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The Impact of Time, Temperature, and Extraction on the Sensory Quality of Drip Brew Coffee

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University of California, Davis

About Me

- Background in chemistry, with a focus in organic chemistry.
- Worked in an artificial flavor and fragrance lab, which introduced me to sensory science.
- Returned to school for a graduate degree in food science, intending to focus in sensory science, which brought me to UC Davis.

Outline

Background on the UC Davis Coffee Center

History and motivation for extraction research

Experiment 1: Fractionation

Experiment 2: Brew Temperature and the Coffee Brewing Control Chart

Conclusions and future directions

UC DAVIS
UNIVERSITY OF CALIFORNIA

28,000 undergraduates, in 104 majors
6,600 graduate students

Famous for bicycles and environmental sustainability

There are many international students and scholars

There are several UC campuses, but only UC Davis has departments focused on food science





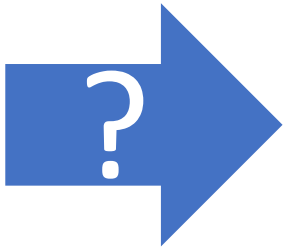

U.C. Davis is a world leader in wine and food science with the facilities at the Robert Mondavi Institute

The UC Davis Coffee Center

- In 2013, professors of chemical engineering Bill Ristenpart and Tonya Kuhl developed an elective course ”The Design of Coffee” to teach basic chemical engineering concepts using coffee as a medium.
- This caught the attention of the coffee industry, which has developed into several dozen faculty from numerous disciplines turning their attention to coffee research.

What does chemical engineering have to do with coffee???

Chemical engineers design ways to convert raw materials into valuable products.

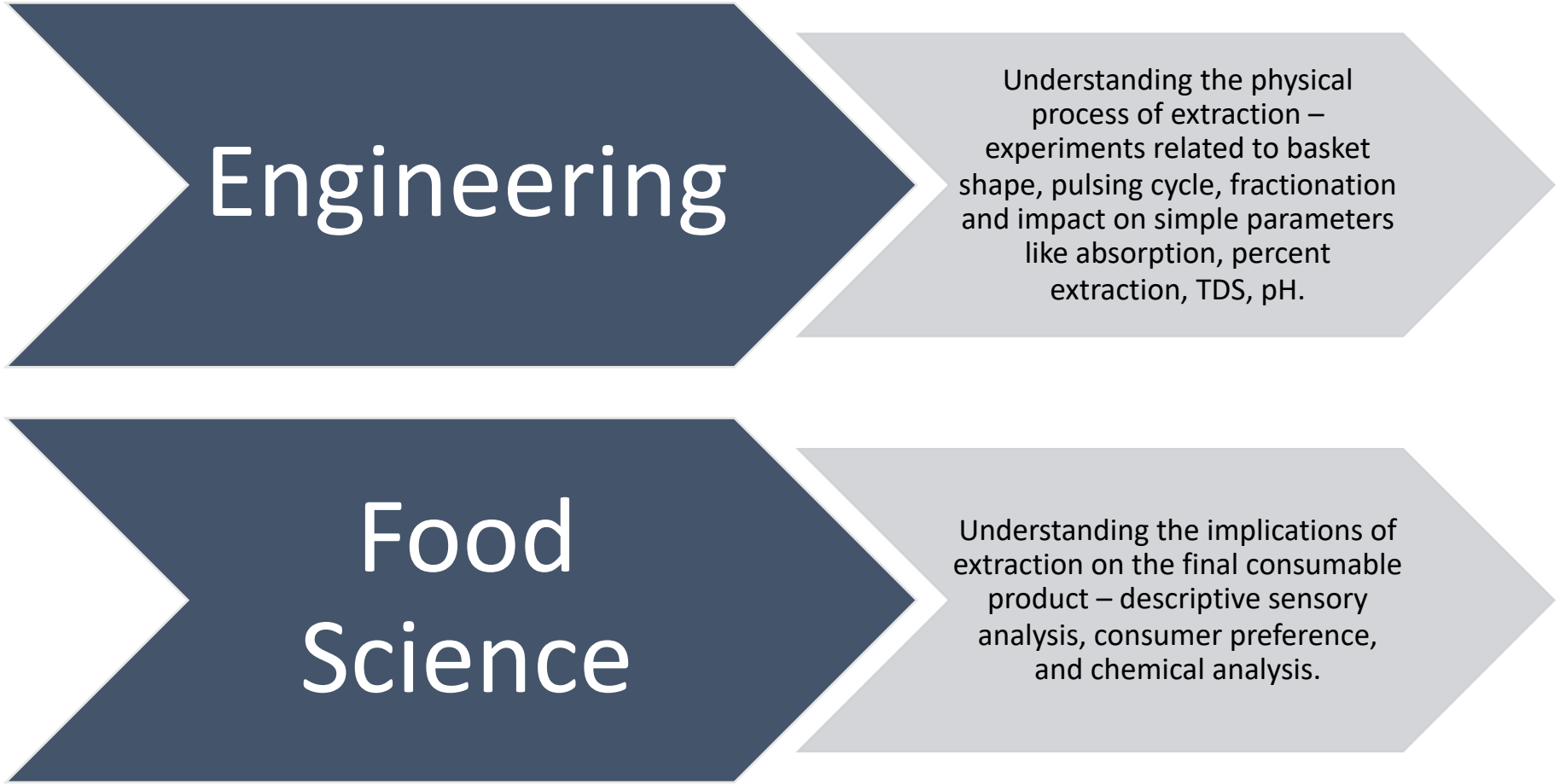


Corner Stones of Chemical Engineering

1. **Transport phenomena –** transport of heat, fluids, and mass
2. **Thermodynamics –** heat and its relation to energy and work
3. **Kinetics –** chemical reactions

All crucial for coffee!

Current Coffee Brewing Research at UC Davis



Broadly: We want to do for coffee what UC Davis has already done for wine and beer

Earnest Earl Lockhart

ca. 1940
(Antarctica)

ca. 1960
(Coffee Brewing Institute)

Nice historical article by Emma Sage re the CBI:

http://www.scanews.coffee/2013/10/04/the-coffee-brewing-institute/

ACCEPTANCE OF SOLUBLE COFFEE

ERNEST E. LOCKHART AND JEAN MURRAY GAINER
Department of Food Technology, Massachusetts Institute of Technology, Cambridge, Massachusetts

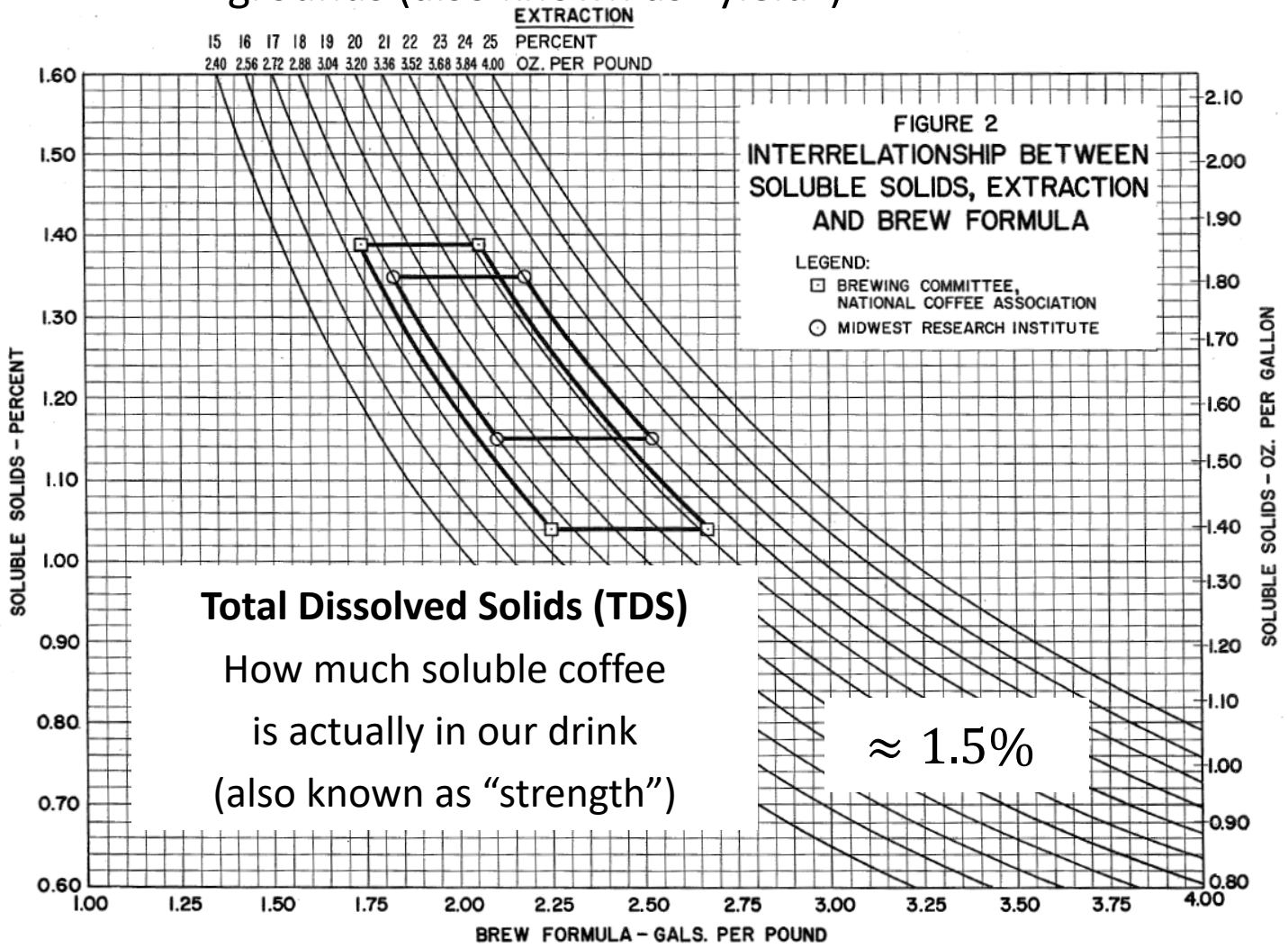
[Received for publication, August 20, 1949]

A recent newspaper survey, Anon. (1949), indicates that in 12 cities across the nation the proportion of families purchasing soluble coffee ranges from approximately 10 to 42 per cent. It is generally assumed that the beverage derived from soluble coffee is distinctly different from that prepared from roasted, ground coffee beans so far as flavor quality is concerned. Prevalent opinions tend to agree that soluble coffee is inferior when compared with that made by approved methods, that it should be considered only as a food product having a new flavor, and finally that its popularity may be due only to its convenience. Although convenience is undoubtedly an important factor, no published information on the acceptability of soluble coffee in its various forms is available. Consequently, the study to be described was undertaken.

Percent Extraction (PE)

How much of the soluble coffee was <u>removed</u> from the grounds (also known as “yield”)

≈ 20%

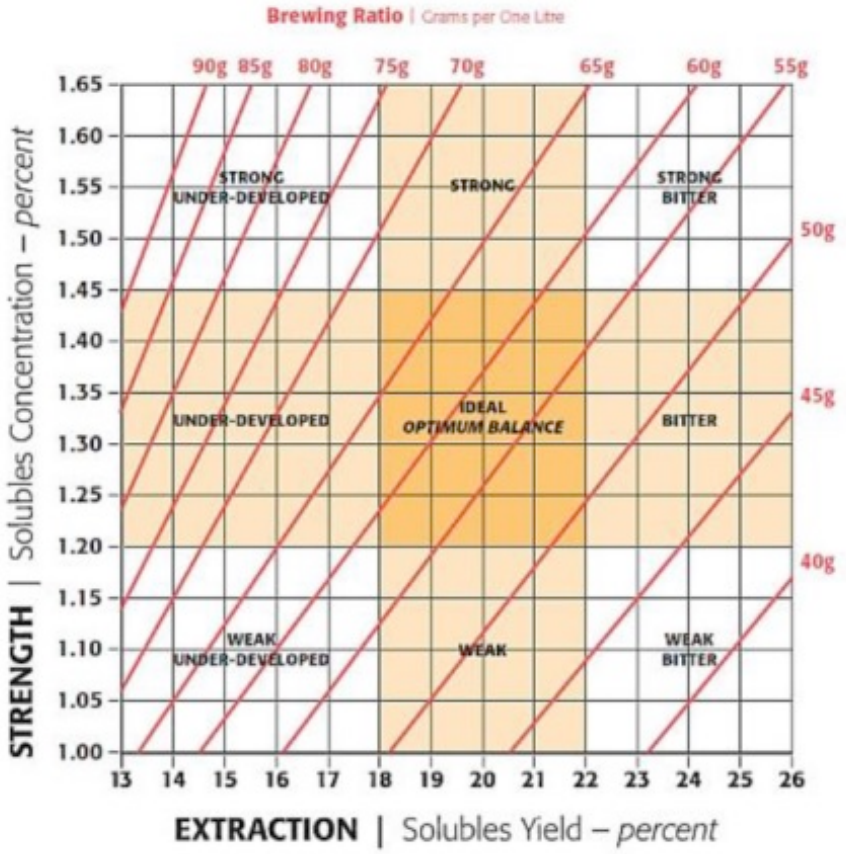


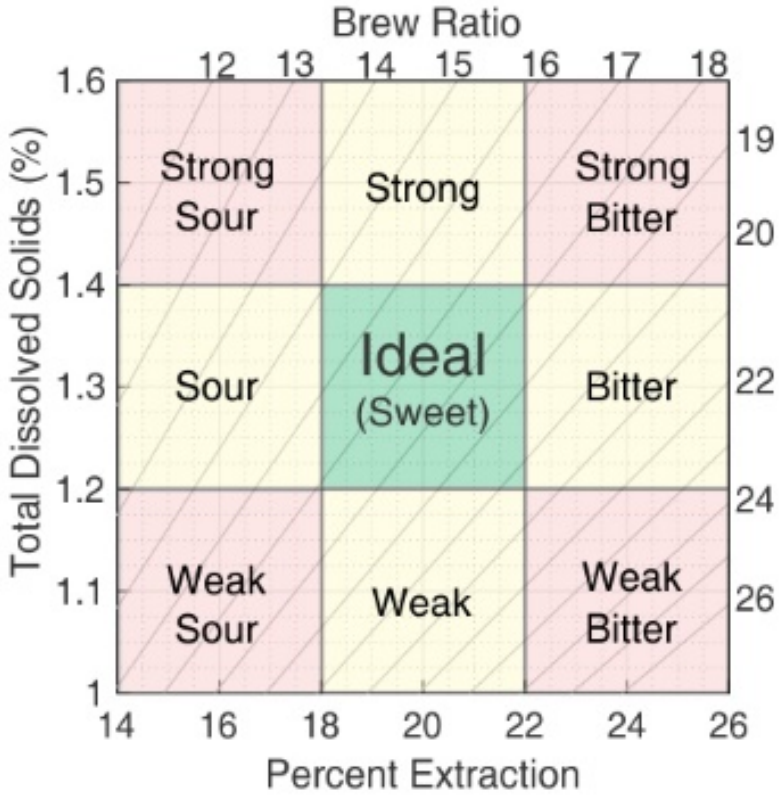
Total Dissolved Solids (TDS)

How much soluble coffee is actually in our drink (also known as “strength”)

≈ 1.5%

The Coffee Brewing Control Chart





(Lockhart, 1960s)

Part 1: Sensory and chemical analysis of drip brew fractions

An investigation into the time evolution of coffee flavor extraction

How does brewing time impact perceptible sensory properties of coffee?

What is happening compositionally as time progresses in a coffee brew?

Current Literature – Limited Sensory Work

Compositional Changes in Brewed Coffee as a Function of Brewing Time

TERRENCE A. LEE, REBECCA KEMPTHORNE, and JAMES K. HARDY

50% of total material is extracted in the first 200mL of the brew

Extraction of coffee antioxidants: Impact of brewing time and method

Iziar A. Ludwig [a], Lidia Sanchez [a], Bettina Caemmerer [b], Lothar W. Kroh [b], M. Paz De Peña [a,*], Concepción Cid [a]

[a] Department of Nutrition, Food Science, Physiology, and Toxicology, School of Pharmacy, University of Navarra, E-31080-Pamplona, Spain
[b] Institut für Lebensmittelchemie, Technische Universität Berlin, Gustav-Meyer-Allee 25, D-13355 Berlin, Germany

Majority of antioxidants in espresso found in the first 8 sec, majority in filter coffee in the first 75-150 sec depending on coffee origin

