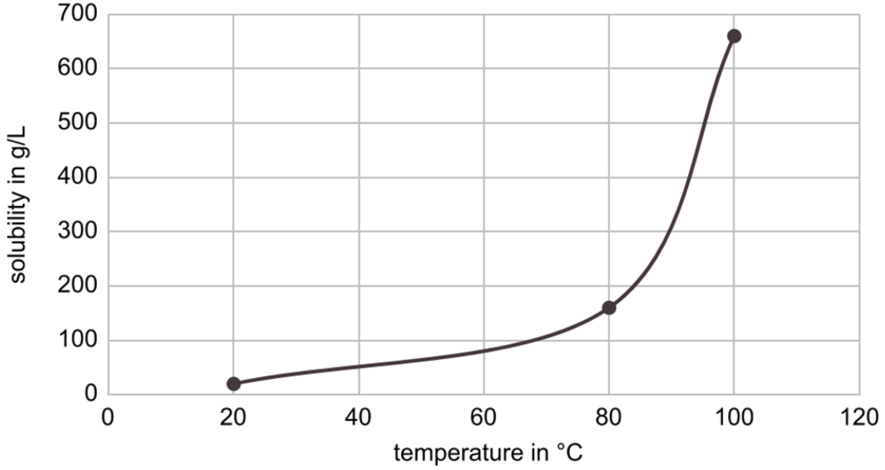
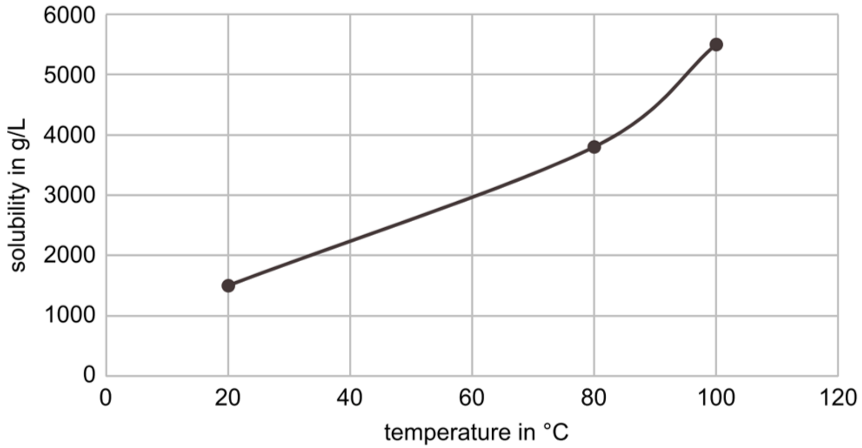
Solubility of most compounds increases with temperature

Caffeine



Mestdagh, et al., 2017

Citric acid

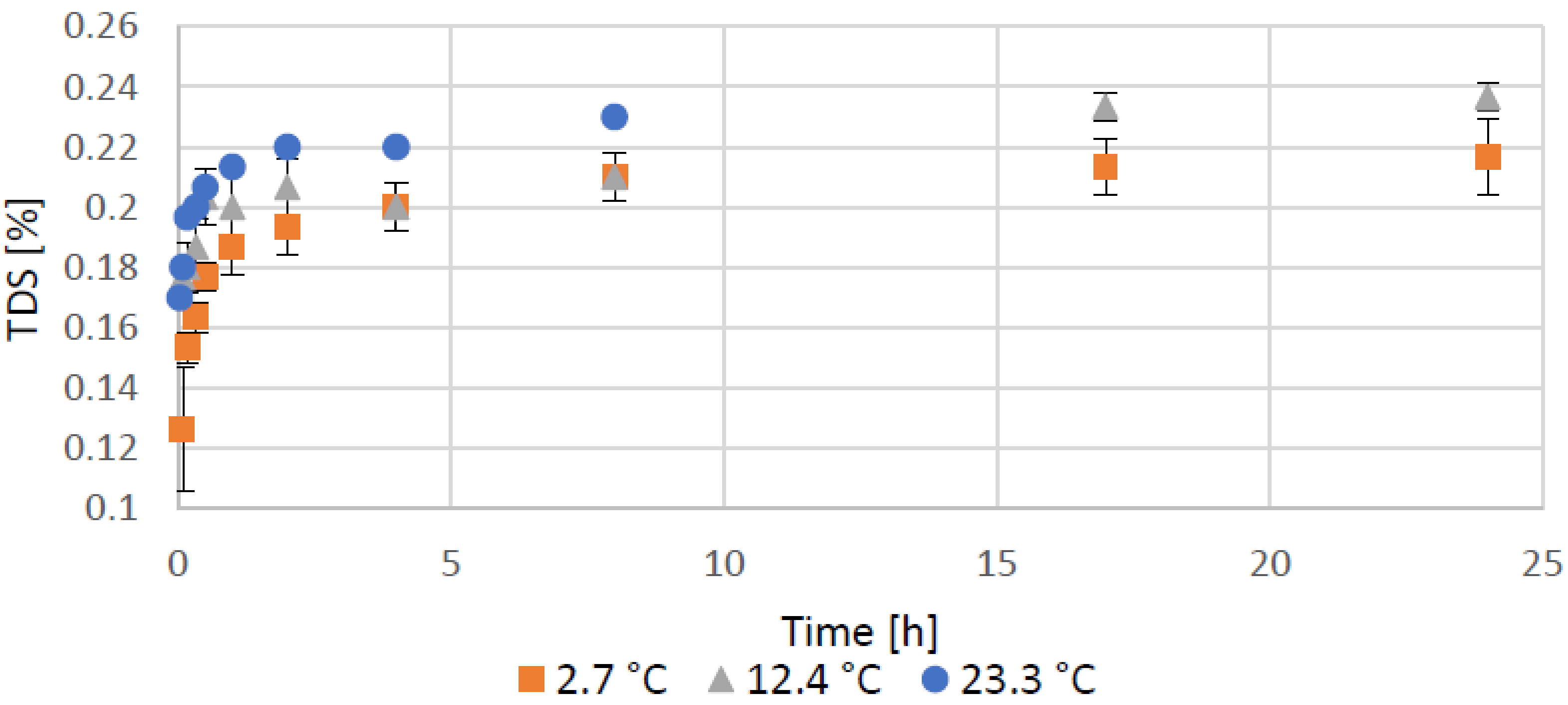


Mestdagh, et al., 2017

Extraction at different temperatures

Highly diluted immersion (max. yield)

- Marija Vincetic BSc, 2020

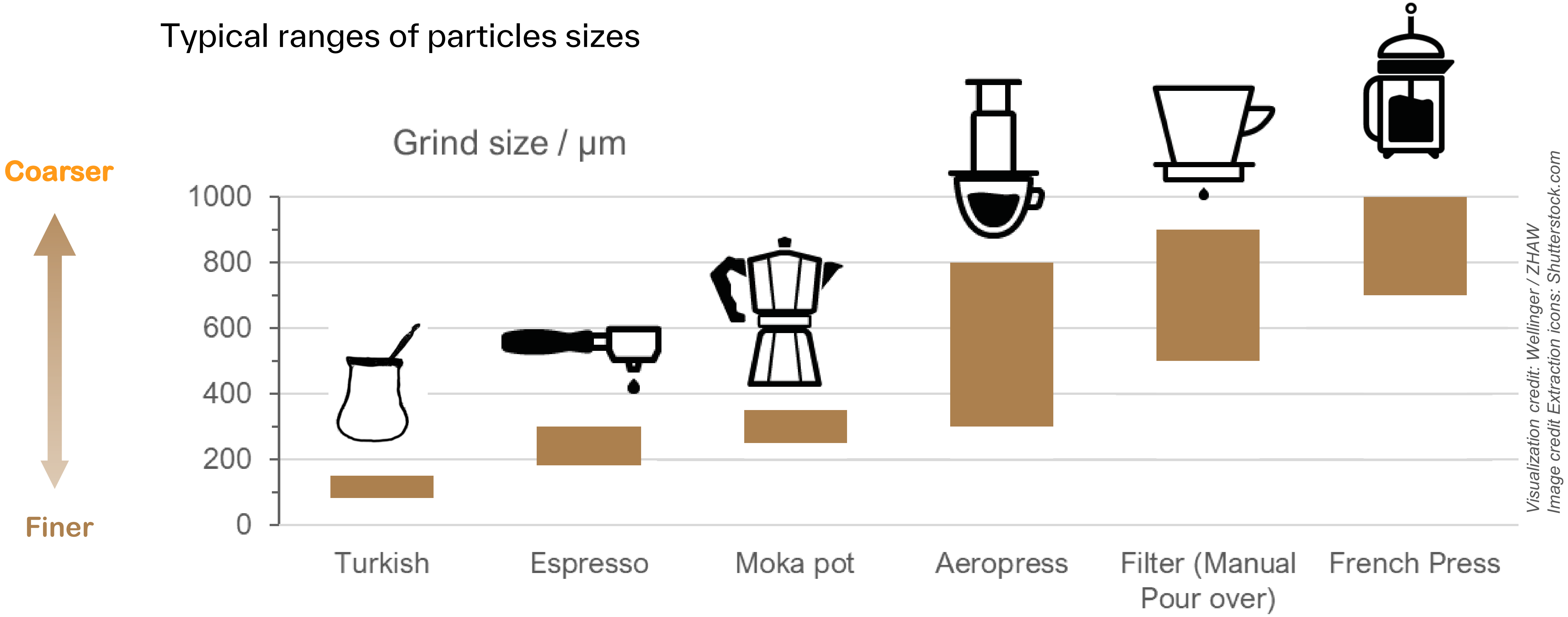


Conclusions from experimental series on temperatures

- Non-volatiles have most often shown an increasing trend when increasing temperature
- Changes in the typical range of 88-96°C are rather small and often not significantly different
- For high-volatile compounds (e.g. aromas) a loss of intensity has sometimes been observed when increasing temperature – most likely due to volatilization (escapes into the air)

2 Particle size & distribution

Typical ranges of particles sizes



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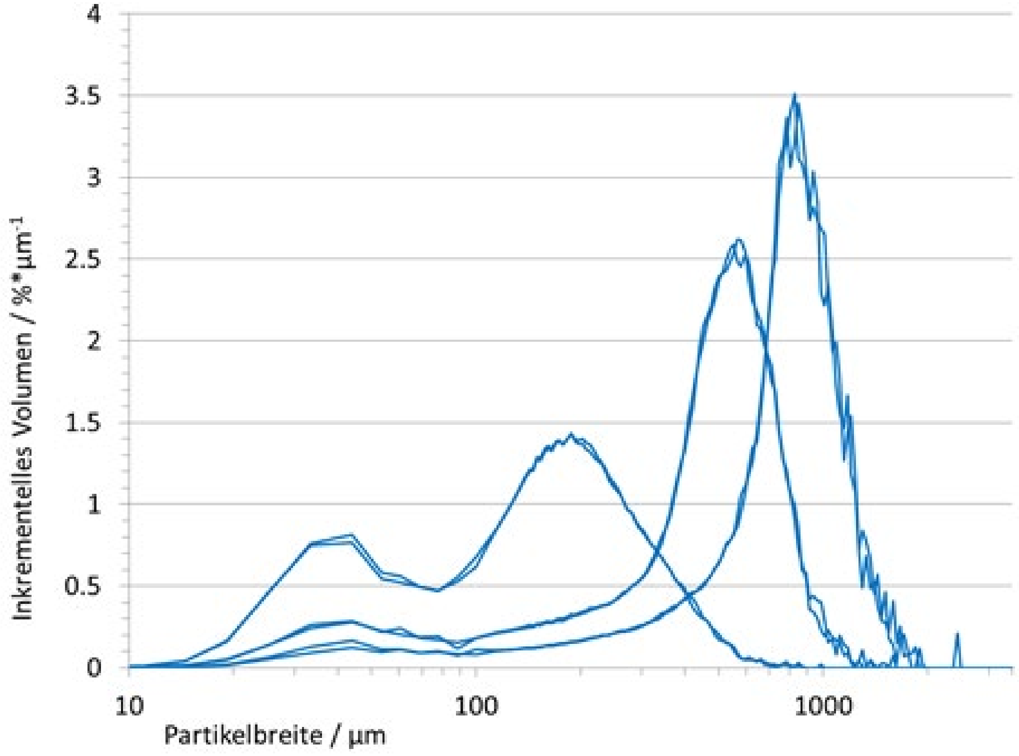
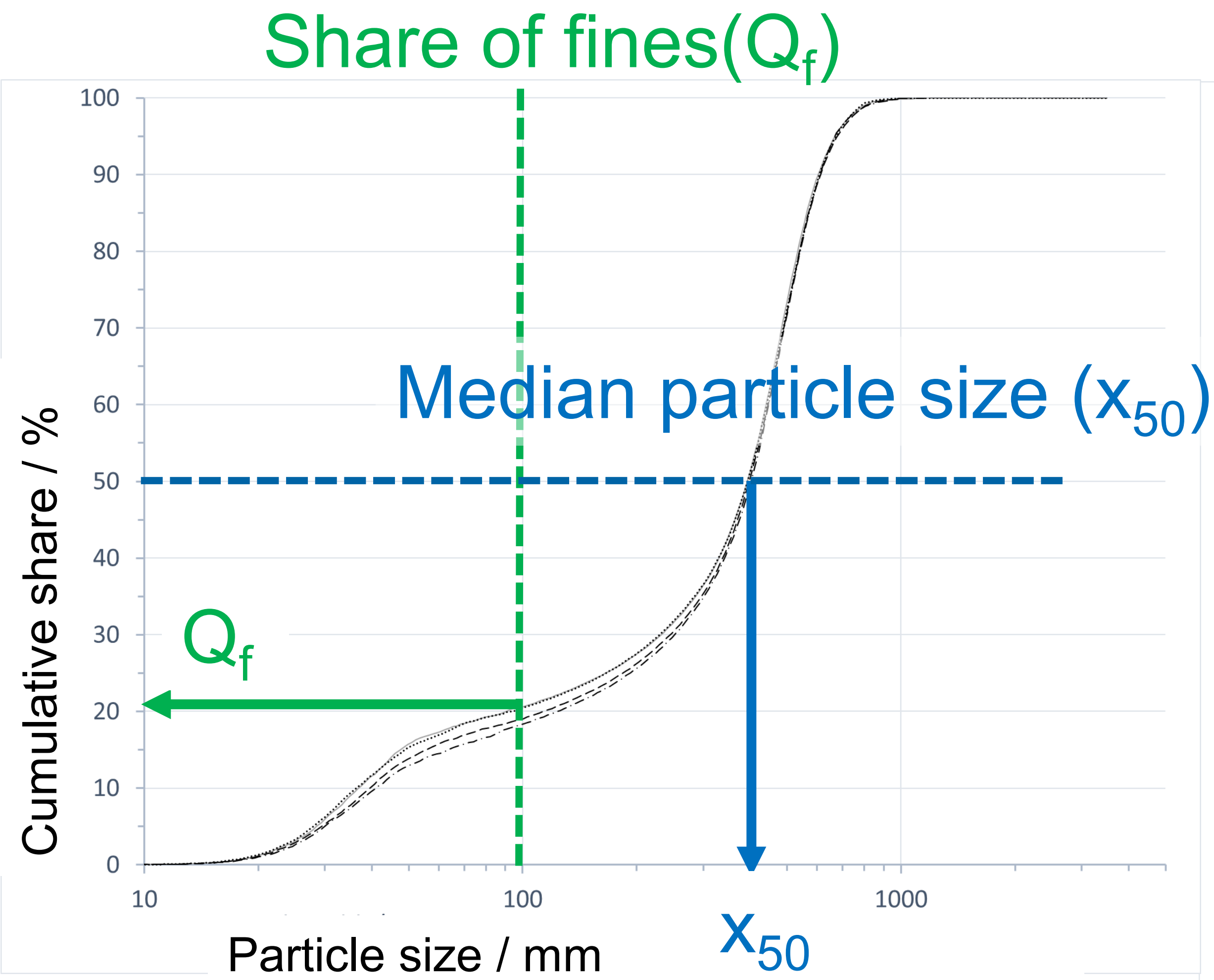
Characteristics of particle size distributions (PSD)