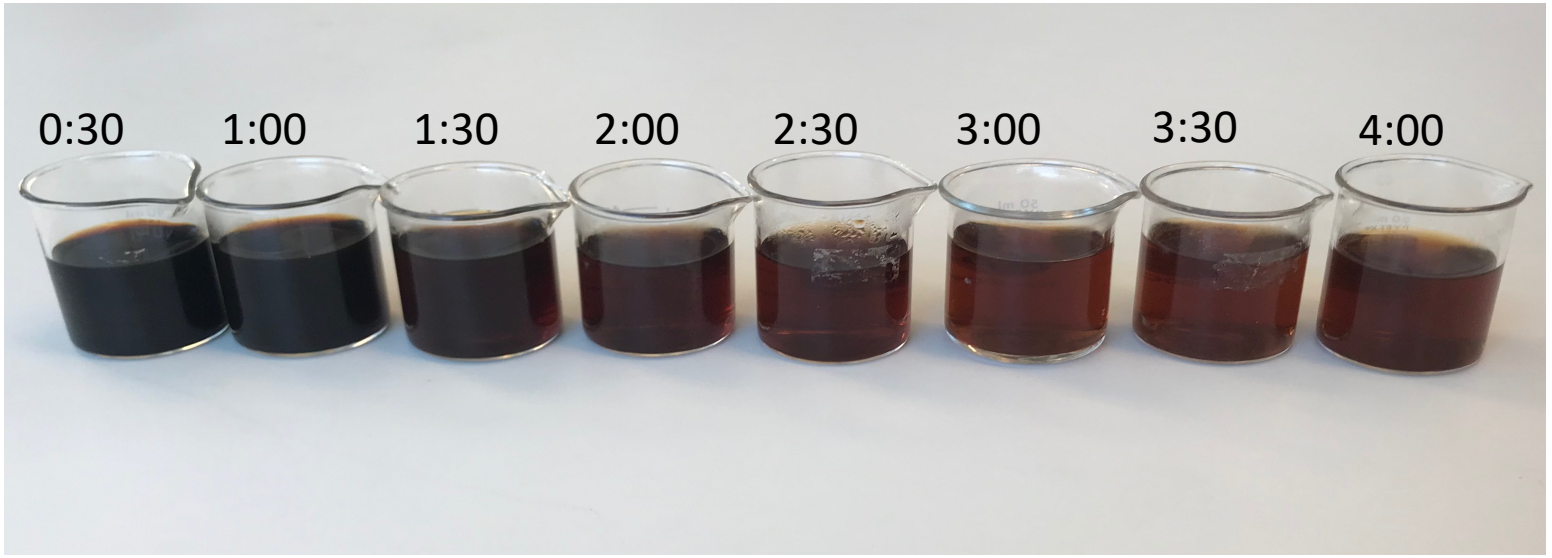
The kinetics of coffee aroma extraction

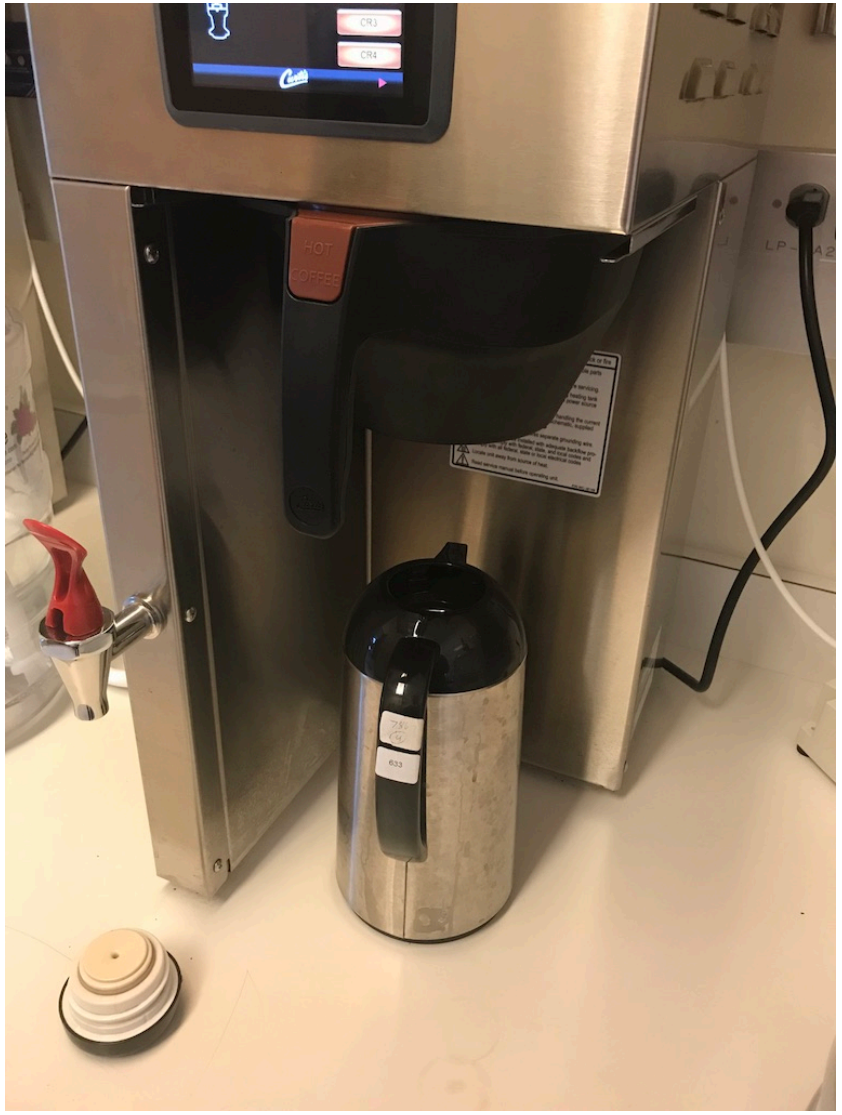
Frédéric Mestdagh [a,*], Tomas Davidek [a], Matthieu Chaumonteuil [a], Britta Folmer [b], Imre Blank [c]

[a] Nestlé Product & Technology Centre Orbe, Route de Chavornay 3, CH-1350 Orbe, Switzerland
[b] Nespresso S.A., Avenue de Rhodanie 40, 1007 Lausanne, Switzerland
[c] Nestlé Product & Technology Centre York, Haxby Road, York YO91 1XY, United Kingdom

Polarity of flavor components was most highly correlated to extraction speed

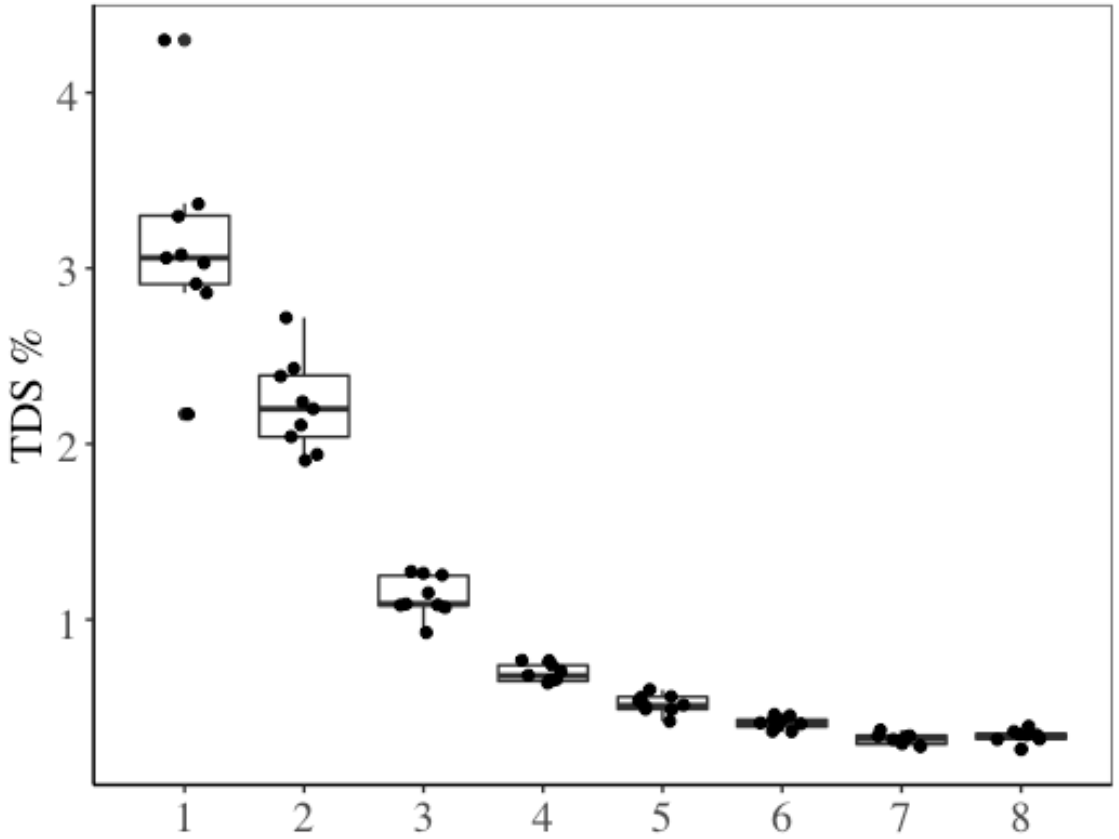
Sensory Study Design



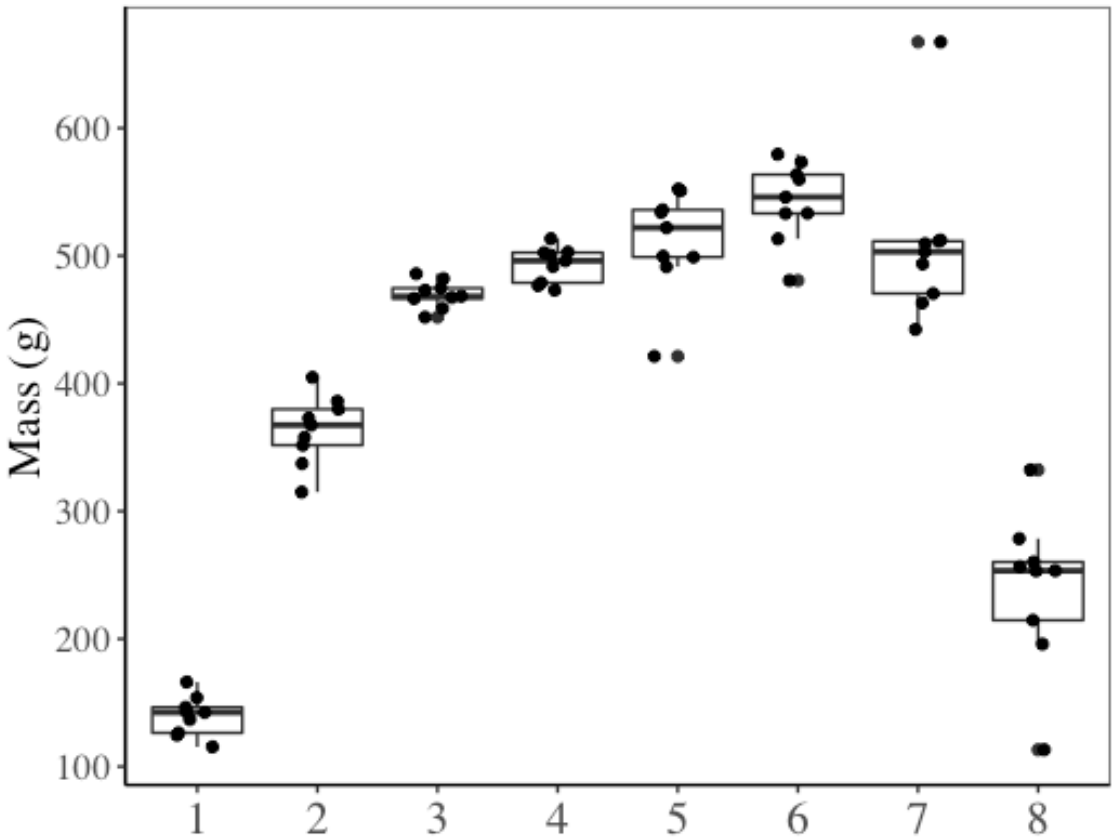


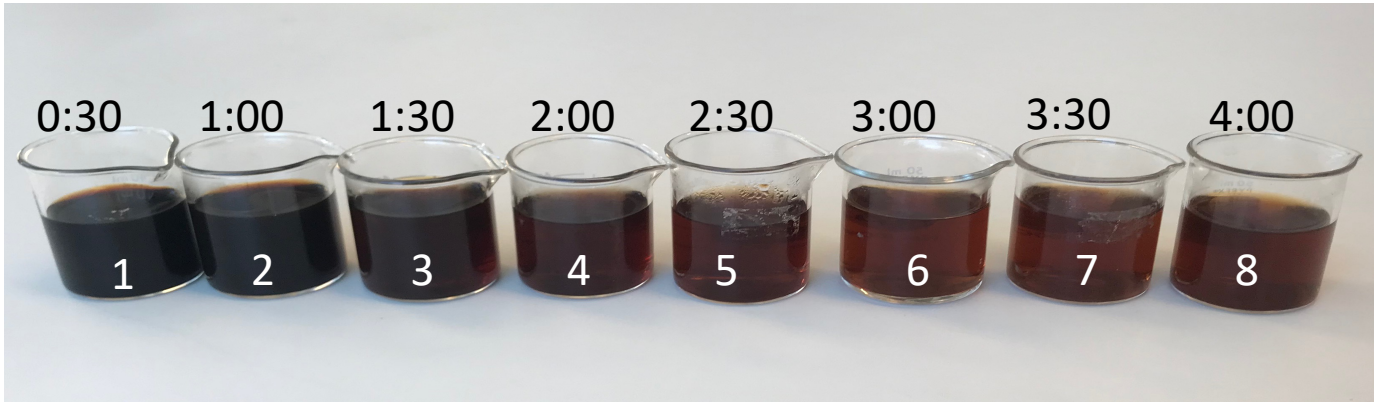
- Carafe was changed every 30 seconds of the first 4 minutes of a brew, collecting 8 samples total, plus a full brew under the same conditions for sensory evaluation.
- Physical measurements: Mass, TDS, PE.
- Medium roast (Agtron score of 54) Colombian coffee donated by Java City Coffee Roasters in Sacramento, CA.

A) Total Dissolved Solids



B) Coffee Brew Mass Dispensed

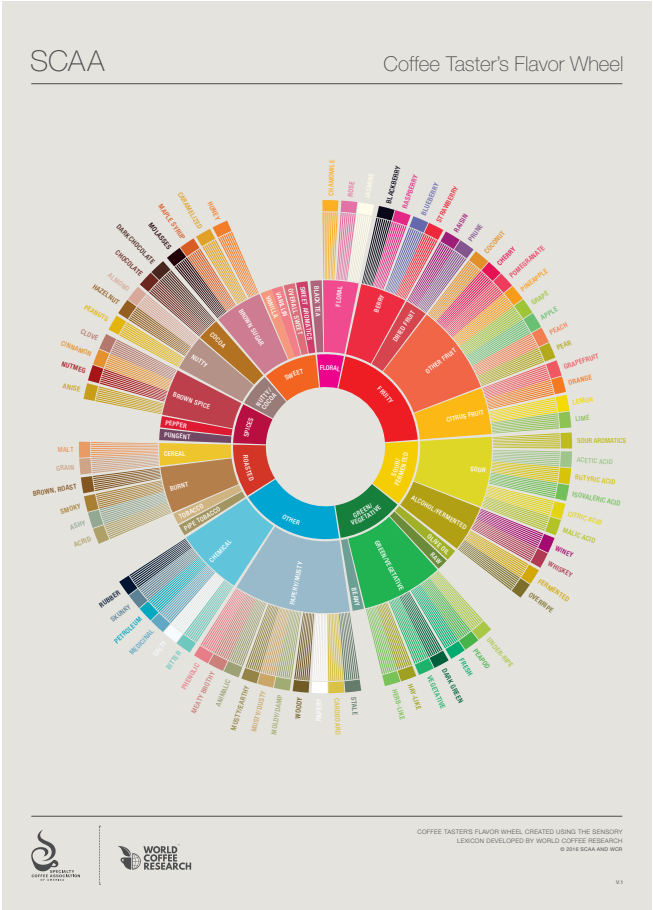




Descriptive Analysis Overview

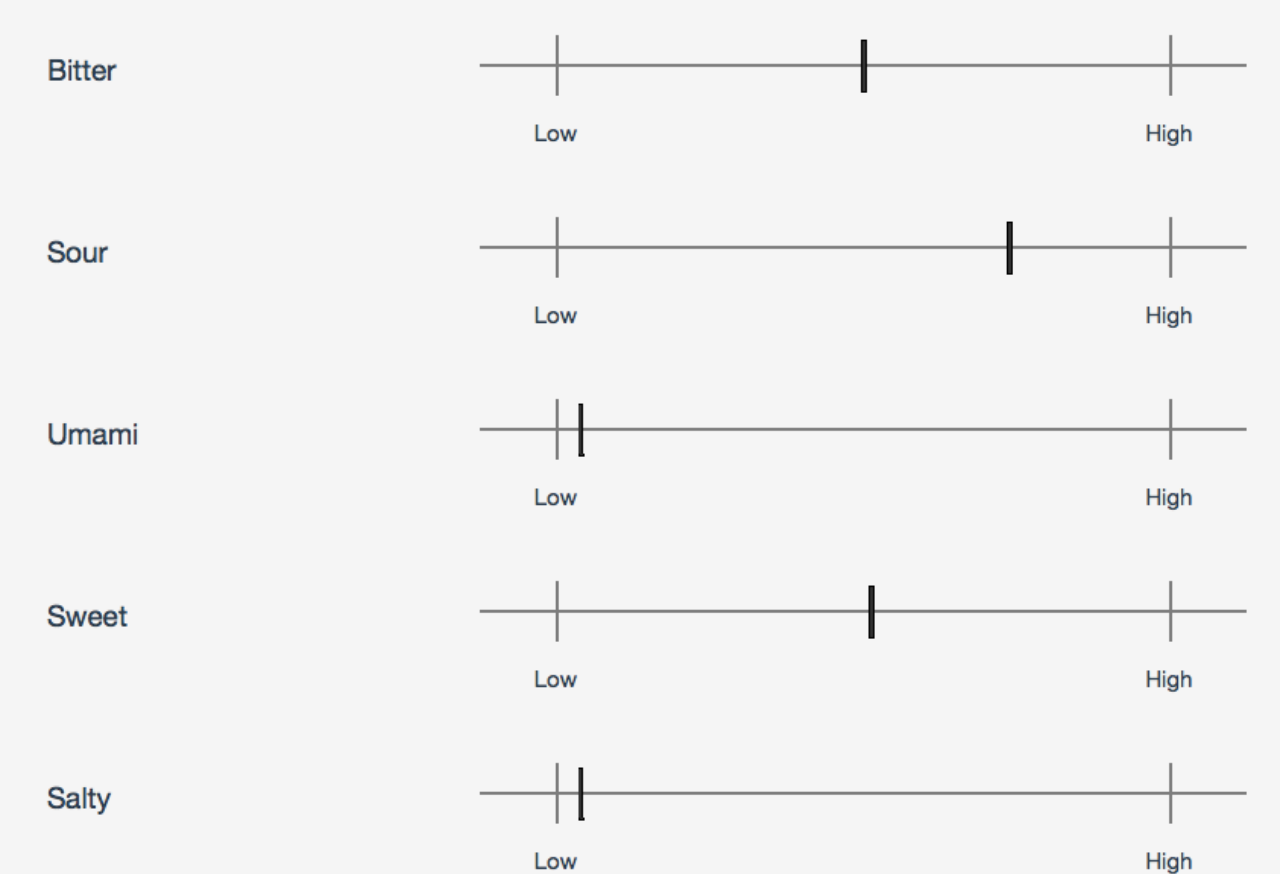
1. Define your product set – Looking for RELATIVE scores
2. Convene a panel of judges
3. Attribute generation
    - Judges are blind to the product treatments
    - Presented the Coffee Lexicon/ Wheel
    - Panel leader remains impartial
    - All vocab is panel generated
4. Vocabulary alignment through reference standards

Aroma	Ingredient
Floral/ Chamomile	Chamomile tea, dry
Smoke/ Acrid	Wright's Liquid Smoke Mesquite
Flavor	
Berry	Private Selection Triple Berry Preserves
Dried Fruit	Mixture of Sun-Maid Prunes and Prune Juice
Raisin	Sun-Maid Raisins
Citrus	Fresh lemon juice
Whiskey	Jack Daniel's Tennessee Whiskey
Dark Green/ Veg	equal parts juice green bean : spinach : asparagus
Hay-Like	McCormick Parsley Flakes
Musty/Dusty	Kretschmer Wheat Germ
Earthy	Miracle-Gro Potting Mix soil
Tobacco	Camel cigarettes (Turkish and Domestic blend)
Brown Roast	C&H Pure Cane Sugar, Golden Brown
Grain/ Malt	Equal parts Rice Chex, Wheaties and Quaker Quick Oats
Brown Spice	Equal parts cinnamon : nutmeg : clove
Hazlenut	Roast hazelnut oil
Almond	Raw almond slivers
Molasas	Grandma's Original Molasses, unsulphured, in water
Chocolate	Toll House semi-sweet morsels
Cocoa	Hershey's Cocoa Powder Natural Unsweetened, in water
Wood	popsicle sticks
Burnt Wood/ Ash	wood ash
Rubber	rubber bands