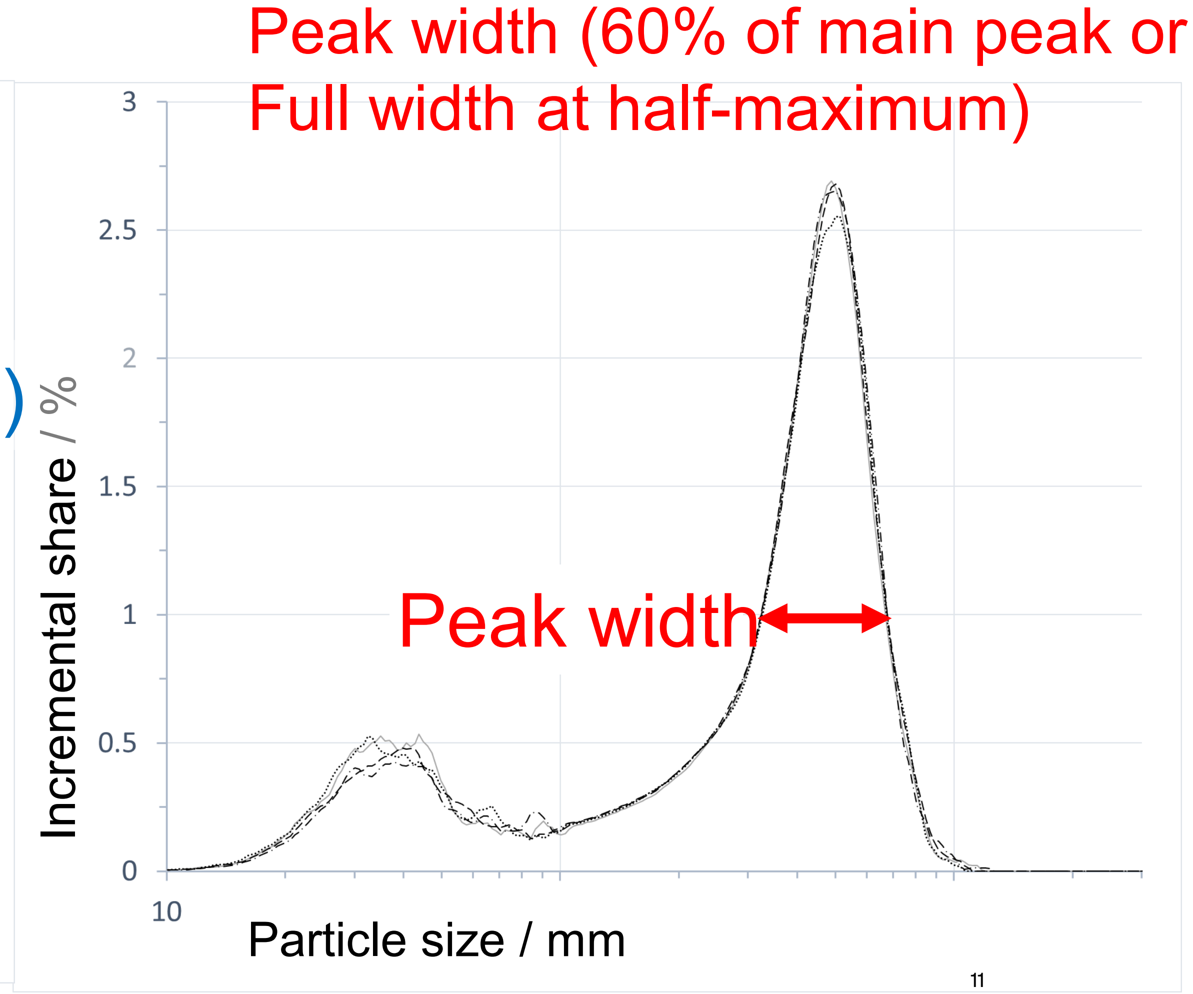
PSDs show three main charaterisitcs:

1. Bimodal distribution: Two Maxima (aka Peaks)
2. Main peak changes linearly (usually 150-1000 µm)
3. Fines peak (< 100 µm) does not change location (always ~ 30-50 µm) – but, the its share of the total amount increases at fine grind