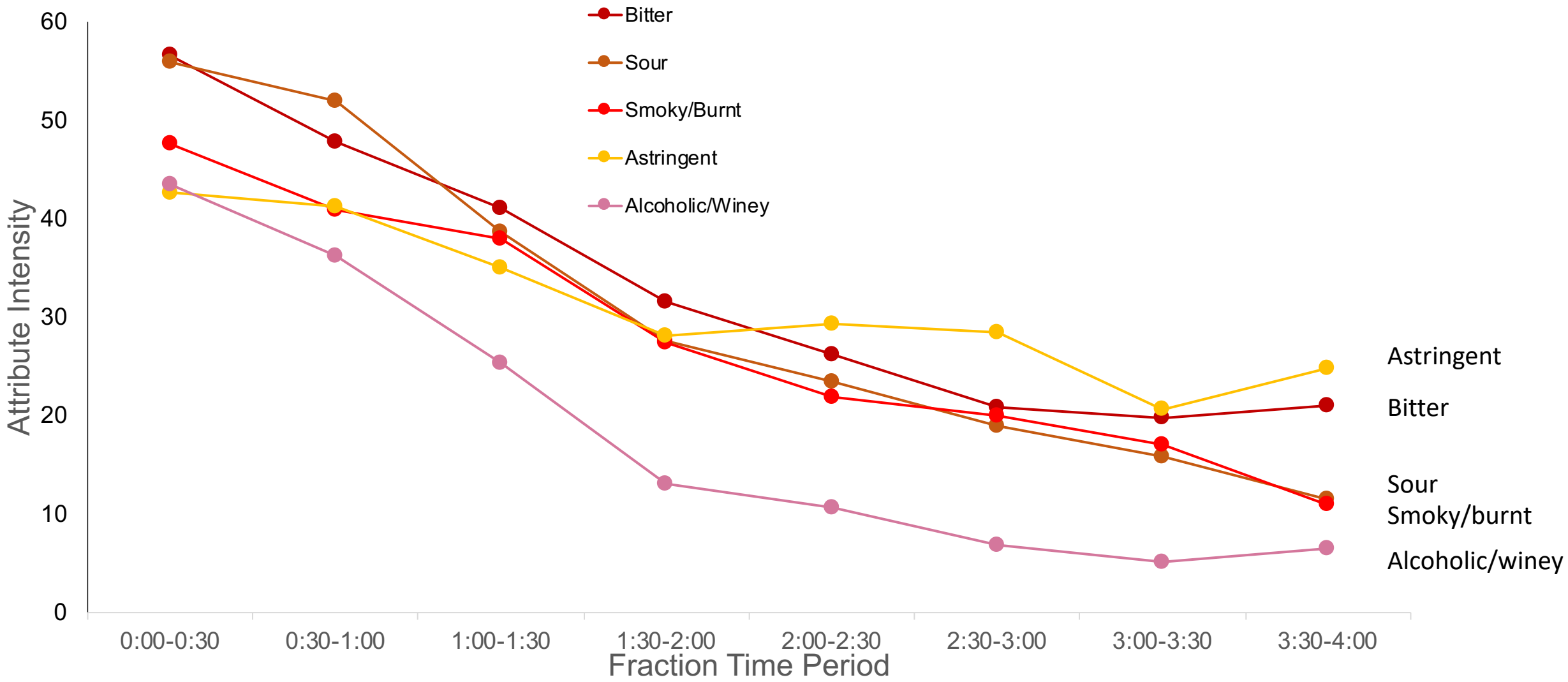
Descriptive Analysis Service

- **12** judges
- **3** replications of each coffee
- Coffee brewed and served in series
- TDS, Extraction Percent, and temperature measures



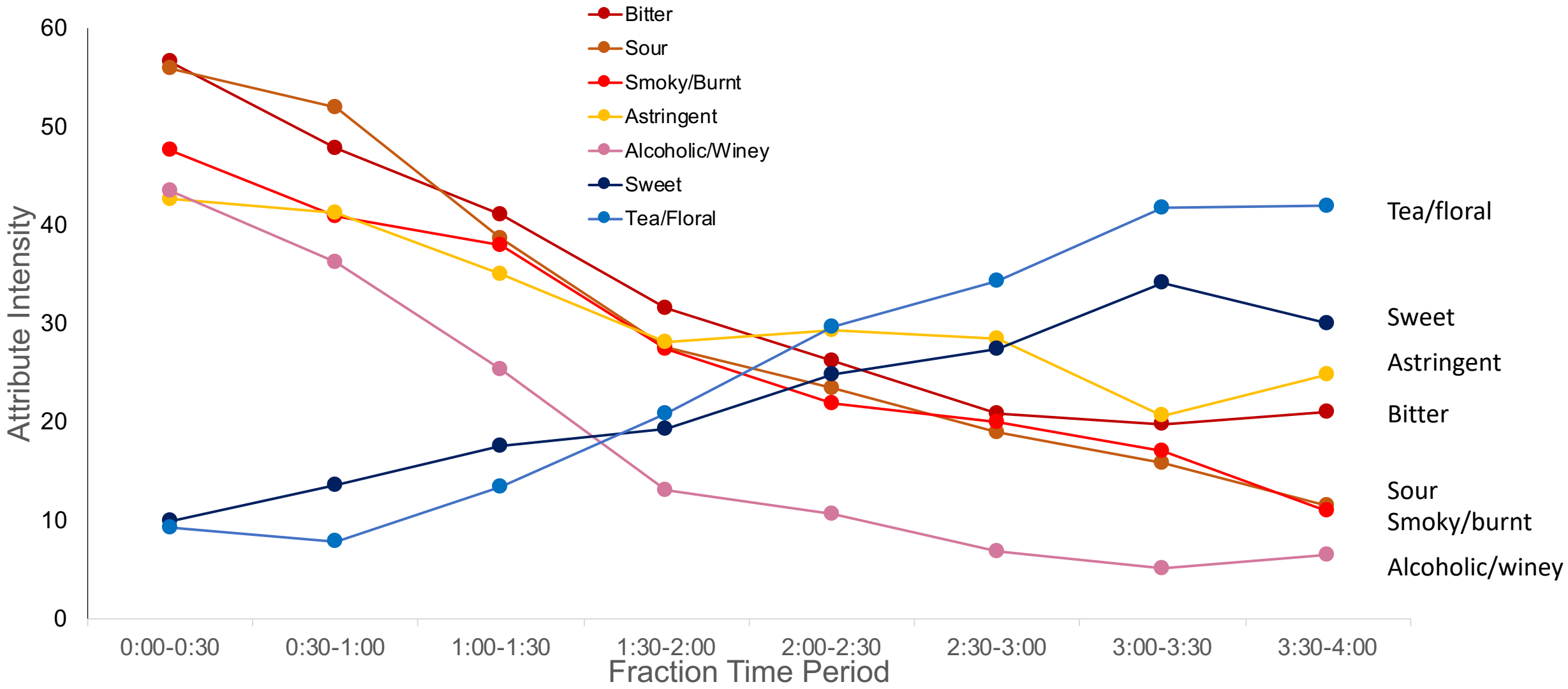
DATA COLLECTION

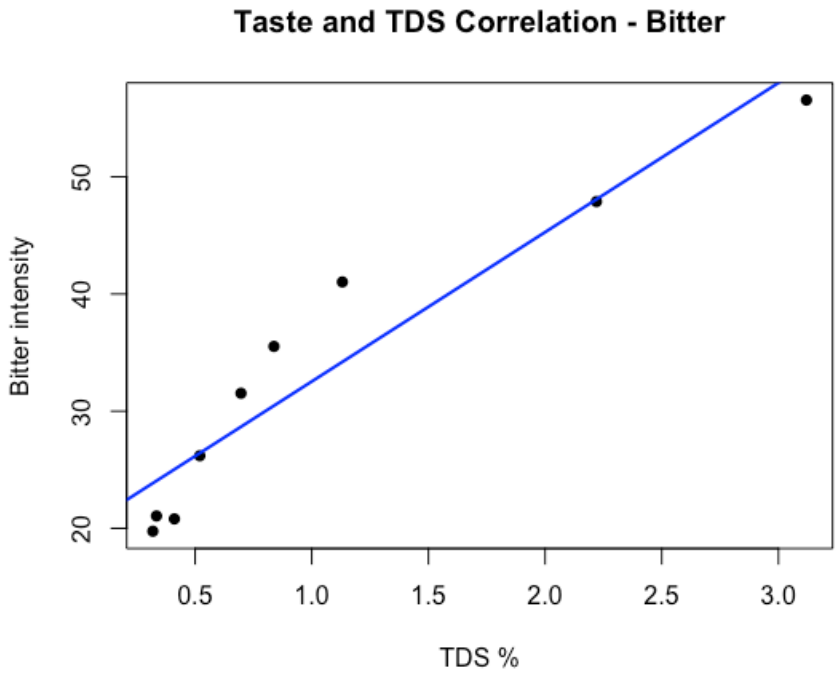
Many attributes decrease over the course of the fractions…

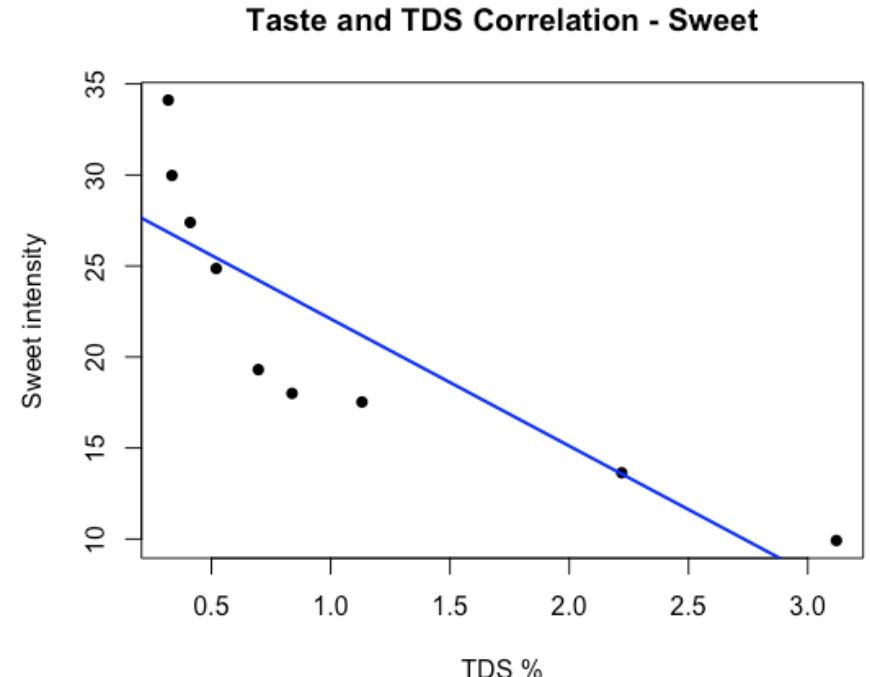


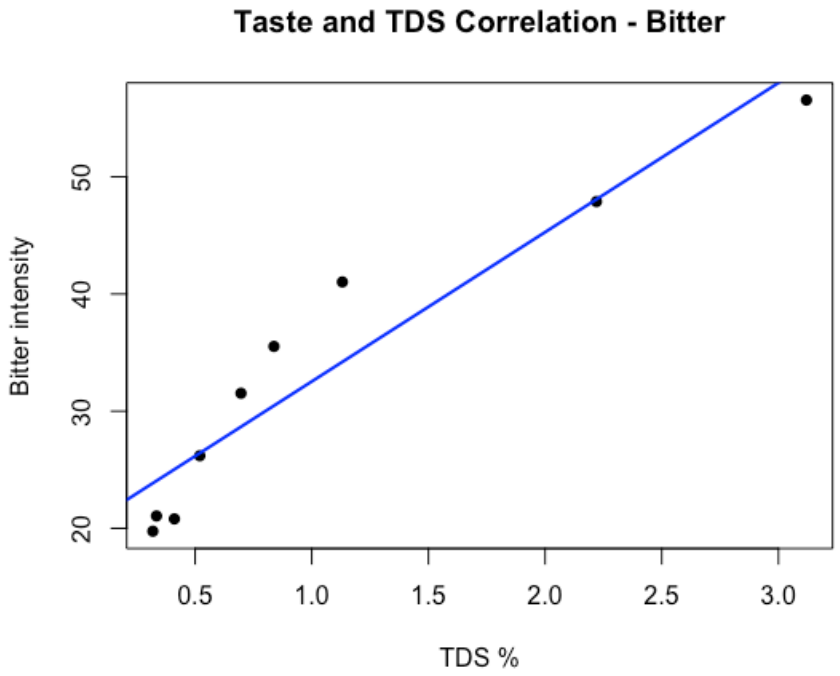
Many attributes decrease over the course of the fractions…

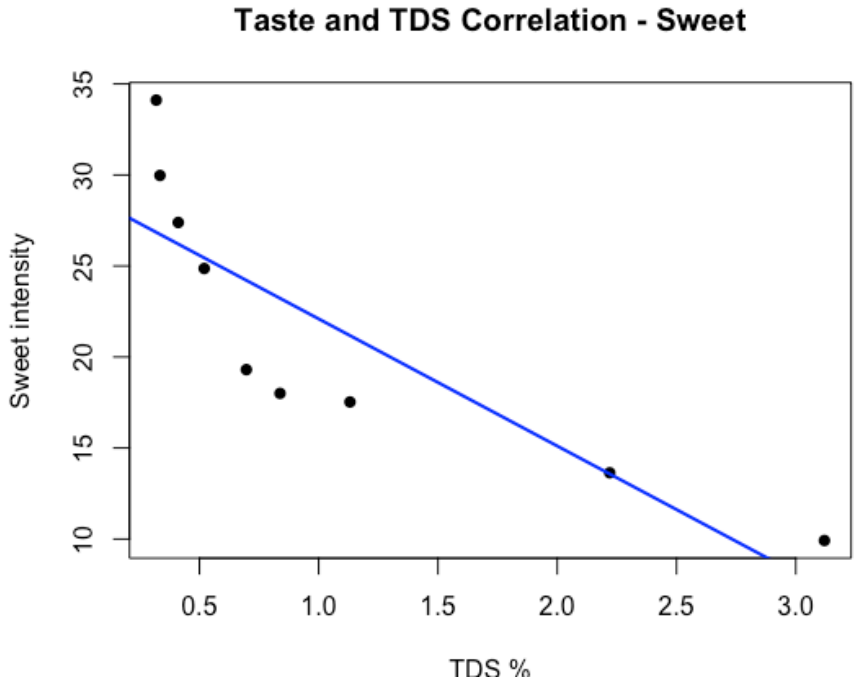
But surprisingly some increased!

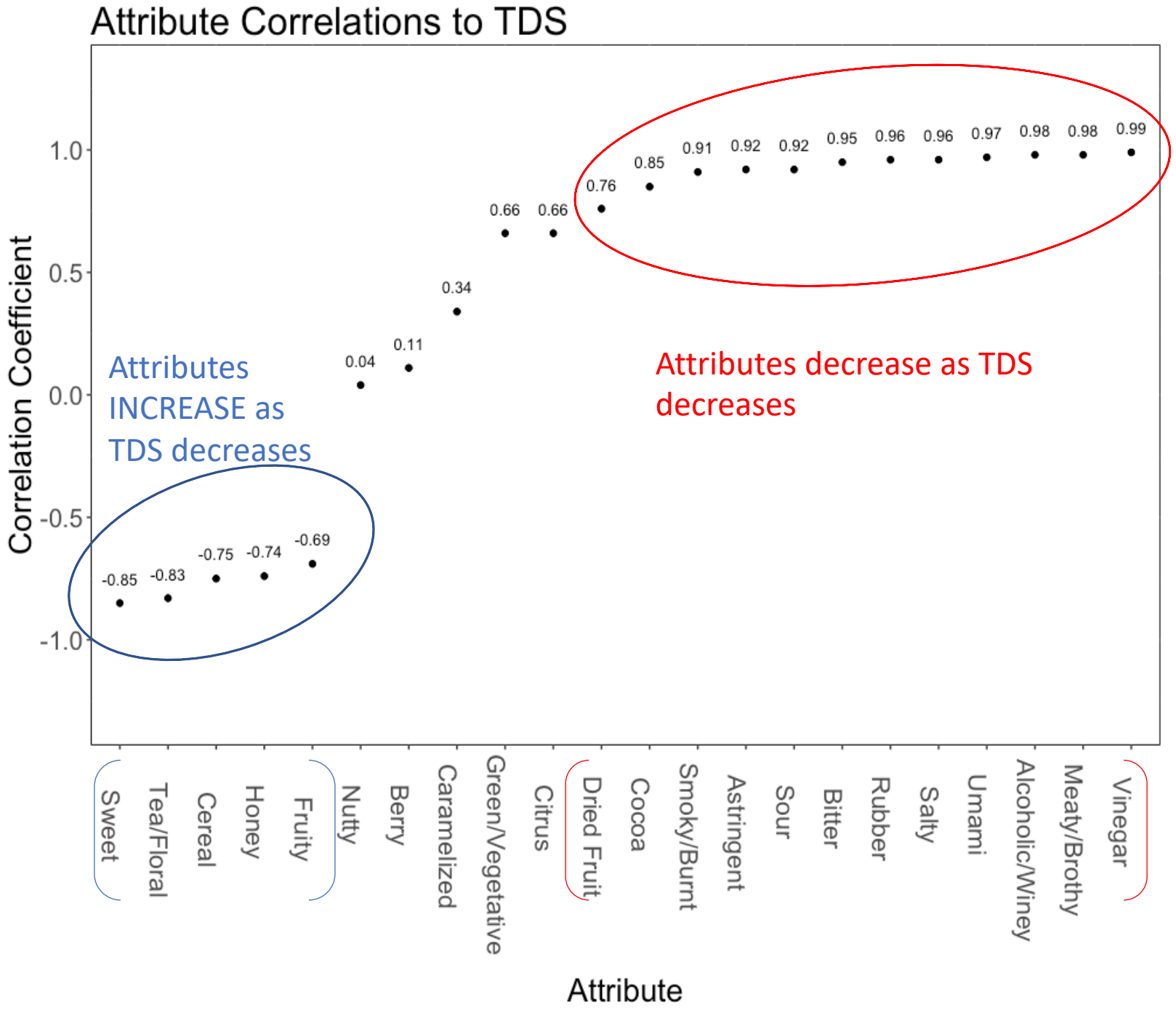


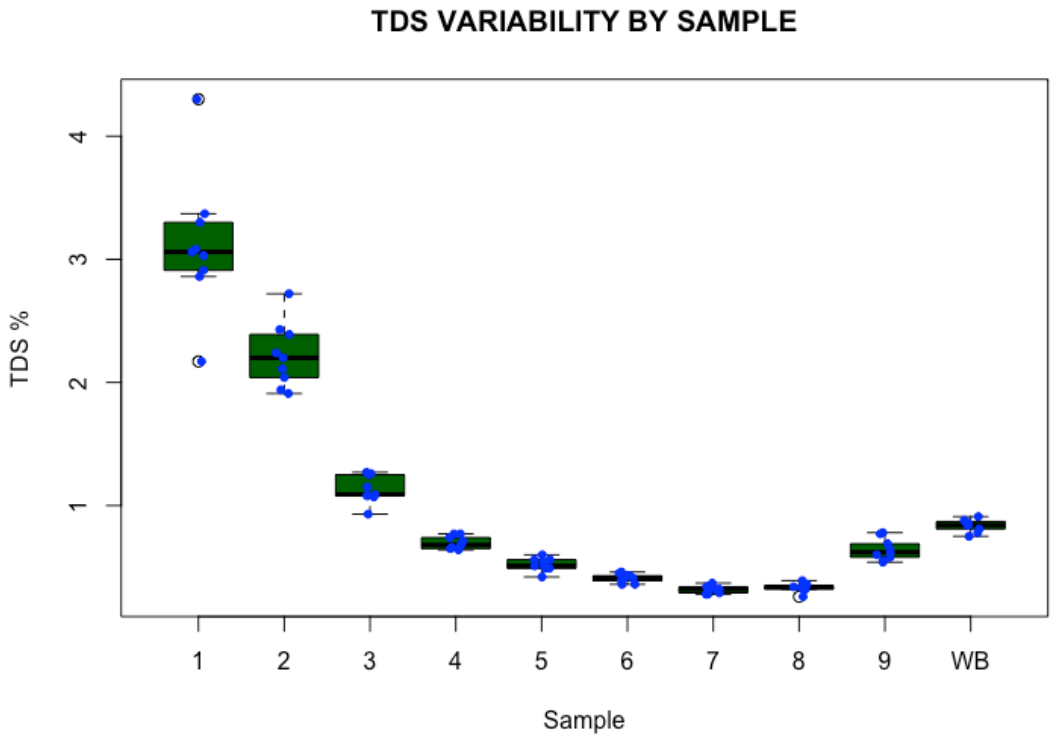

Taste and TDS Correlation - Bitter
Bitter intensity
20
30
40
50
0.5
1.0
1.5
2.0
2.5
3.0
TDS %