Characterizing PSDs by key parameters

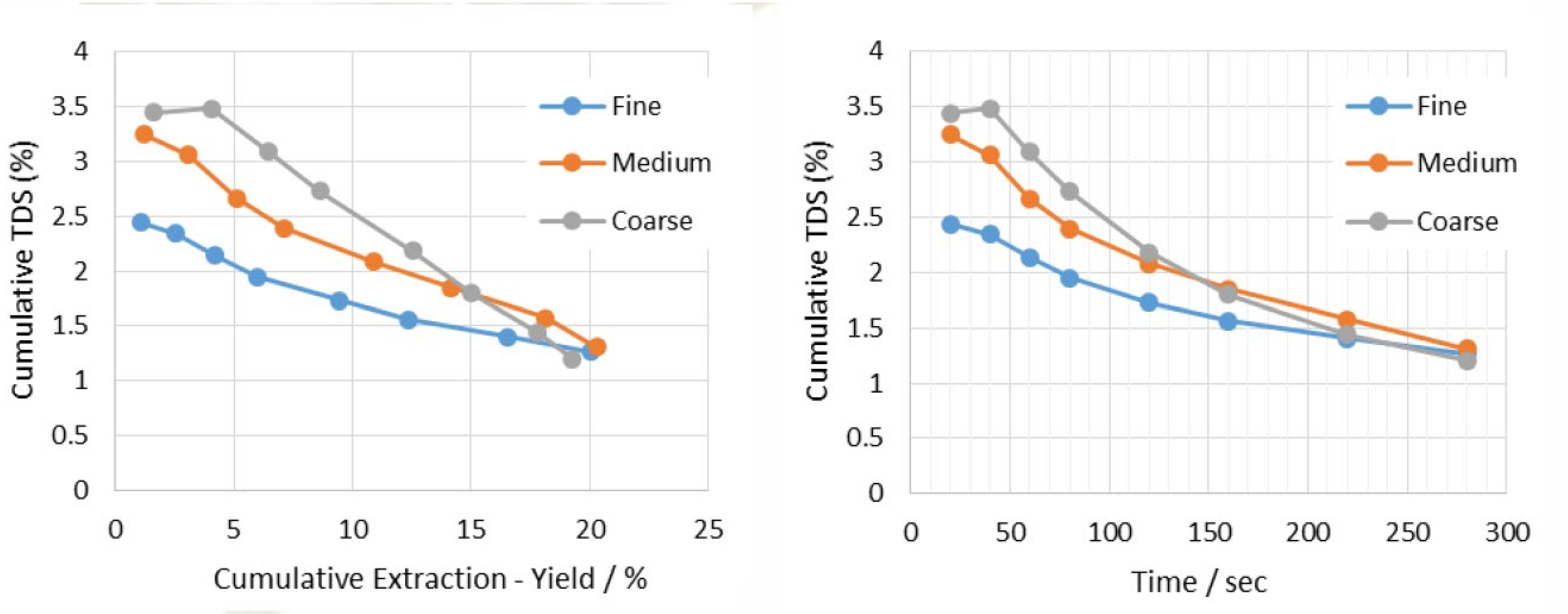




Experiments with filter coffee

Mizue Kishigami, 2019

Fine ground coffee extracts slower initially but catches up or even overtakes towards the end – possibly due to slower wetting



Uniformity, peak shape and sensory impact

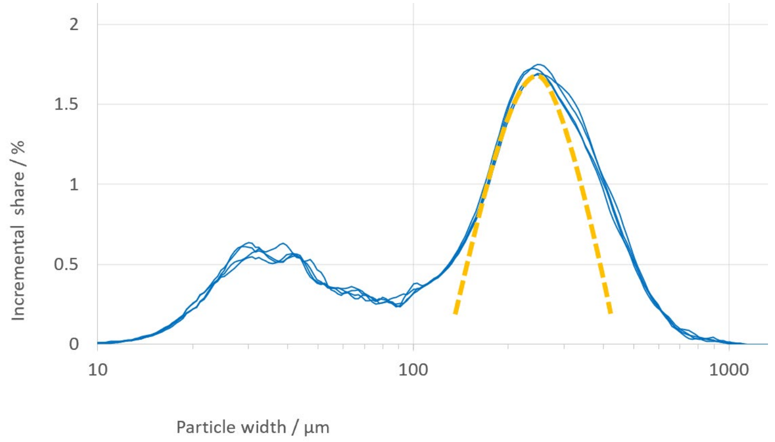
Asymmetrical peaks favor either over- or underextraction:

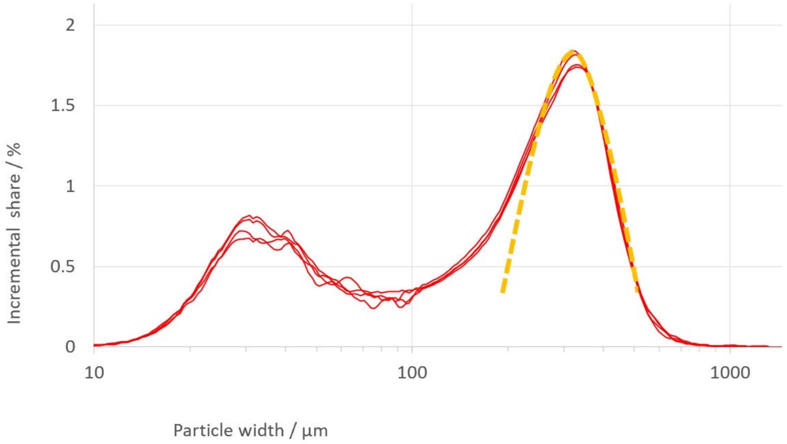
- Compared to a perfectly symmetrical peak (orange dotted line):
  - A peak with a shoulder to the right (larger particles – blue – left chart) has a higher share of less extracted particles
  - A peak with a shoulder to the left (smaller particles – red – middle chart) has a higher share of more extracted particles

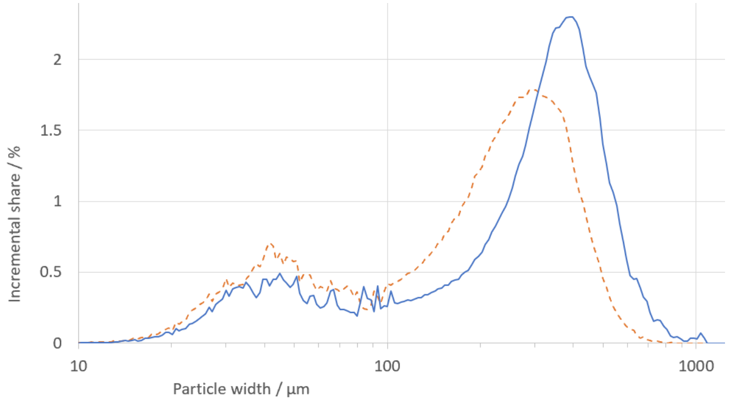
Peaks of differing widths need to be ground at different sizes to achieve the same flow resistance in espresso (right chart)

- Narrower peaks -> more uniform extraction but higher x50 (lower EY) – light blue
- Wider peaks -> less uniform extraction but lower x50 (higher EY) – red dotted line

Beware: Choosing bin size and and chart on linear or logarithmic axes impacts the (visual) peak shape