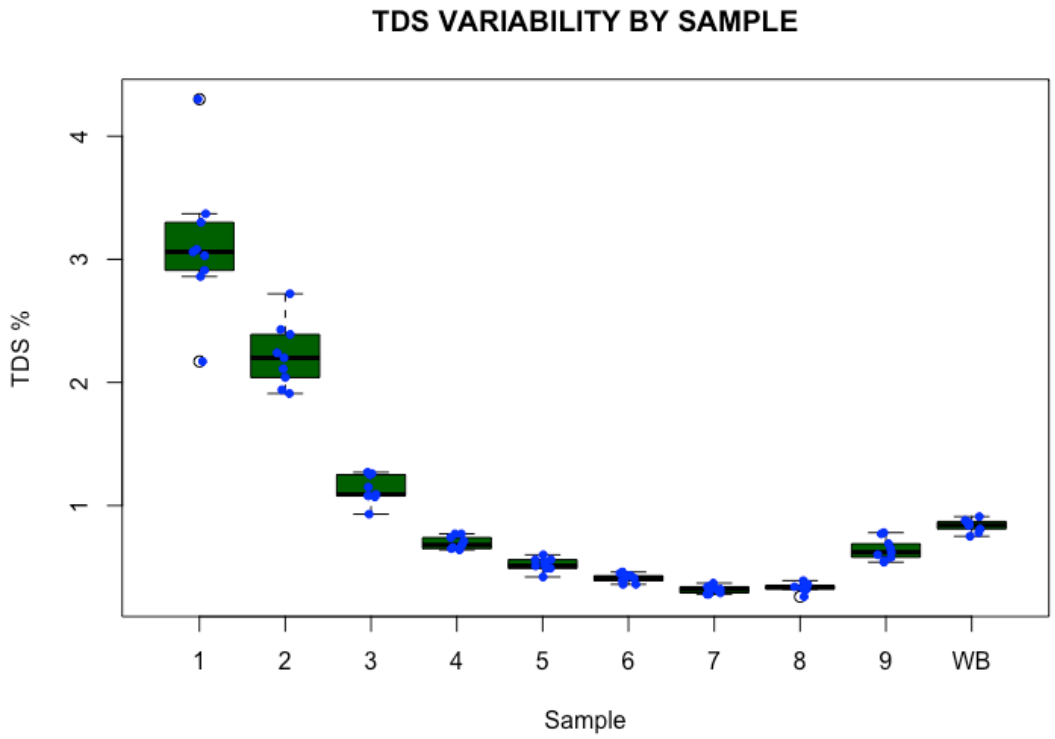

Taste and TDS Correlation - Sweet
Sweet intensity
10
15
20
25
30
35
0.5
1.0
1.5
2.0
2.5
3.0
TDS %


Taste and TDS Correlation - Bitter
Bitter intensity
20
30
40
50
0.5
1.0
1.5
2.0
2.5
3.0
TDS %


Taste and TDS Correlation - Sweet
Sweet intensity
10
15
20
25
30
35
0.5
1.0
1.5
2.0
2.5
3.0
TDS %


Attribute Correlations to TDS
Correlation Coefficient
1.0
0.5
0.0
-0.5
-1.0
-0.85
-0.83
-0.75
-0.74
-0.69
0.04
0.11
0.34
0.66
0.66
0.76
0.85
0.91
0.92
0.92
0.95
0.96
0.96
0.97
0.98
0.98
0.99
Attributes INCREASE as TDS decreases
Attributes decrease as TDS decreases
Sweet
Tea/Floral
Cereal
Honey
Fruity
Nutty
Berry
Caramelized
Green/Vegetative
Citrus
Dried Fruit
Cocoa
Smoky/Burnt
Astringent
Sour
Bitter
Rubber
Salty
Umami
Alcoholic/Winey
Meaty/Brothy
Vinegar
Attribute





Further exploration of extraction rates

- Sample 9 was the last minute of drip out from the brew – not enough sample for sensory analysis, but enough for TDS and chemical analysis.

- Increase in TDS seen in that last drip out fraction
  - Slower flow rate = more contact time with grounds and more material extracted

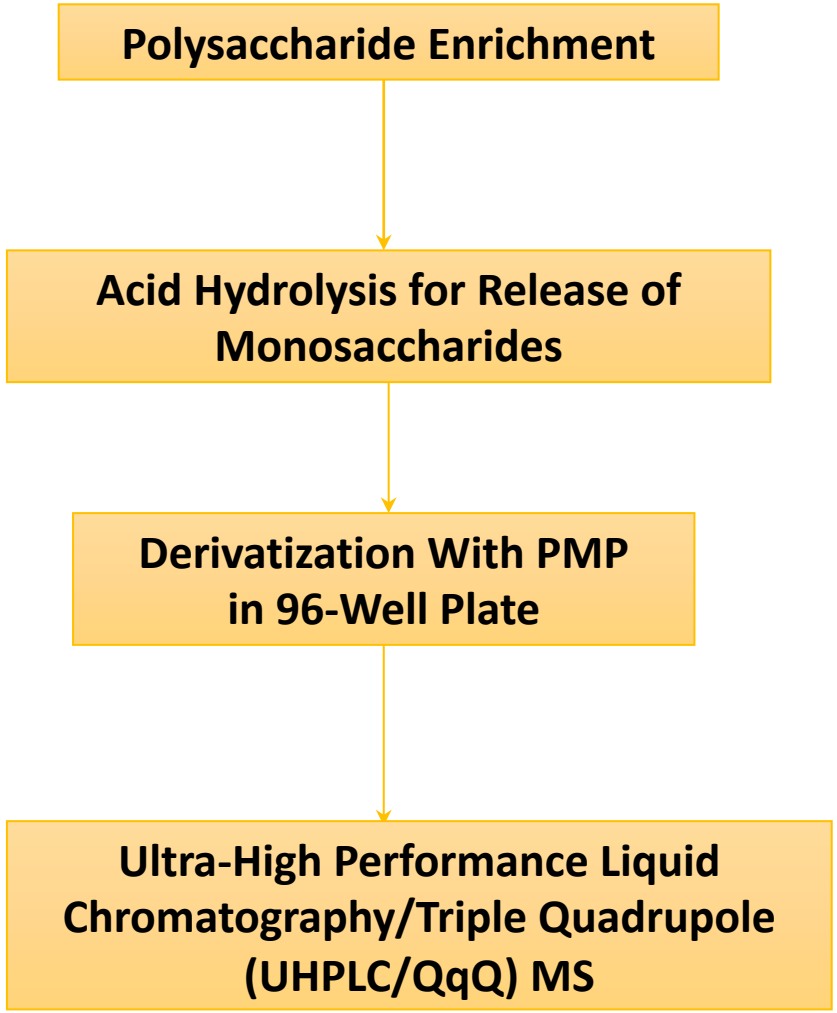
Chemical Composition: Monosaccharide Content

- If sweetness is increasing, maybe the concentration of sugars is increasing?
- Sugars that make up plant material might extract more slowly than acids, caffeine, etc

- Monosaccharides:
- Simple sugars that cannot be hydrolyzed to a smaller sugar. Building blocks of disaccharides (ex. sucrose and lactose), as well as polysaccharides like cellulose and make up a large part of plant material.

Method for Monosaccharide Analysis of Coffee Samples

More complicated than you'd think – Full week of lab time on a ~$600K instrument



Sample and standard preparation

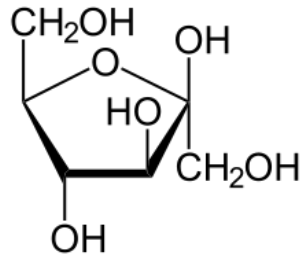
Treatment with trifluoroacetic acid to break down polysaccharides

Hydrolyzed and free monosaccharides reacted with 1-phenyl-3-methyl-5-pyrazolone for extremely sensitive detection

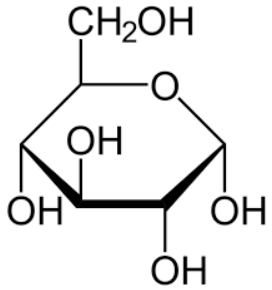
UPLC for compound separation and resolution, MS measures each compound

Analyst. **2017**, 143(1), pp 200-207
International Journal of Mass Spectrometry, **2018**, 438, pp 22-28

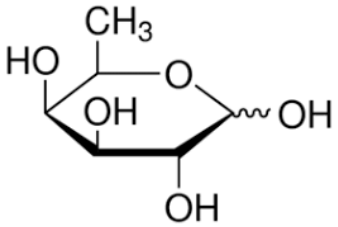
- Fructose



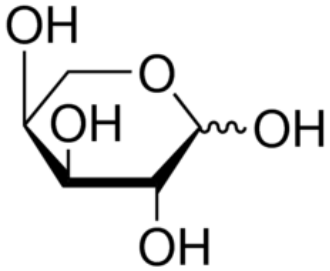
- Glucose



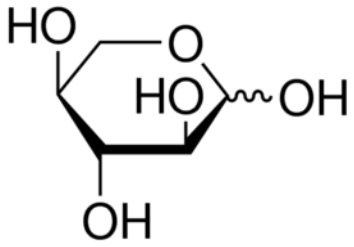
- Fucose



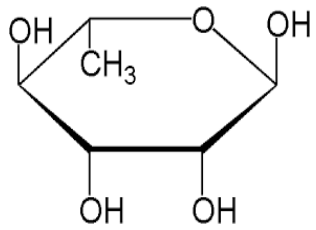
- Arabinose



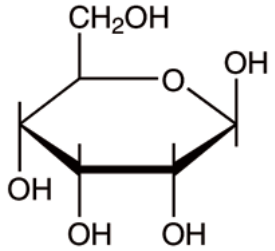
- Xylose



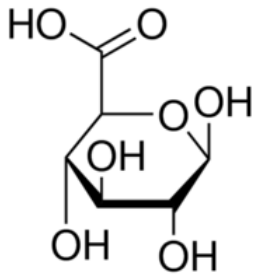
- Rhannose



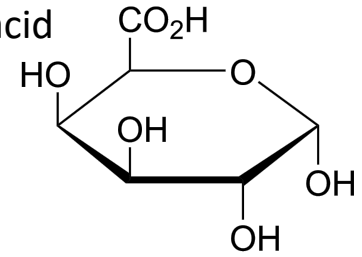
- Allose



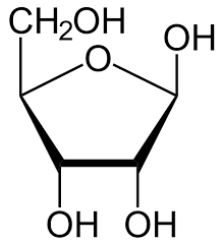
- Glucuronic acid



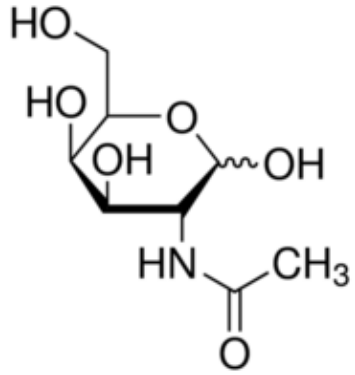
- Galacturonic acid



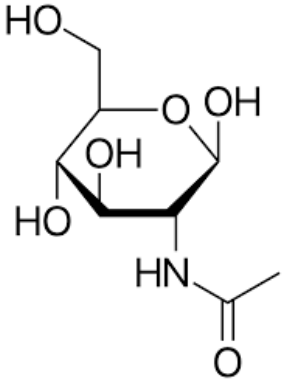
- Ribose



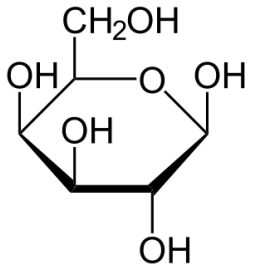
- N-acetyl galactosamine



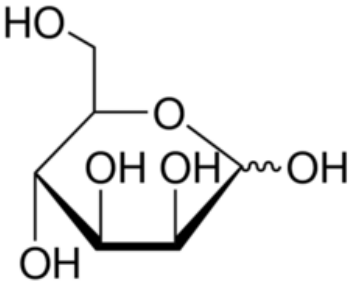
- N-acetyl glucosamine



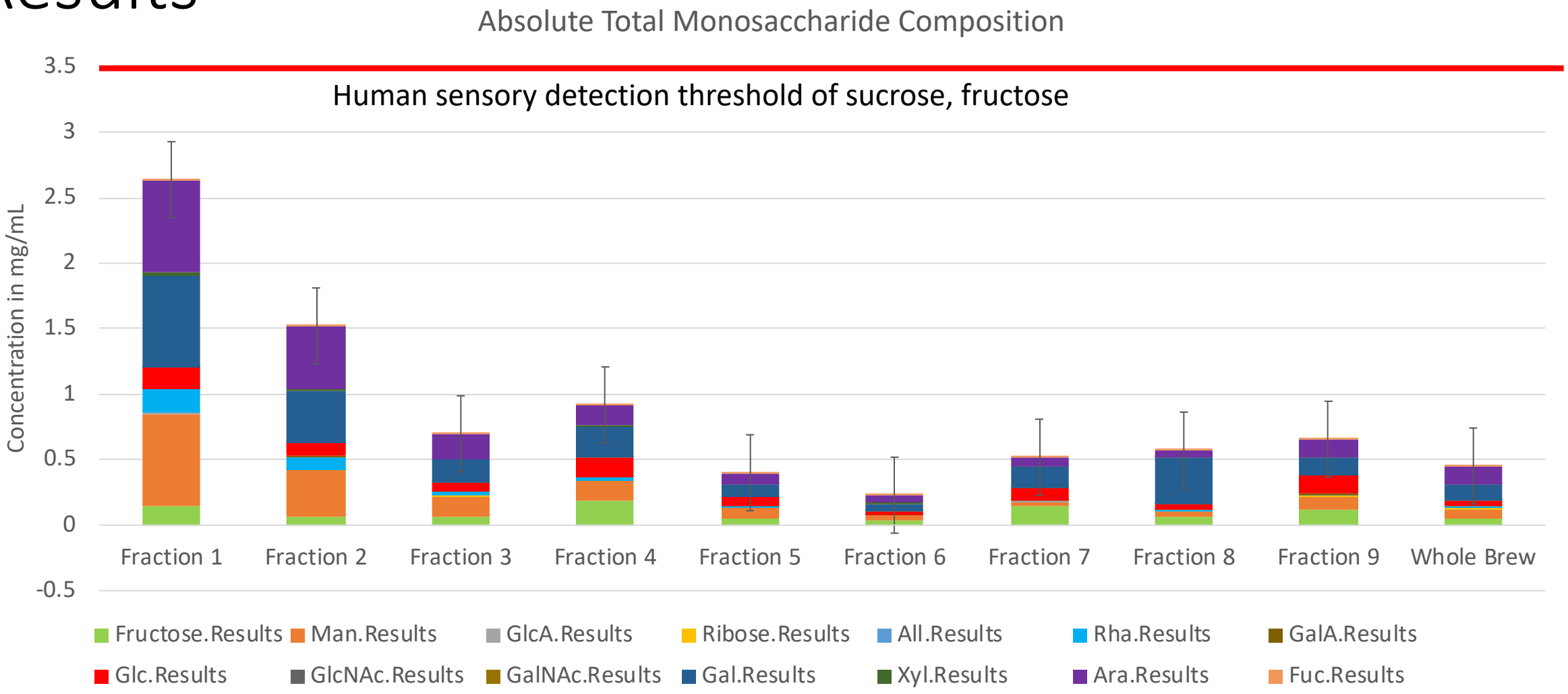
- Galactose



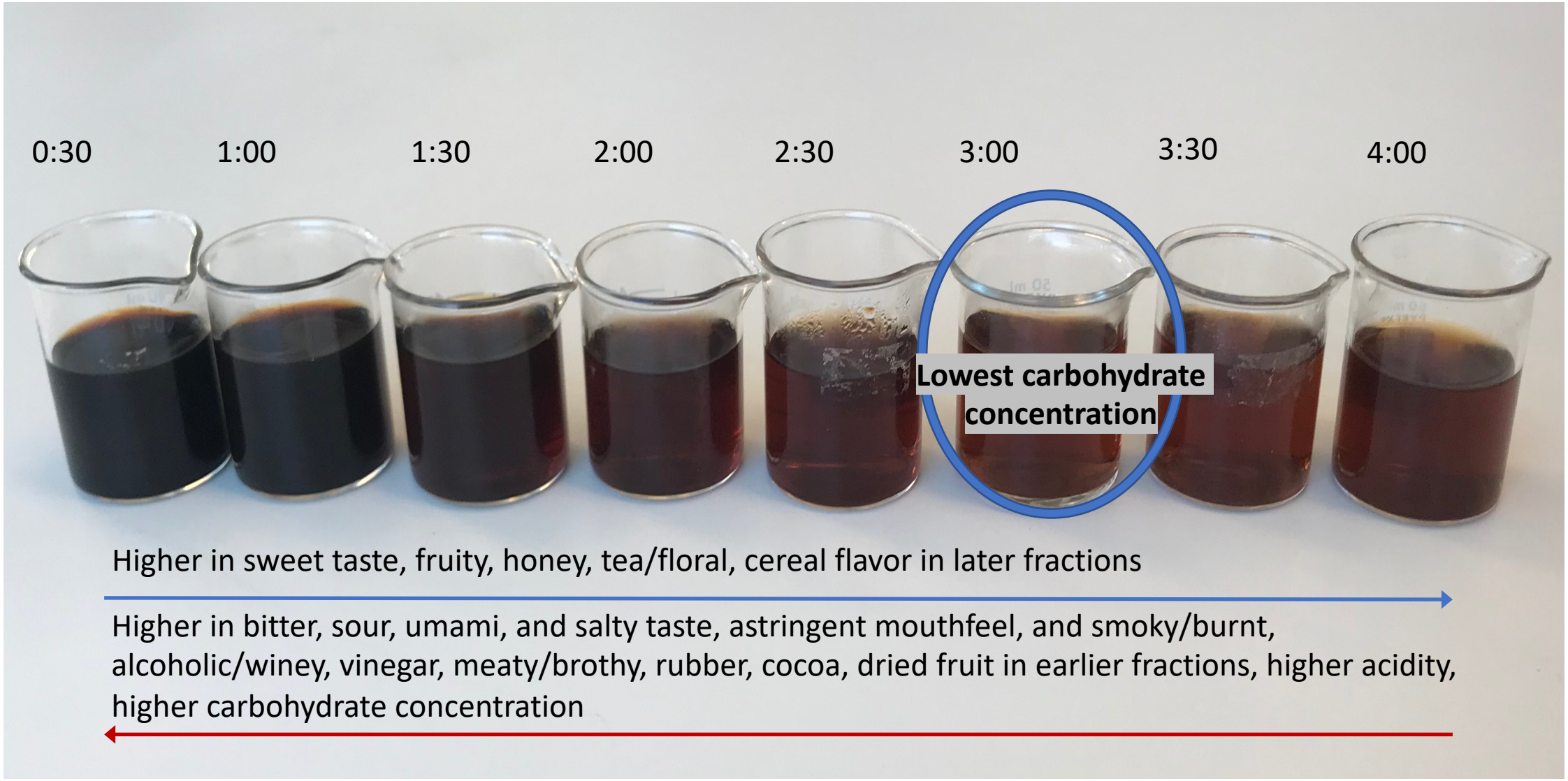
- Mannose



Results


Absolute Total Monosaccharide Composition
Human sensory detection threshold of sucrose, fructose
Concentration in mg/mL
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Fraction 1
Fraction 2
Fraction 3
Fraction 4
Fraction 5
Fraction 6
Fraction 7
Fraction 8
Fraction 9
Whole Brew
Fructose.Results
Man.Results
GlcA.Results
Ribose.Results
All.Results
Rha.Results
GalA.Results
Glc.Results
GlcNAc.Results
GalNAc.Results
Gal.Results
Xyl.Results
Ara.Results
Fuc.Results

Summary and Conclusions



So what IS causing the increase in sweetness?

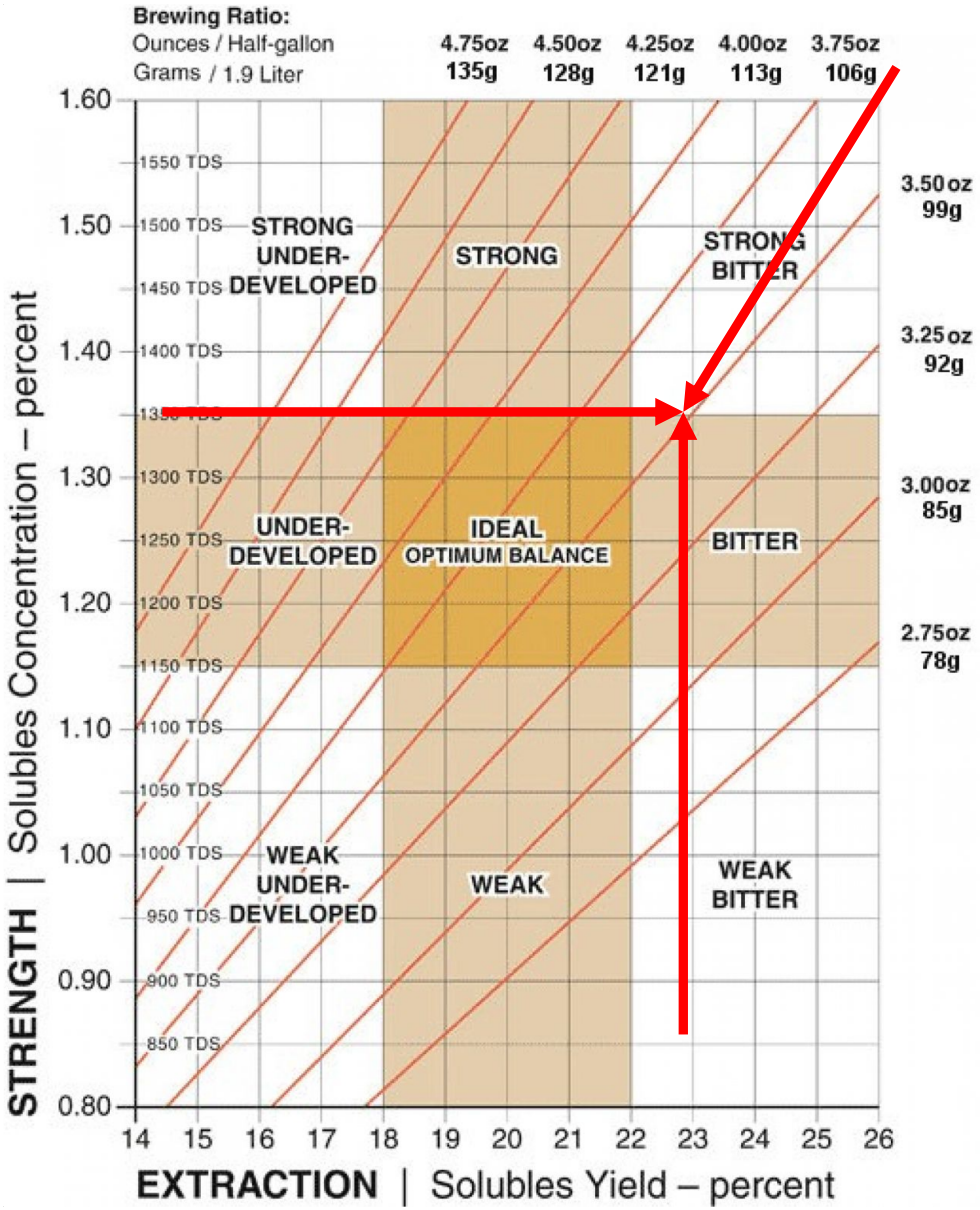
Other higher molecular weight molecules might follow a similar extraction profile (maillard reaction products) contributing to the increased perception of “honey” and “cereal” flavors.

Perception of sweetness could be related to aroma compounds that are generally more associated with sweetness like “fruity” and “honey” – combined with the lack of bitter and sour tastes.

The results presented here are published:
“Sensory and Monosaccharide Analysis of Drip Brew Coffee Fractions versus Brewing Time”
Batali, Frost, Ristenpart, Lebrilla & Guinard, *Journal of the Science of Food and Agriculture.*

Part 2: Brew Temperature and Sensory Quality Across the Coffee Brewing Control Chart

TDS



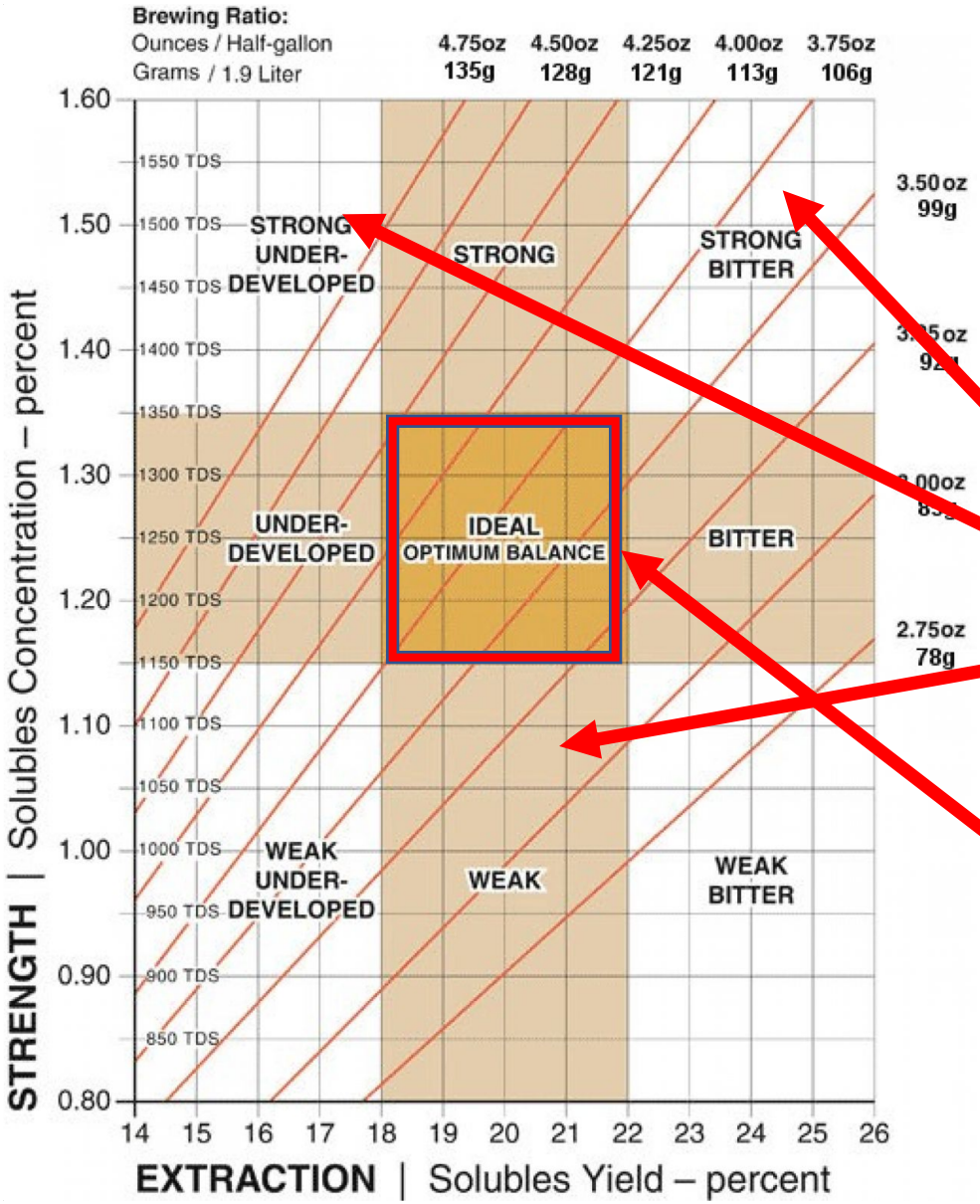
PE

**The Coffee Brewing Handbook, SCAA 2011*

The Brewing Control Chart

The **mass relationship** between

- Total dissolved solids – STRENGTH
- Yield – PERCENT EXTRACTION
- The brew formula - DOSE



The Brewing Control Chart

The **mass relationship** between

- Total dissolved solids – STRENGTH
- Yield - EXTRACTION
- The brew formula - DOSE

The addition of the verbiage
-Developed
-Underdeveloped
-Bitter
-Strong
-Weak

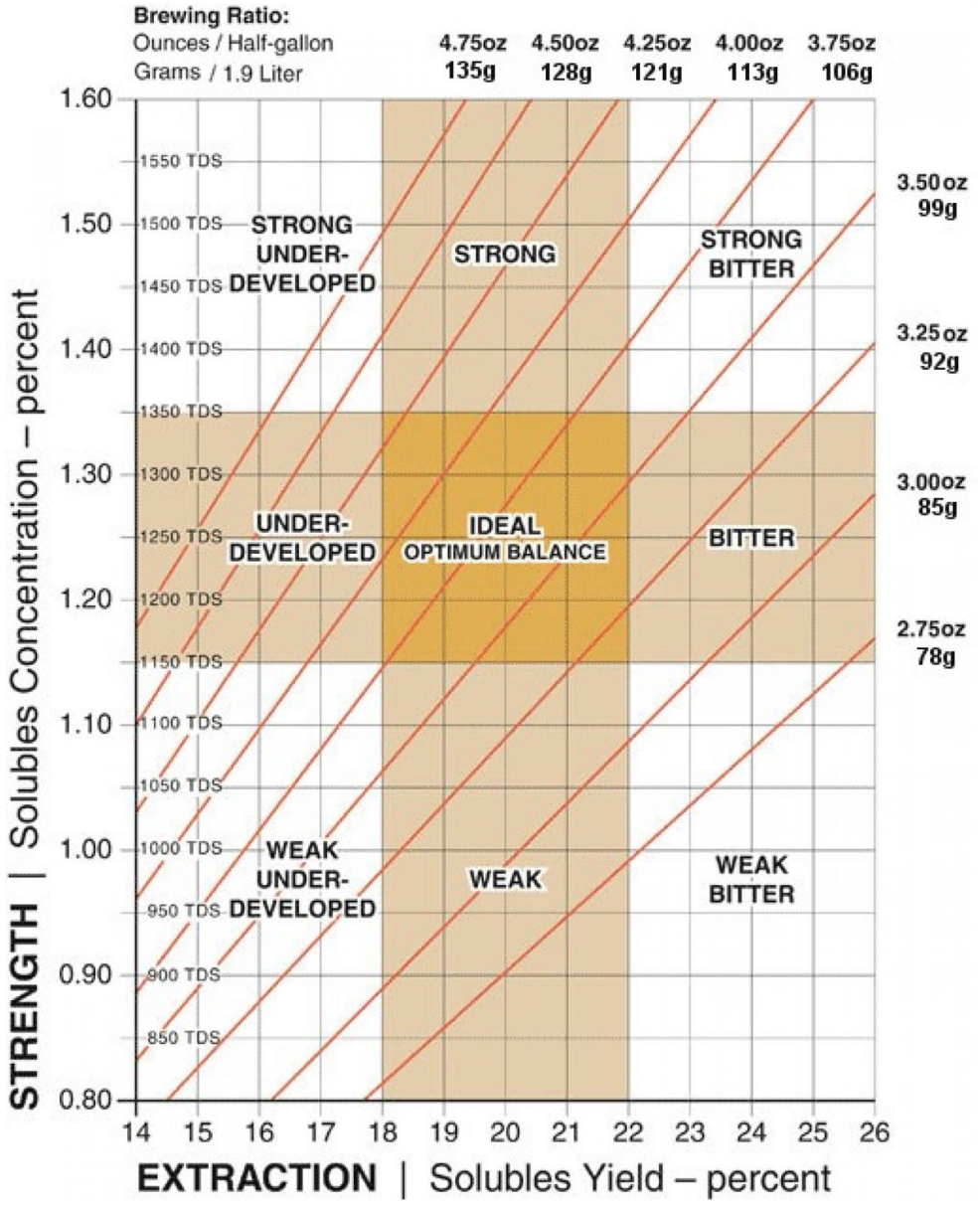
Ideal?

-says who….

**The Coffee Brewing Handbook, SCAA 2011*

But coffee is so much more!!!!

?



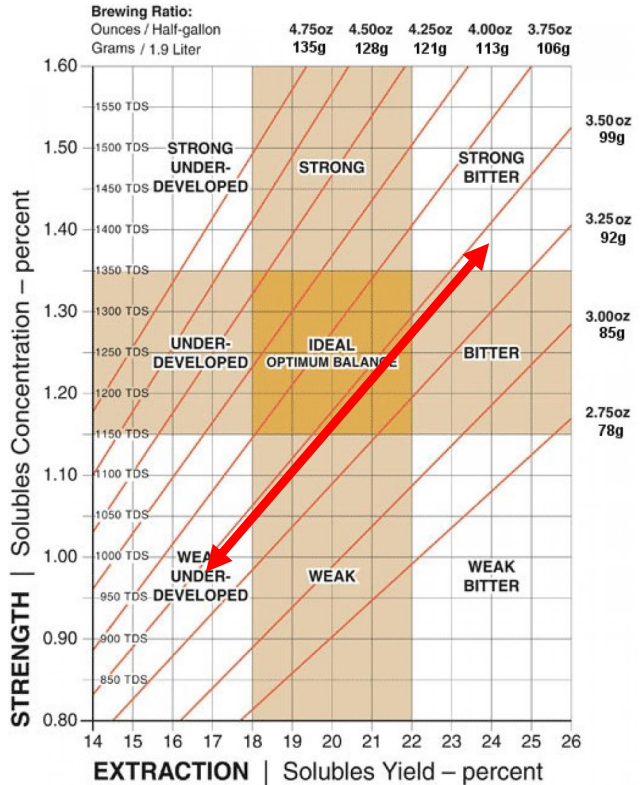
Research Objectives

Question?

How do specific sensory attributes change in respect to the Brewing Control Chart?

Hypothesis?

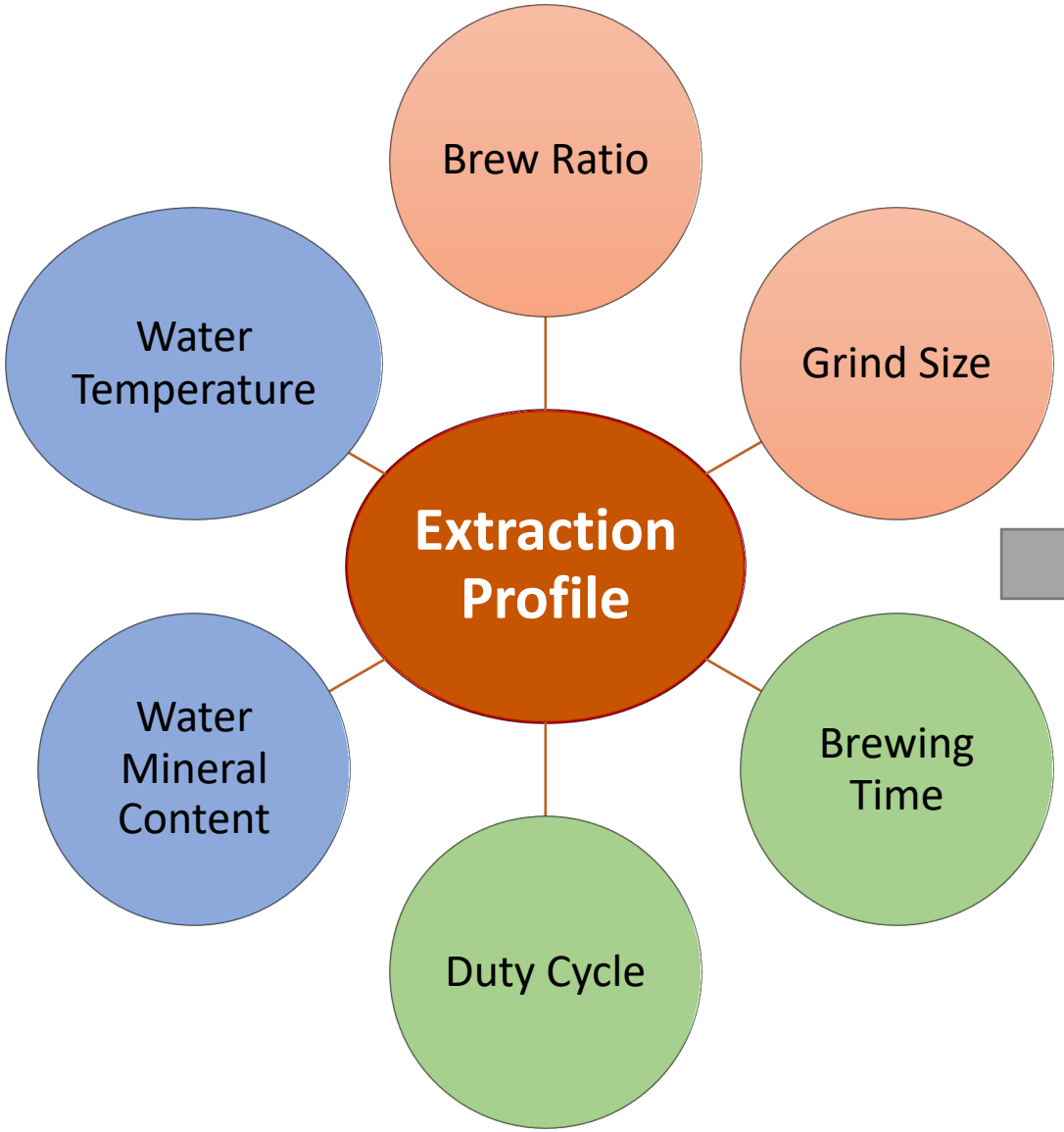
If coffee is brewed at different index positions, then perceived sensory will change.