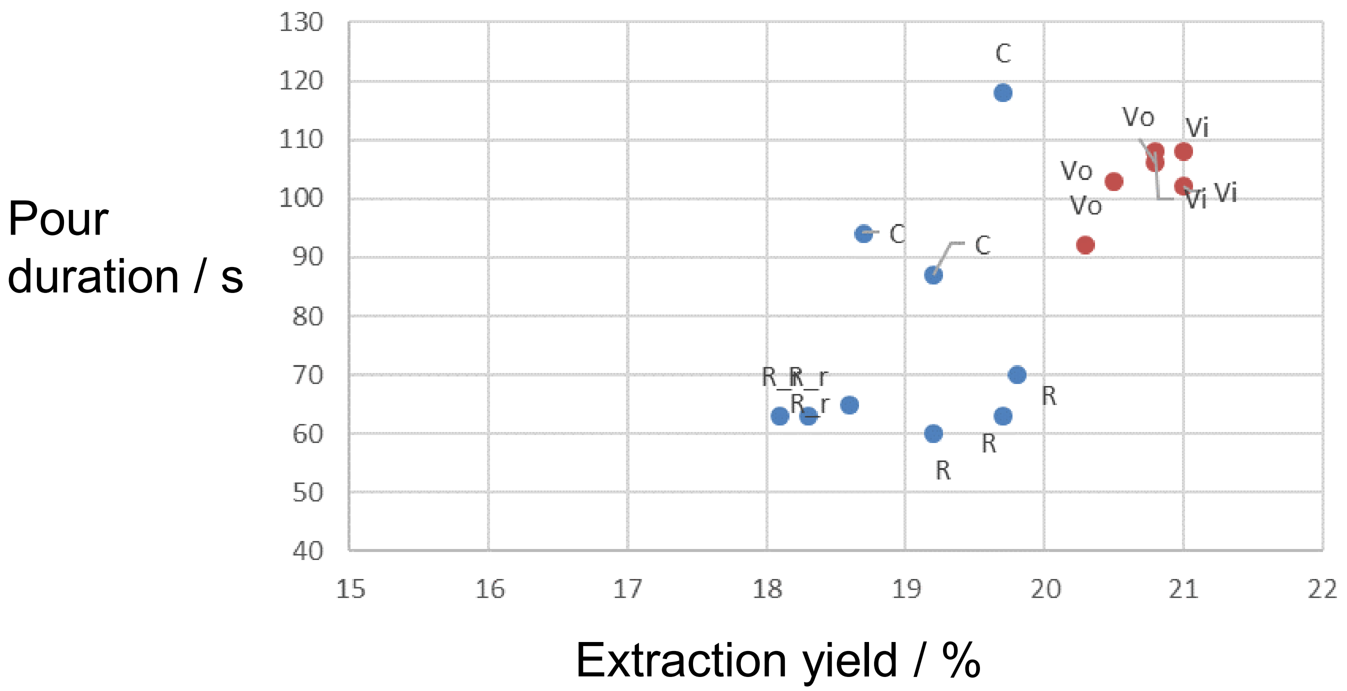




3 Extraction time

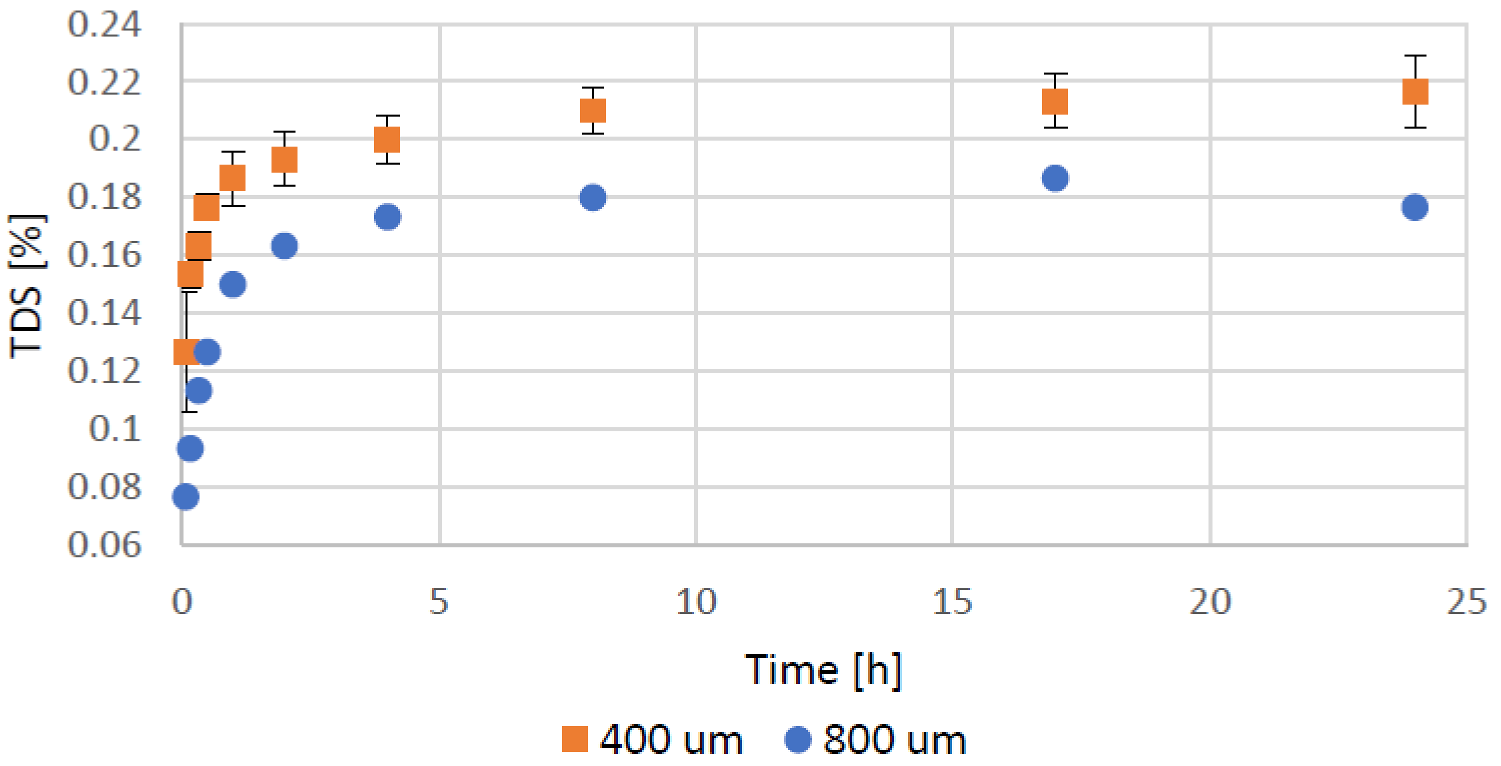
- One of the most used parameters to influence extraction (efficiency) and the resulting sensory attributes
- Range: 5 s to 24 h
- Immersion: easy to change – not impacted by other parameters
- Drip: easy to change within limits determined by: pour speed, grind size and filter paper (thickness, permeability)
- Espresso: only possible to change for flow or pressure profiling machines – otherwise determined by pressure, dose, grind size (and the resulting bed height)

Example of the impact of pour time (speed) on extraction efficiency in filter coffee



Highly diluted immersion extraction (max. yield)

- Marija Vincetic BSc, 2020 – experiments done at 2.7 °C



Most recent results on espresso

- Extraction time is one of the main driver of extraction yield
  - The longer the extraction the higher the extraction yield
- When comparing different flow speeds for otherwise fixed conditions an effect of increasing extraction yield for higher flow speed was observed – going contrary to the general trend – most likely due to increased turbulence around the coffee particles accelerating the removal of solubles around the particles