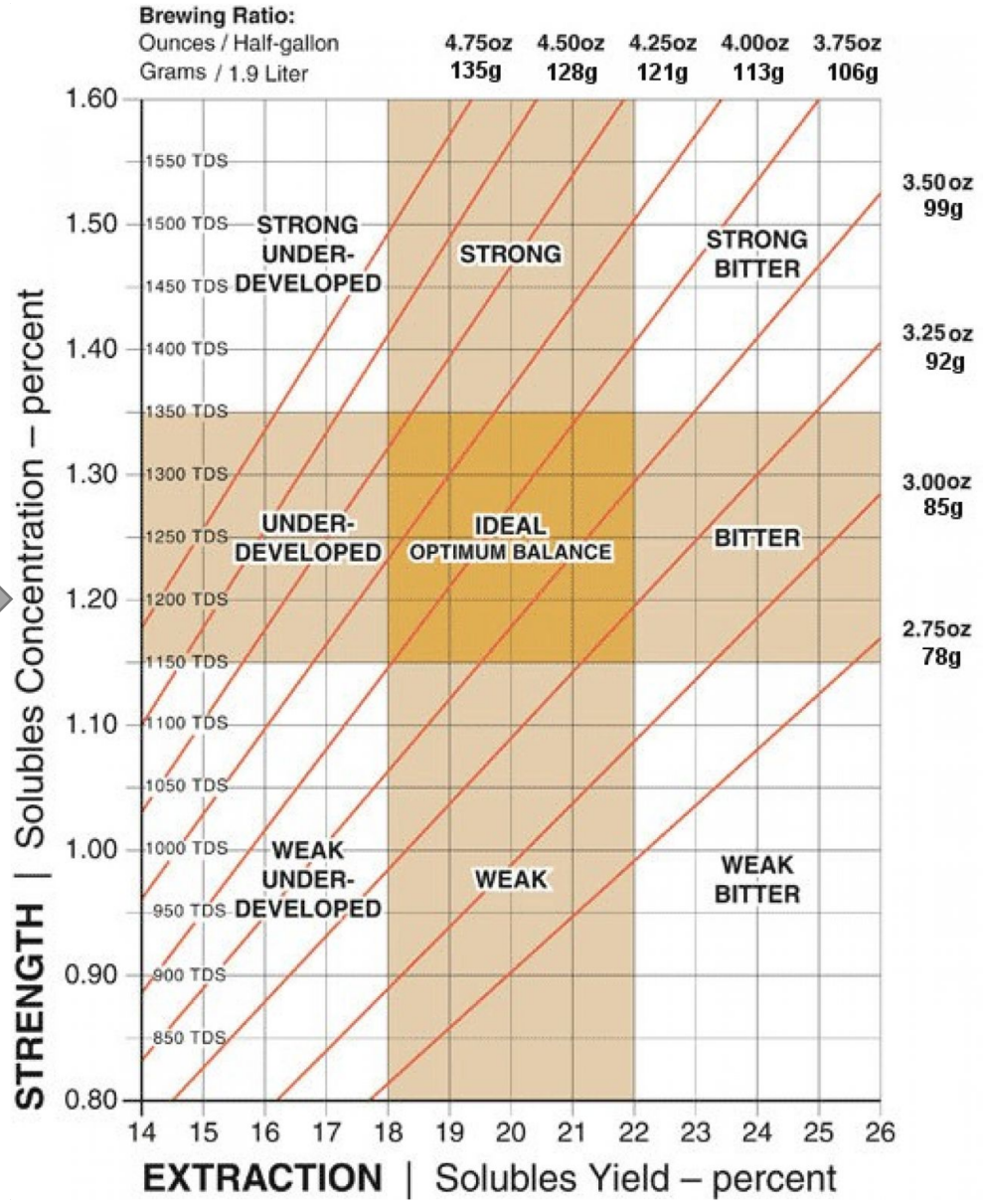


Breville®

Specialty Coffee Association

What factors impact extraction in a drip brew?





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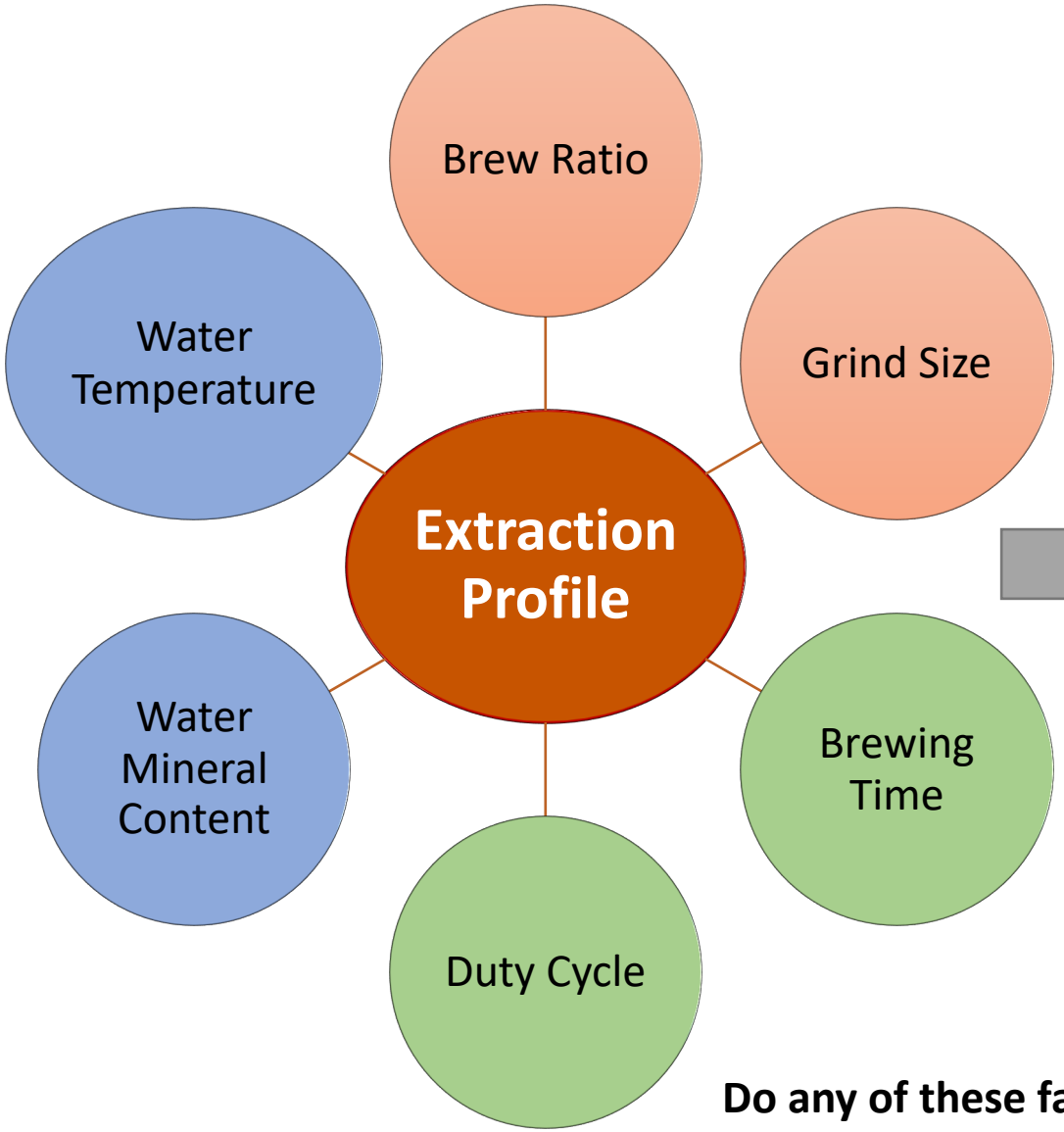
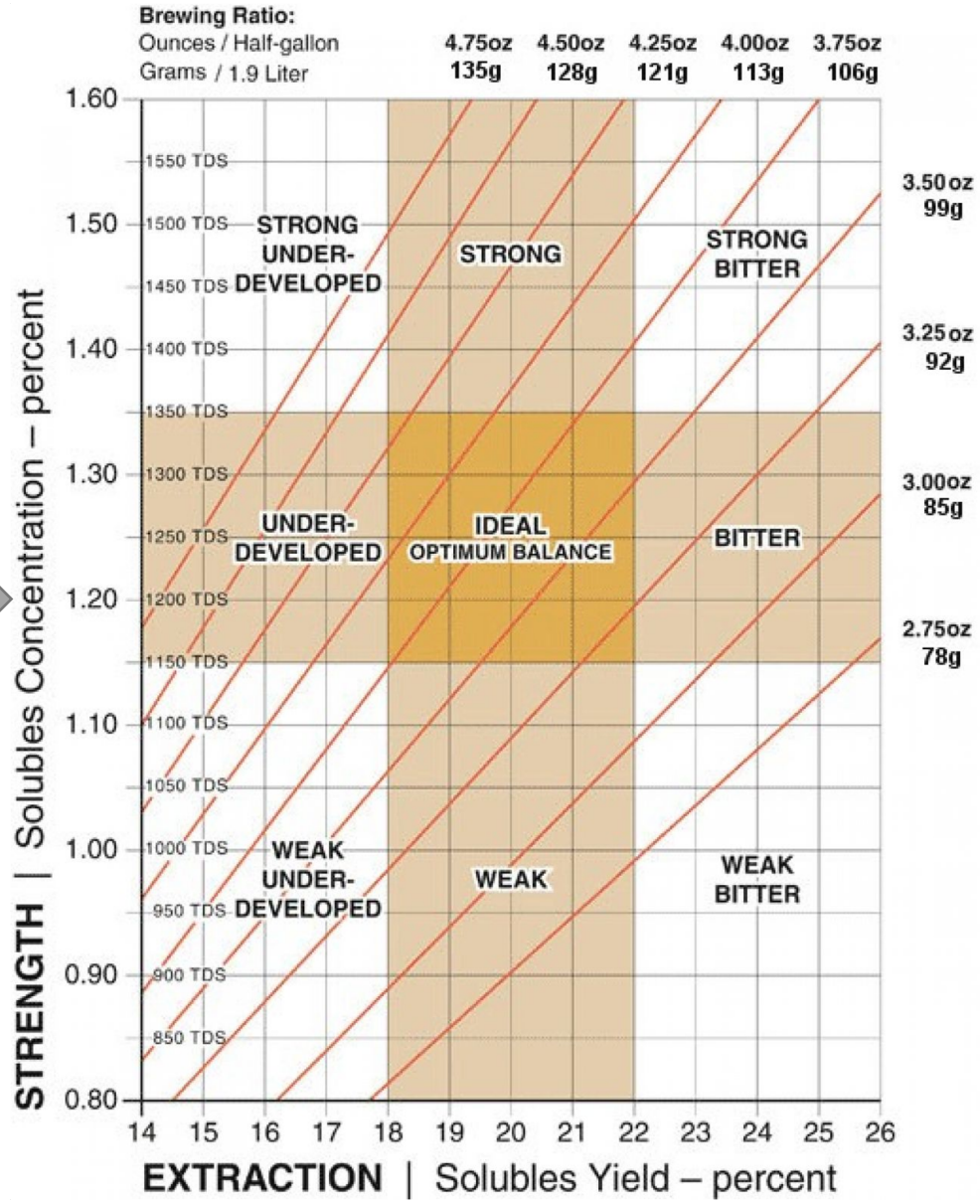


Do any of these factors make a difference when extraction is controlled?



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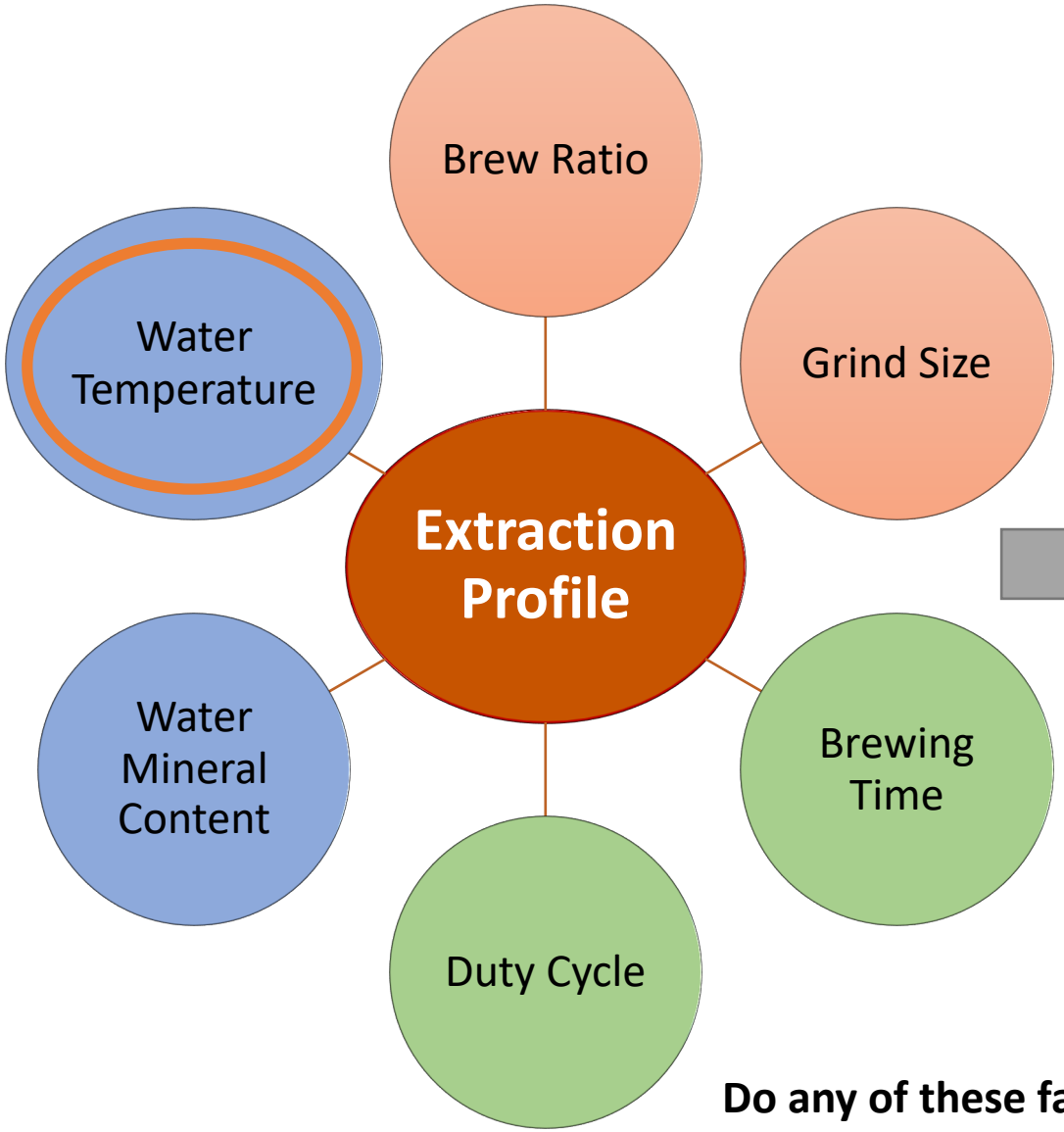

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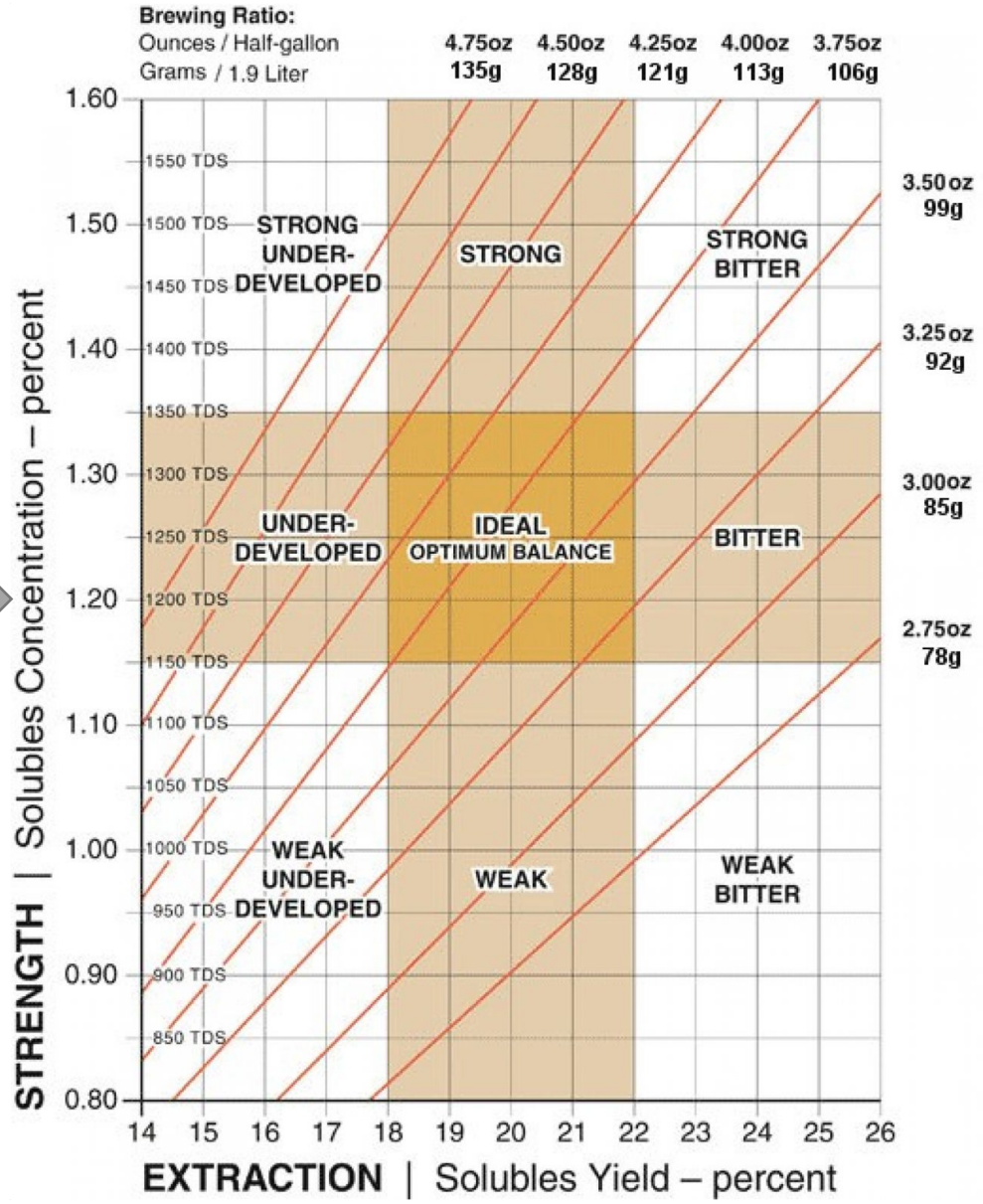


Why do we care about brew temperature?