4 Concentration gradient = Concentration difference

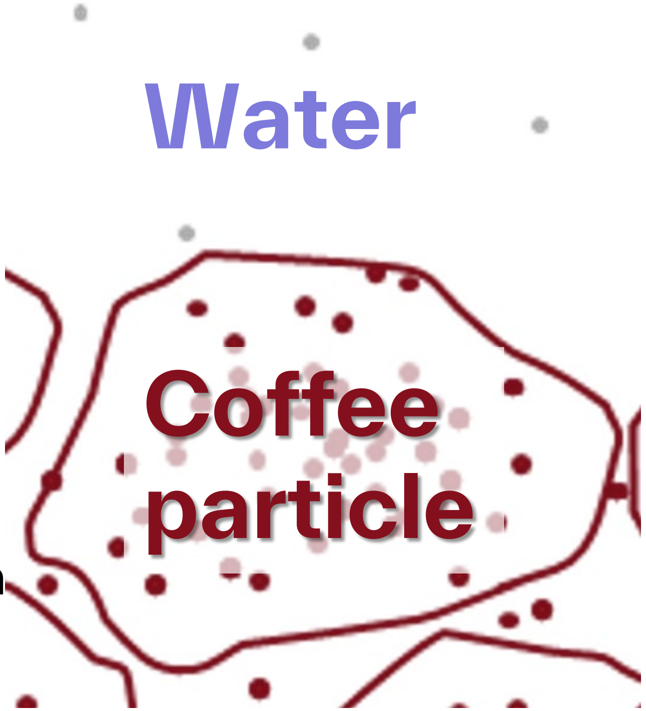
Diffusion of solubles is directly proportional to the difference of solubles in the water VS the coffee particles

Concentration of solubles at the start

- Water < 0.1 %
- Coffee particle > 20%

The main reason why you cannot extract coffee fully in very concentrated form when doing immersion

Not the ability of water to take up solubles is limiting but rather the diminishing concentration gradient limiting further extraction



Batch vs Flow-through

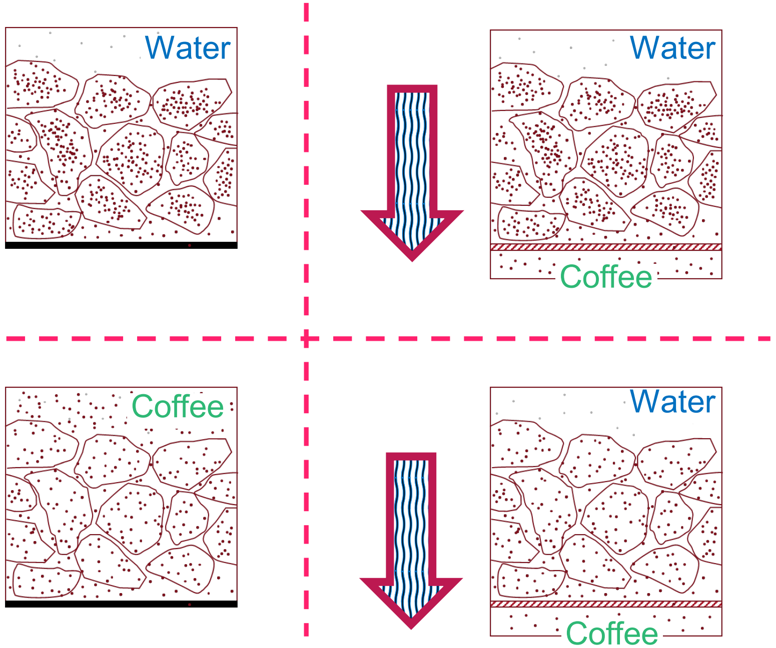
Immersion

Drip or Espresso

Water: < 0.1 %

Coffee > 20 %

Start of the extraction



Water: < 0.1 %

Coffee > 20 %

Water/Solution: 1-2%

Coffee < 5 %

End of the extraction

Water: < 0.1 %

Coffee > 5 %

5 Height of coffee bed

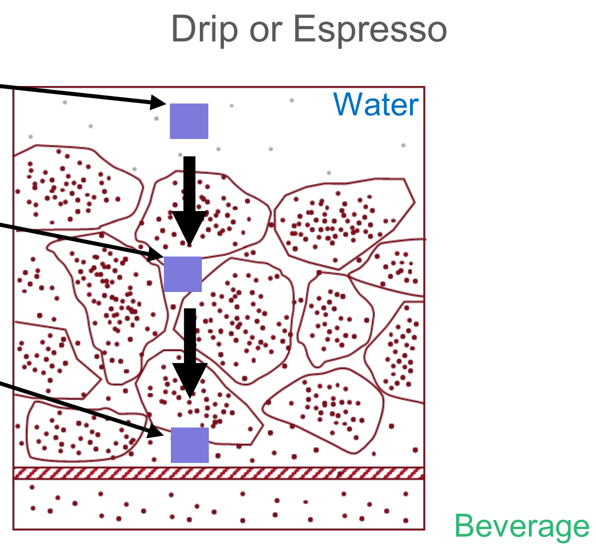
- Concentration of solubles increases as water travels through the coffee bed -> Decrease in concentration gradient -> (s)lower extraction
- For a very shallow bed of coffee it is more difficult to avoid channelling (in espresso as in manual pour over)

Espresso only:

- Evenness of coffee bed (dosing and distribution) leading to an even flow across the whole cross-section gets more difficult for large bed diameters
- Pressure gradient gets more steep for shallow beds –> increased chance of channeling

Looking at a single 'package' of water moving though the bed

1. Starts at < 0.1%
2. Picks up at lot of solubles at the beginning
   -> concentration gradient decreases
3. Picks up less an less additional solubles the further it will have travelled



Evolution over the course of the extraction:

The first part of the extraction (first 10%) are around 2-3fold of the final beverage concentration
– e.g. > 20% TDS for a 10% TDS Espresso

The last 10% of the extraction are around half of the final beverage concentration
– e.g. ~5% TDS for a 10% TDS Espresso

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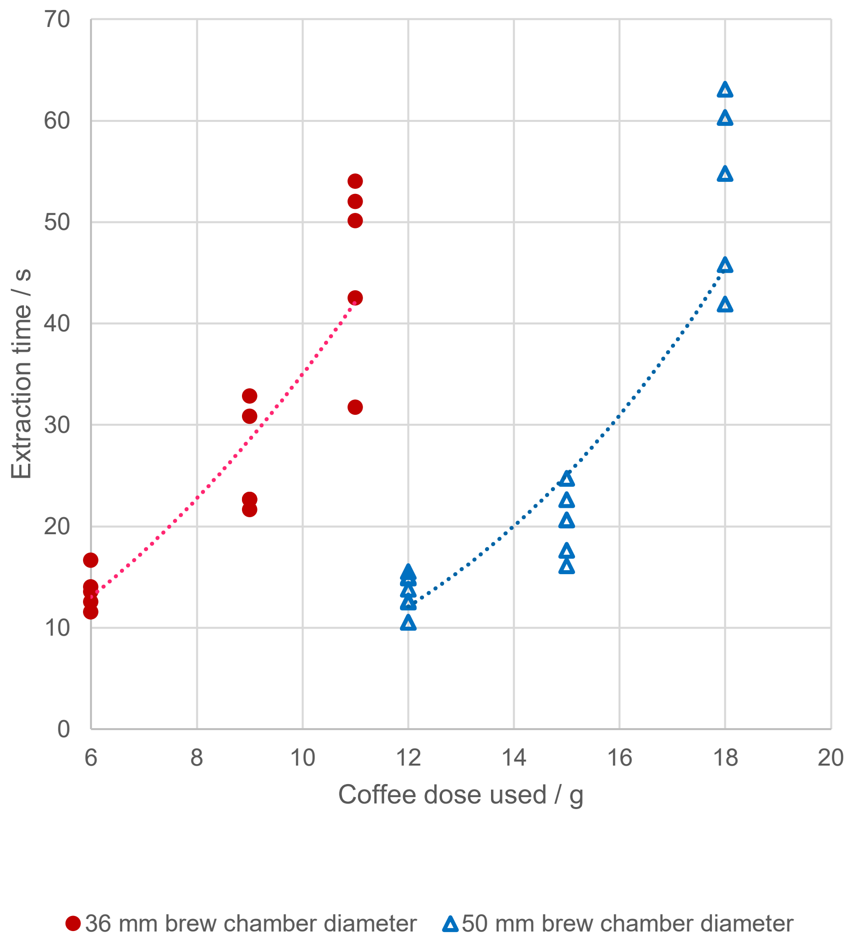
Resistance vs bed height / dose

- The higher the puck height the higher the flow resistance
- Not a propotional (linear) relationship:
  - For 36 mm:
    +50% dose -> + 90% extraction time:
    almost double the increase (x1.8)
    +83% dose -> + 238% extraction time:
    almost triple the increase (x2.9)
  - For 50 mm:
    +25% dose -> + 55% extraction time:
    more than double the increase (x2.2)
    +50% dose -> + 304% extraction time:
    almost triple the increase (x6.1)



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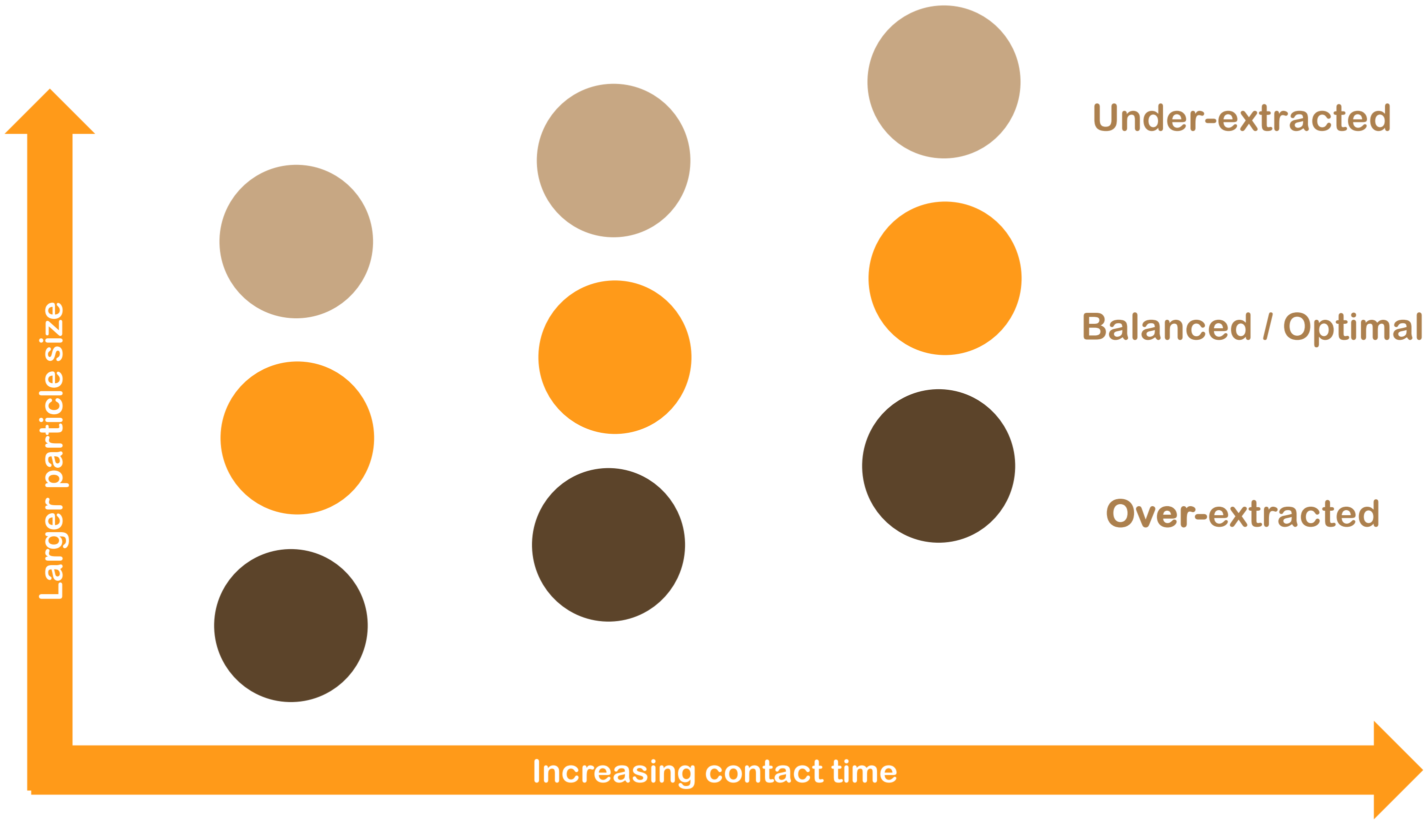
Synthesis I

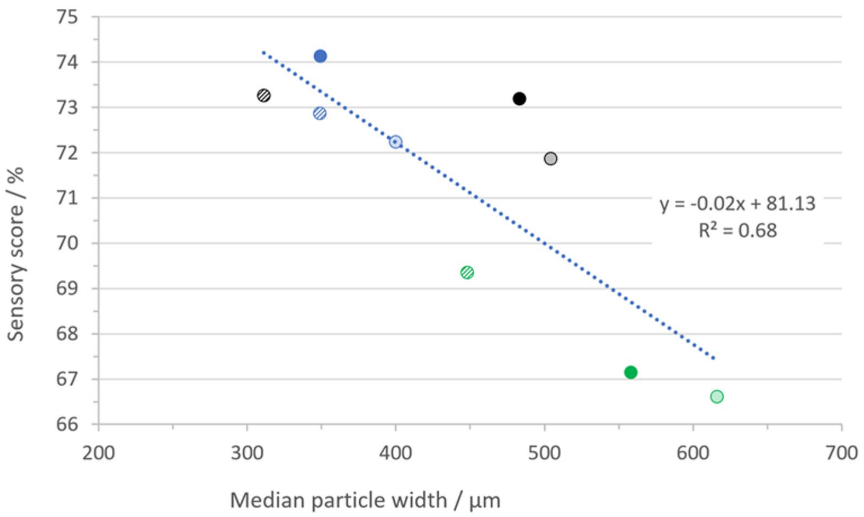
- There is usually more than one combination of parameters leading to a similar results
  - For espresso the mutual dependency of parameters often makes it impossible to vary only one parameter
- And also: Not all people have the same taste preference