- More extreme example – cold brew versus iced coffee
- Different flavor compounds will extract at different temperatures
- Higher brew temperatures require more energy in a coffee shop
- Within a more modest range, we would hypothesize that the temperature of hot brewed coffee at the same extraction brewed at different temperatures would have a different sensory profile

Two goals, three variables

- The impact of extraction (Total Dissolved Solids and Percent Extraction) on sensory quality of drip brew coffee.
- The impact of brew temperature at fixed extraction on sensory quality of drip brew coffee.

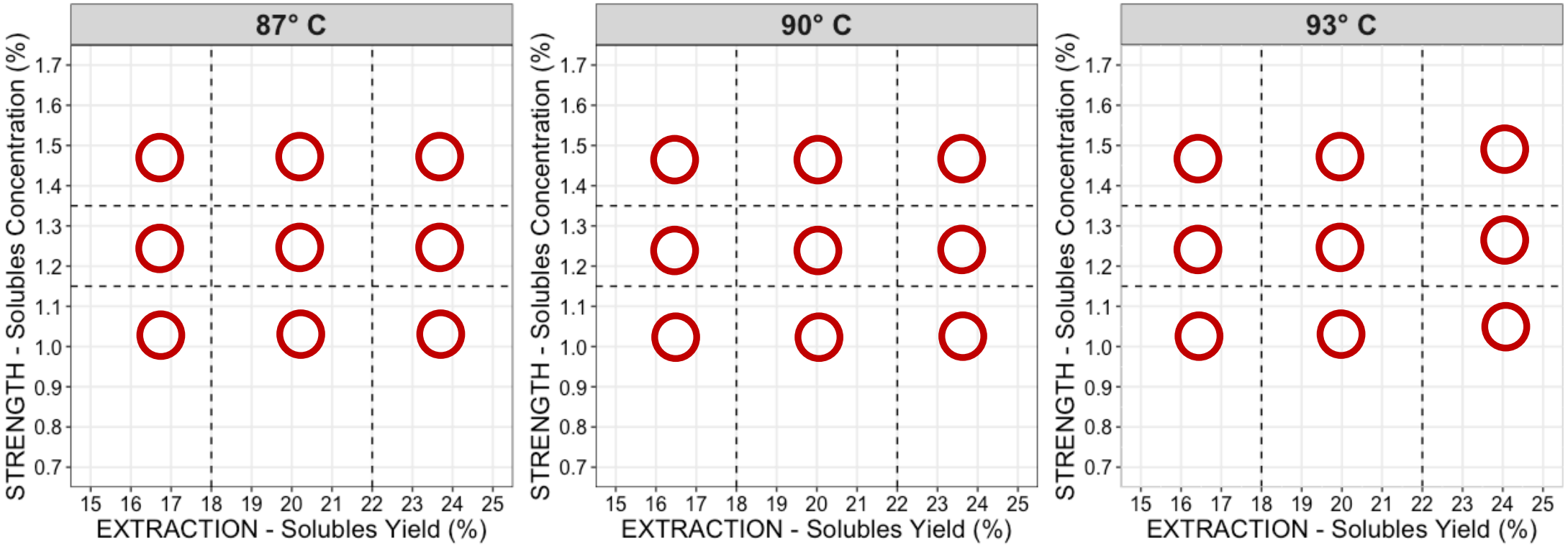
Experimental Design

Three Water Temperatures: 87°C – 90°C – 93°C

Three PE: 16.0% – 20.0% – 24.0%

Three TDS: 1.00% - 1.25% - 1.50%

27 different brews from the single medium roast washed coffee.



Water Mass: 3100 g

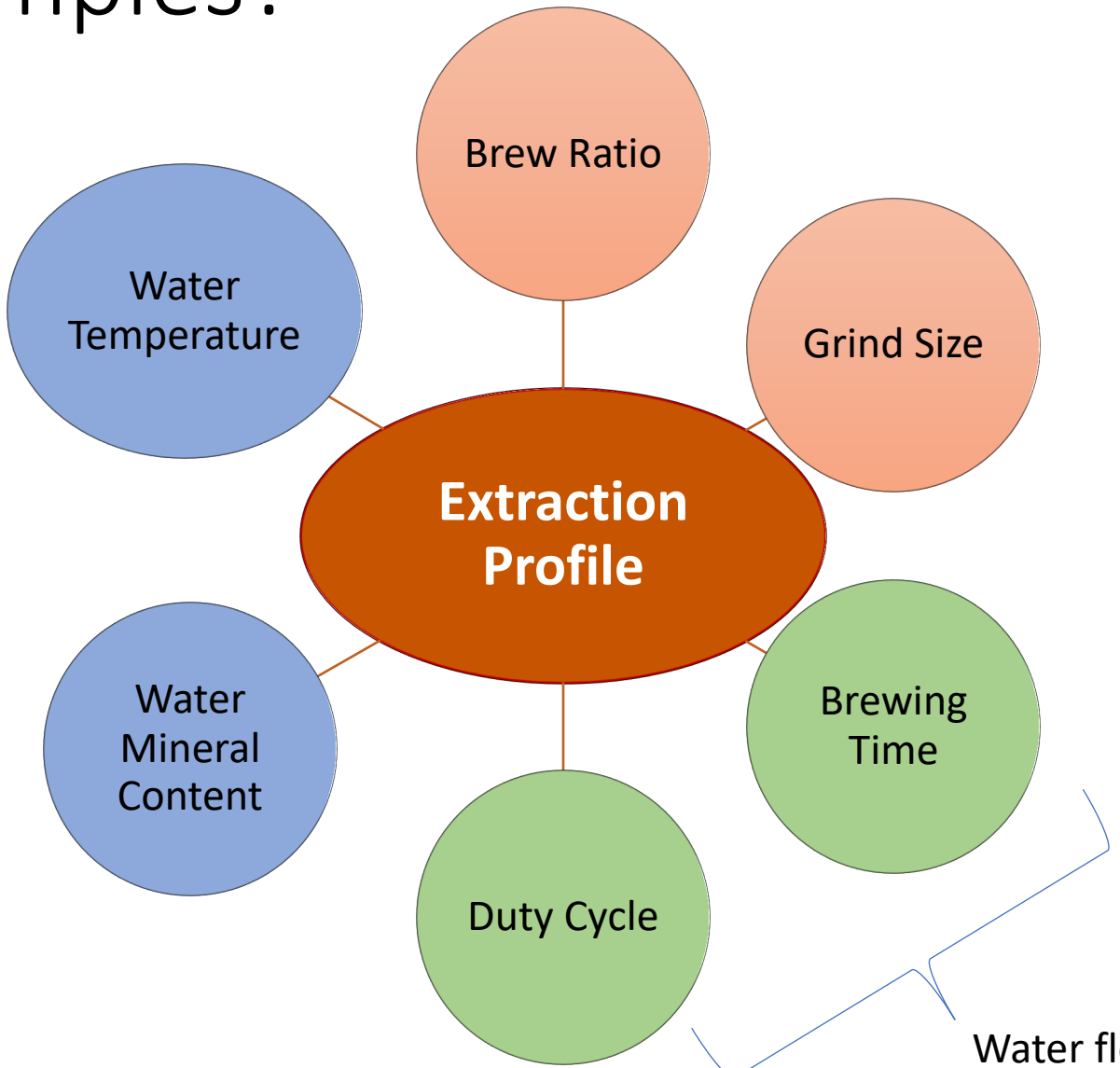
The Coffee

ORIGIN INFORMATION

Grower	Café Organico Marcala, S.A. (COMSA) | 1500 coffee producers
Variety	Bourbon, Catuai, Caturra, Lempira, Ihcafe 90, Pacas, and Typica
Region	Marcala, La Paz, Honduras
Harvest	November - February
Altitude	1300 – 1700 meters
Soil	Clay minerals
Process	Fully washed and dried in the sun and mechanical driers
Certifications	Organic

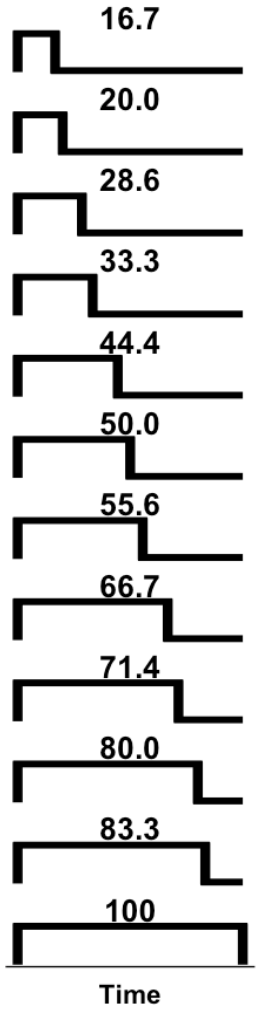
From: Royal Coffee

How did we systematically brew all of those different samples?

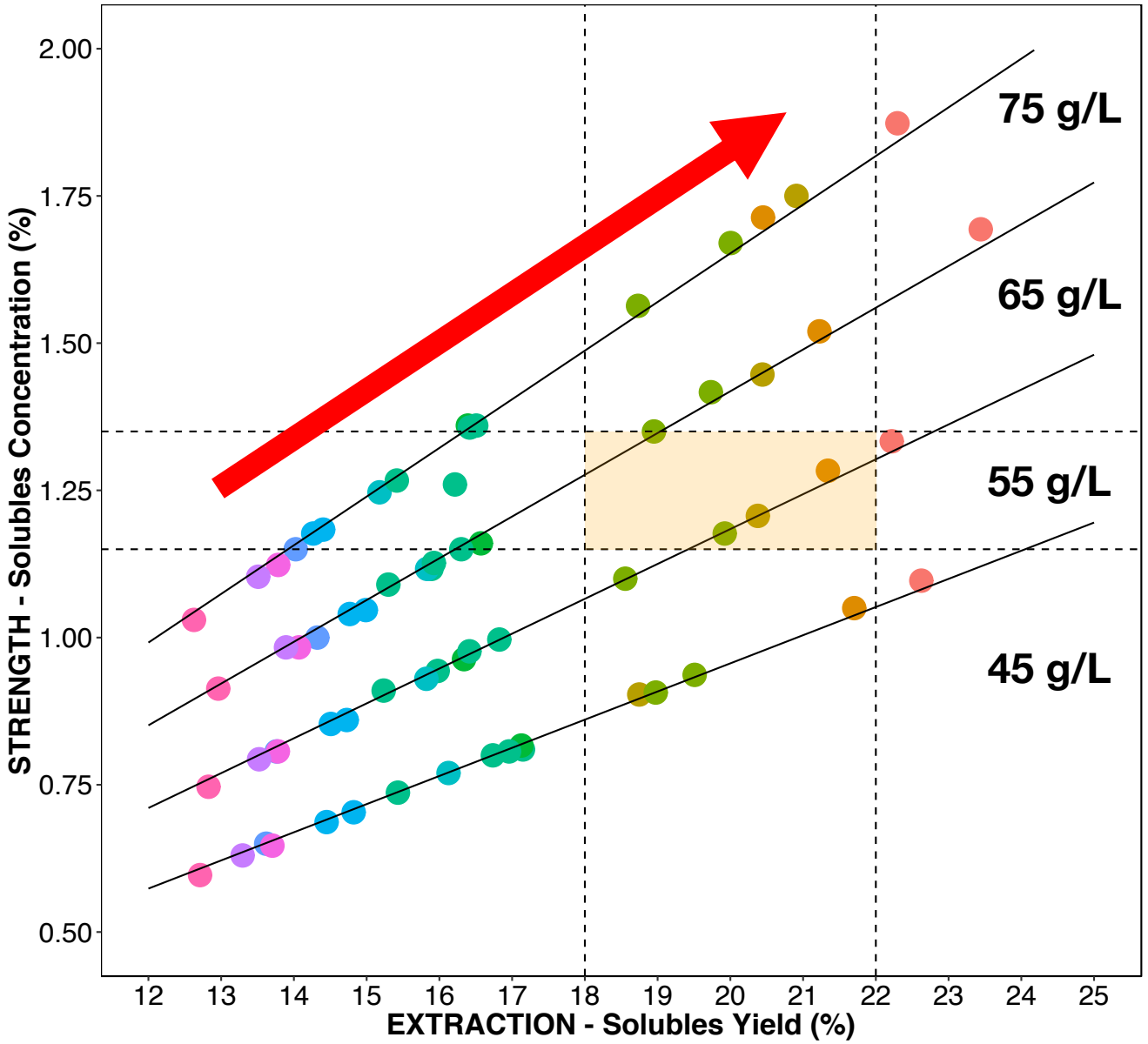


Flow rate can be manipulated by water pulsing duty cycle

Example:
40 sec Pulse ON – 40 sec Pulse OFF
4 cycles to complete brew
50 % Duty Cycle



Covering the entire chart just by changing dose and duty cycle:



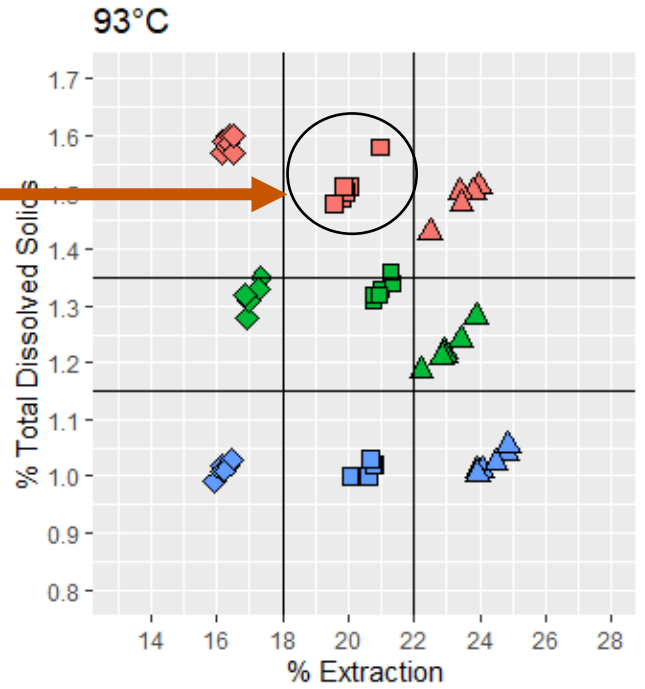
Decrease Duty Cycle, increase extraction and strength

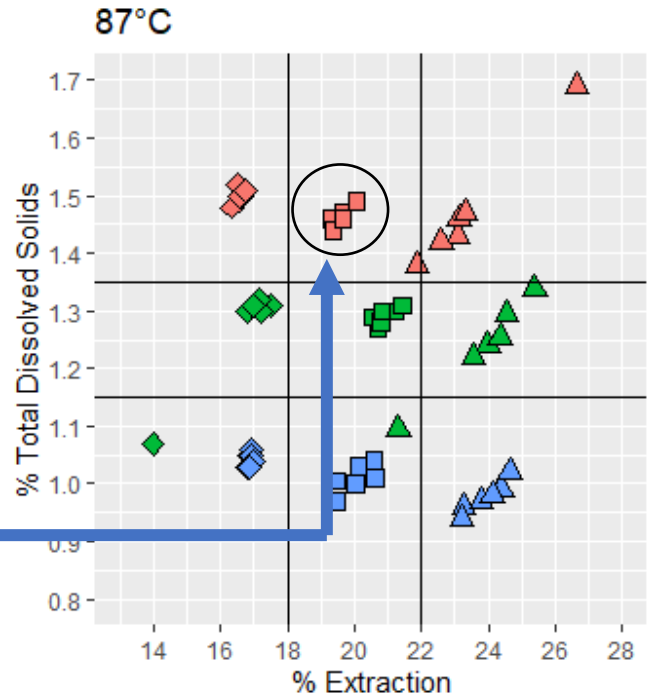
DutyCycle

- 16.7
- 20.0
- 28.6
- 33.3
- 44.4
- 50.0
- 55.6
- 66.7
- 71.4
- 80.0
- 83.3
- 100

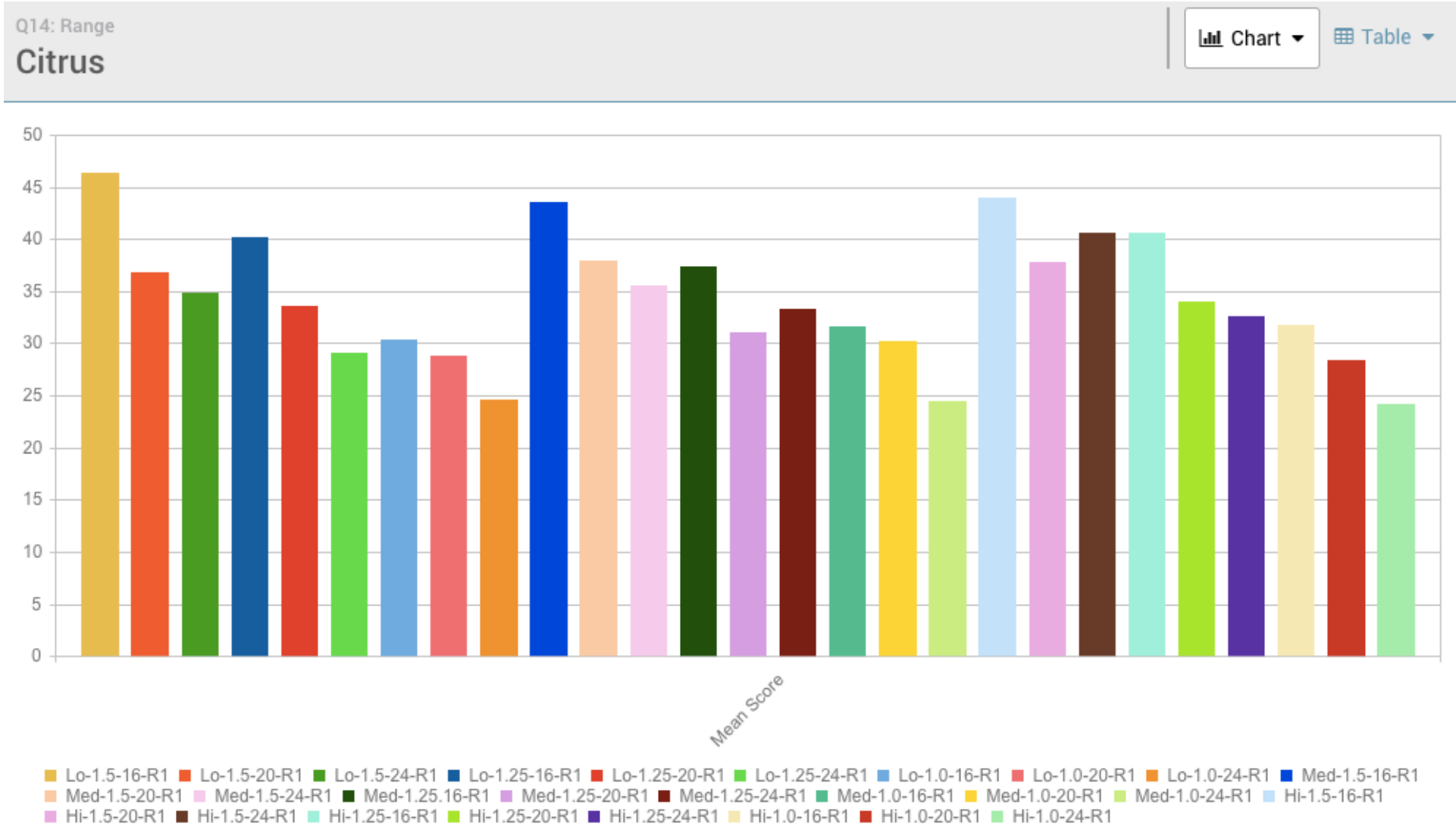
Same Extraction Different Temperatures

Target TDS	1.5%	
Target PE	20%	
Water Temp	87°C	93°C
Dose	207.6g	207.6g
Grid Size	3	4
Brew Time	7:28	8:20
Duty Cycle	40 sec water 27 sec wait 4x 3 min drip out	40 sec water 40 sec wait 4x 3 min drip out