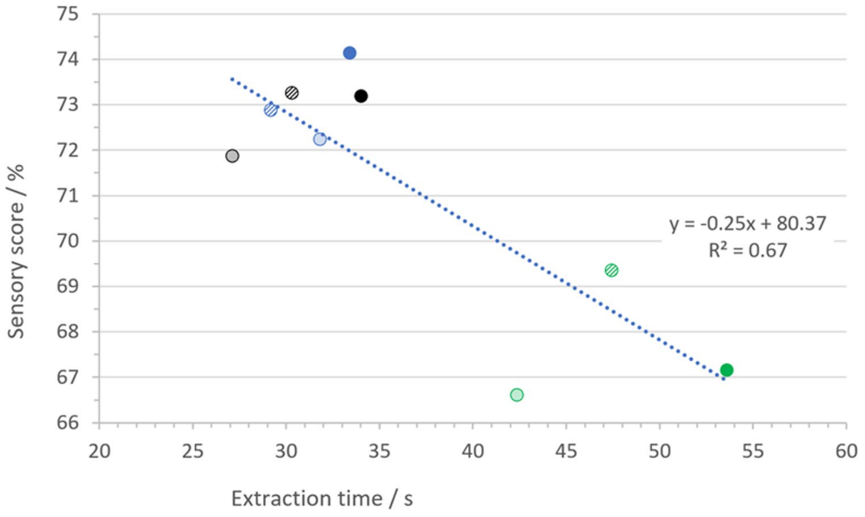
=> Embrace diversity – also in matters of taste



Synthesis II

- Example from a benchmark test for long cups (café crème aka lungo) on domestic super-auto (bean to cup) machines
- Possible solutions: try different flow profiles to enable a fast extraction at small grind size - increase brew chamber diameter



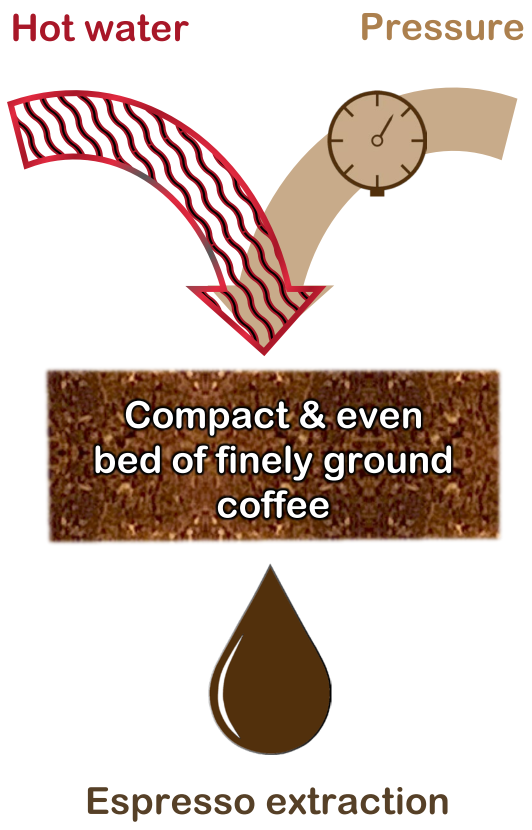


Synthesis III – Evenness

- In the majority of use-cases we tested the coffee will taste best when the extraction is most even
  - Even over time – constant during the extraction – and from one to the next
  - Vertically even: low puck height
  - Horizontally even: even water distribution and homogeneous puck density

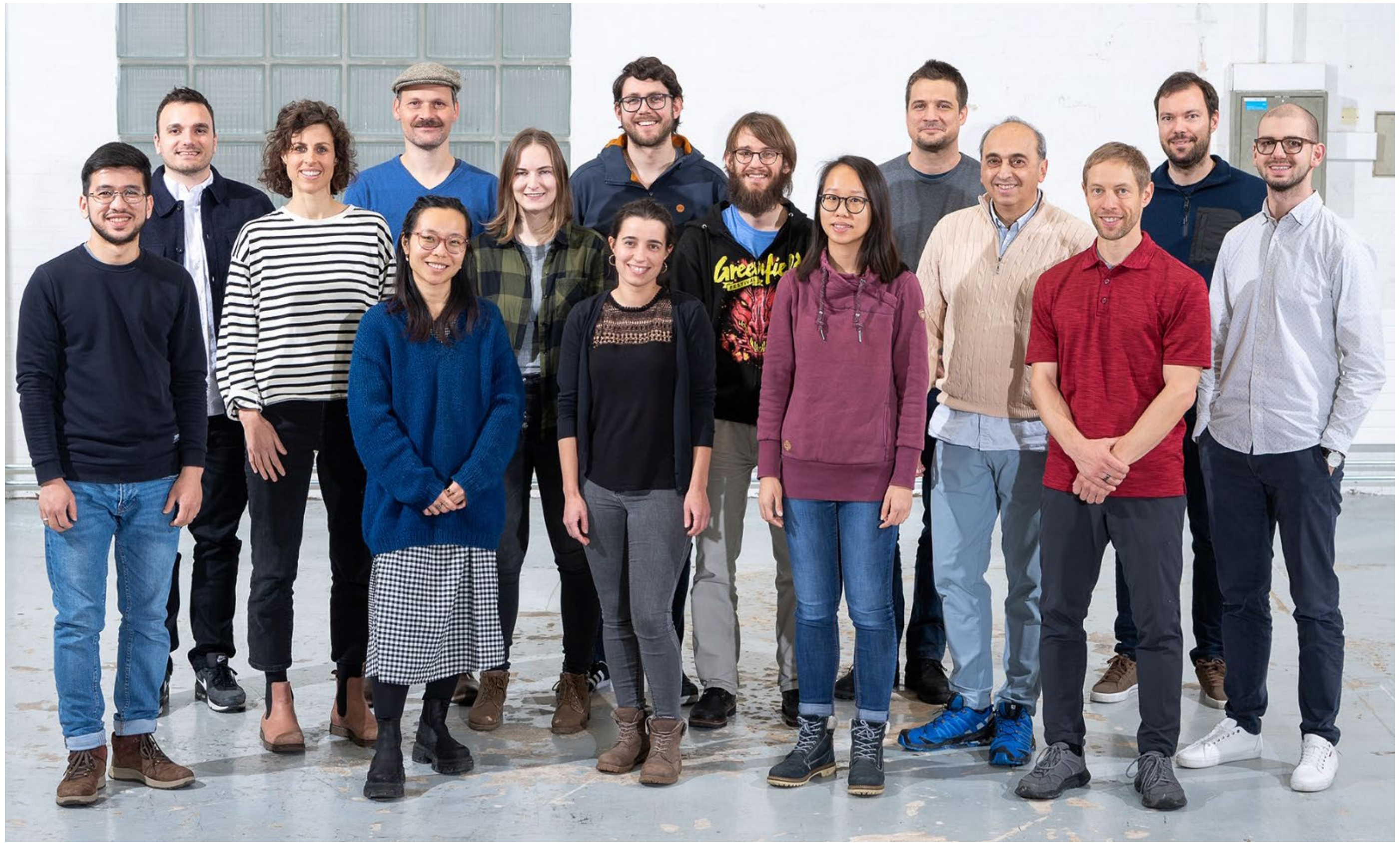
- Some single origins with a rather 'narrow' flavour profile (low number of flavour attributes) taste better (more complex) when extracted more uneven
  Similar observations have been made when doing a very rigorous sorting a coffee (regarding size or slightly defective beans)

- If you are going for more clarity and higher overall exraction yield try to increase evenness
- If you are rather trying to increase complexity some unevenness can actually improve the cup quality



Acknoledgments

A huge thanks to our group at the coffee excellence center and all past and current students that have contributed here



Thank you for your attention

Questions?

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Let‘s stay in touch

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