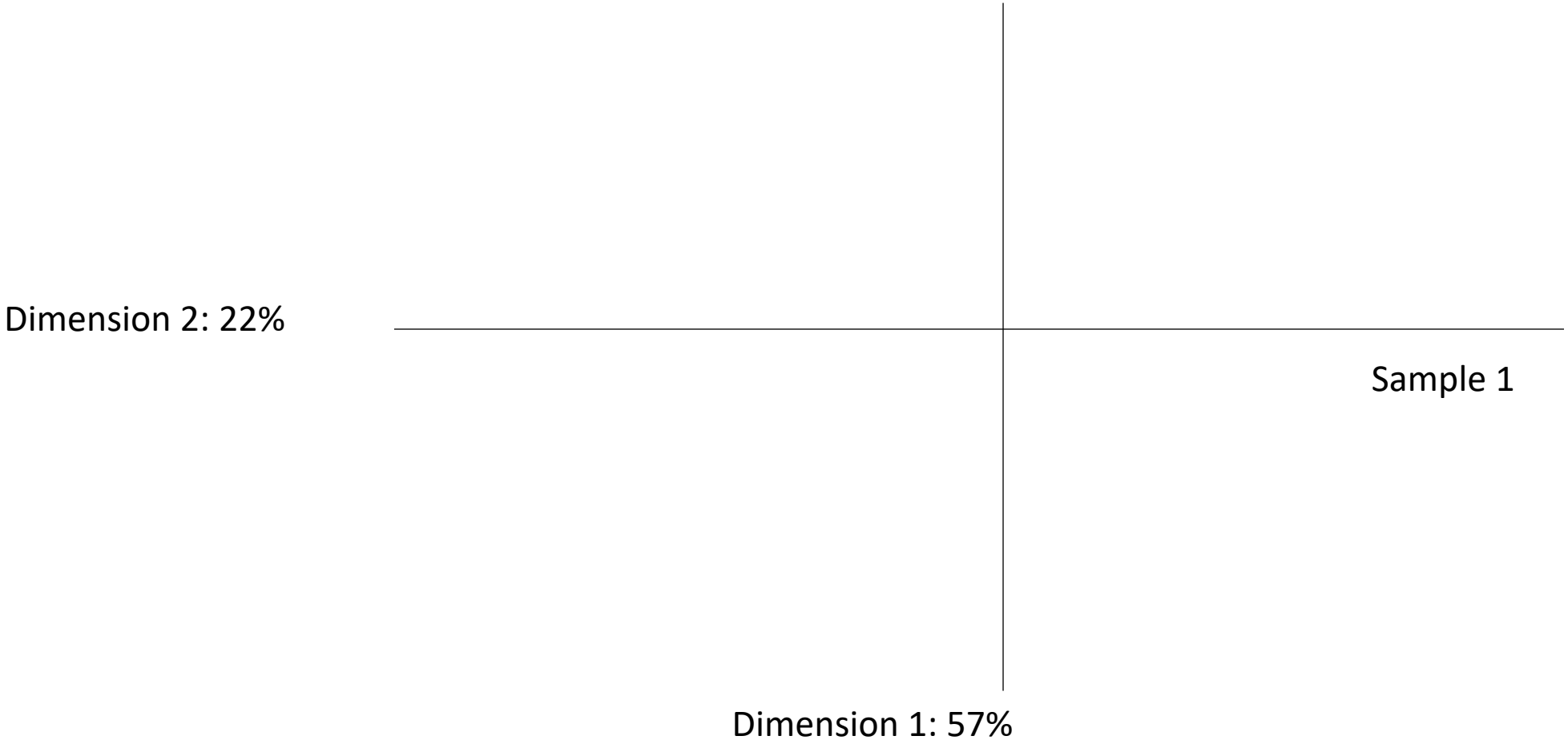




27 coffees with 30 attributes evaluated…need a better way to visualize



Multivariate Data Visualization



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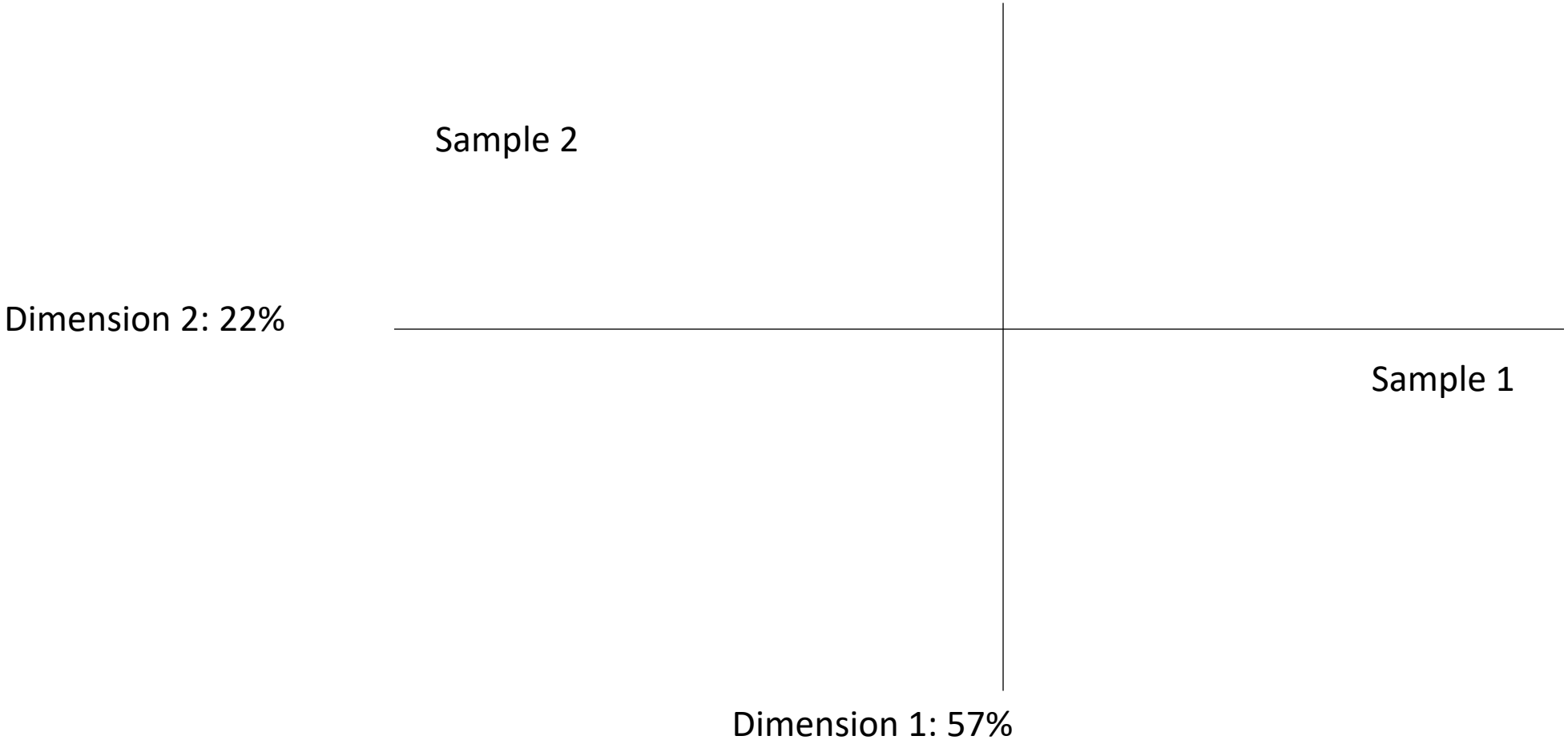

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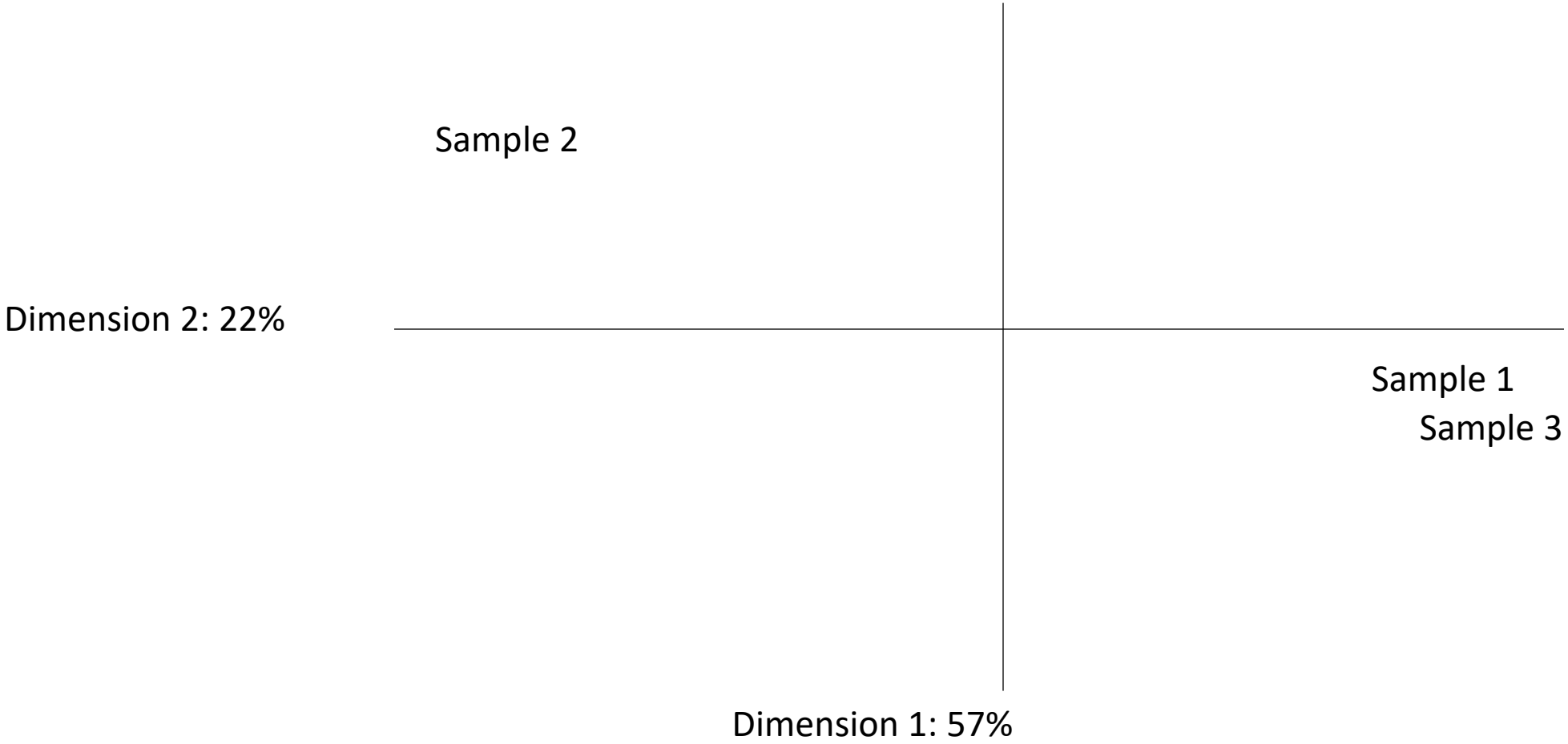

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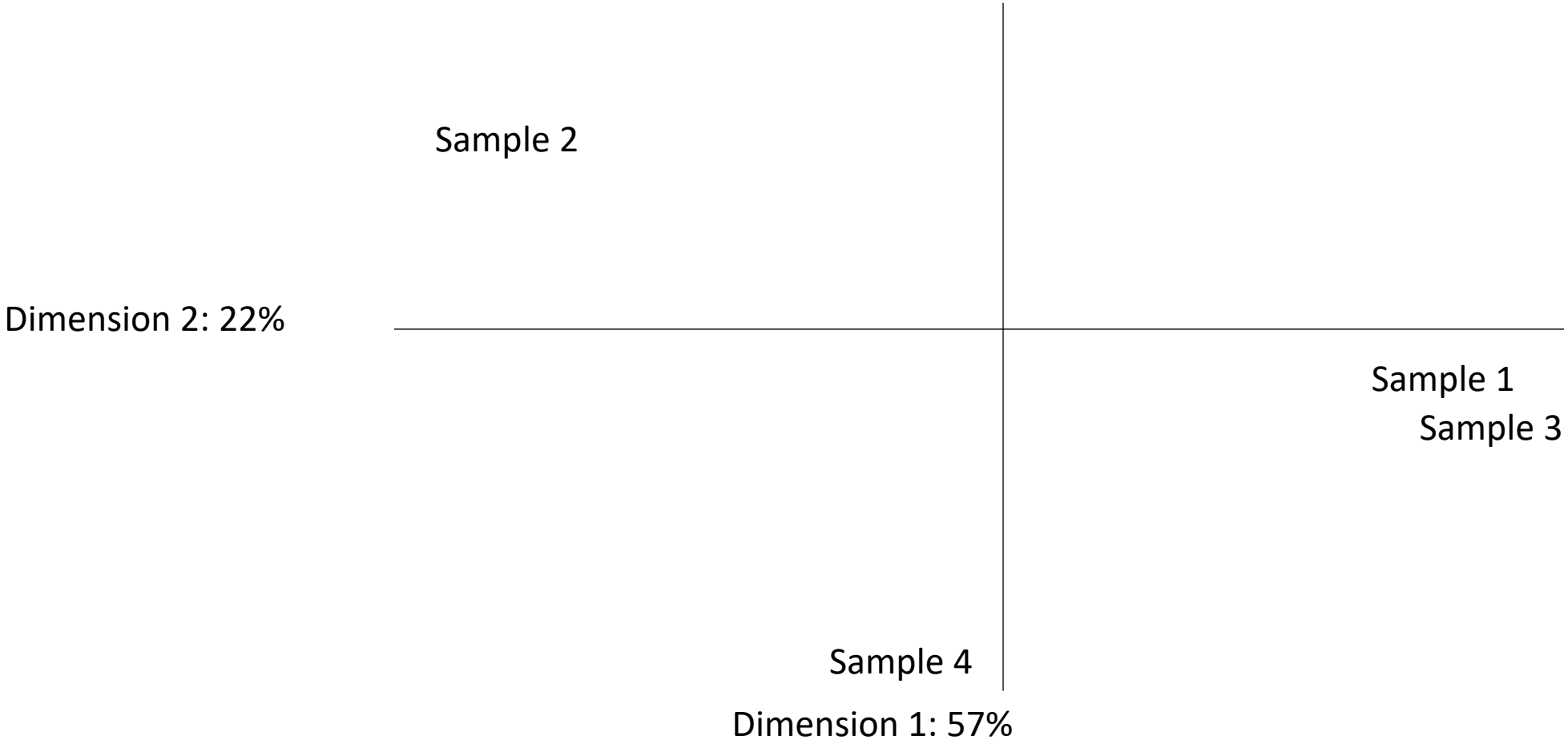

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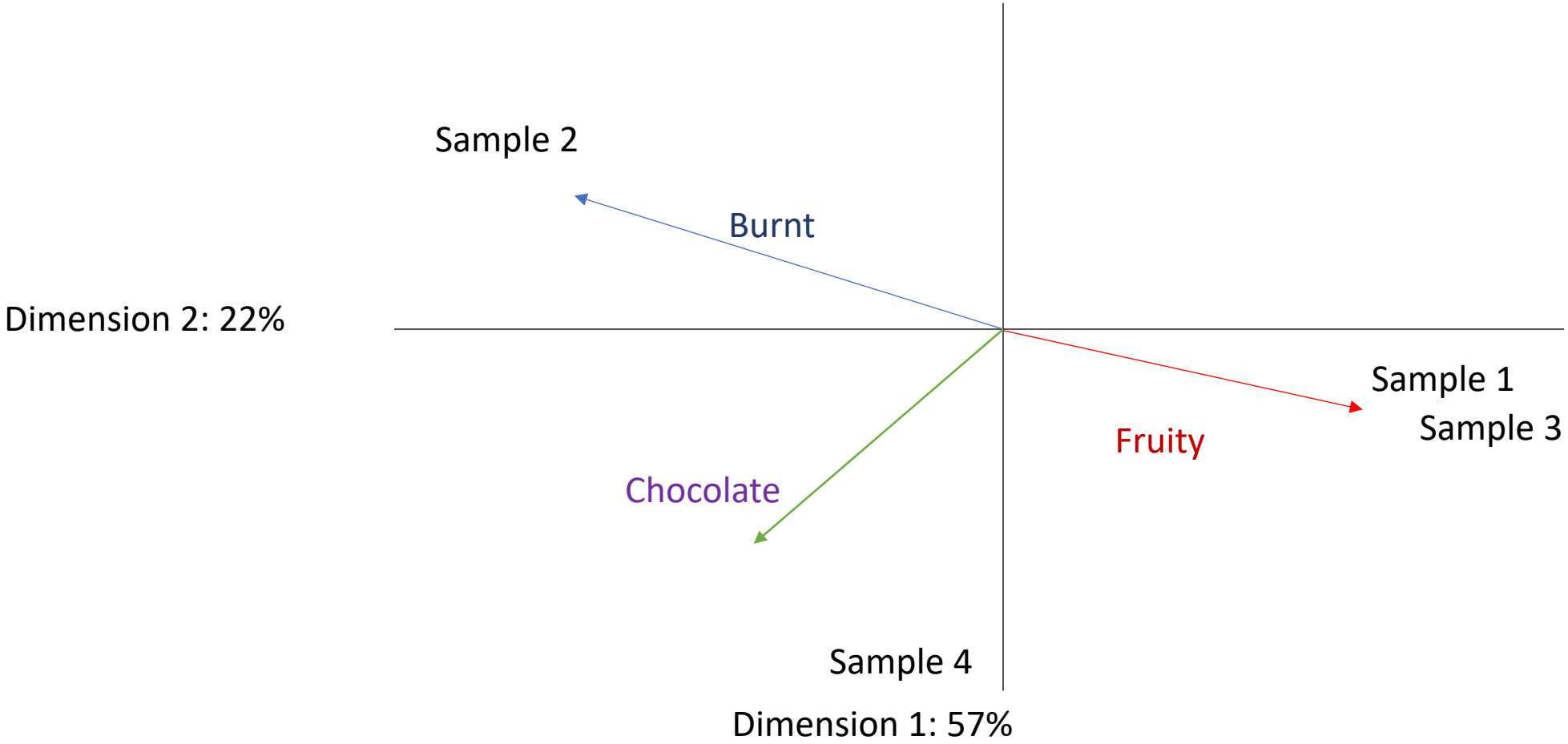
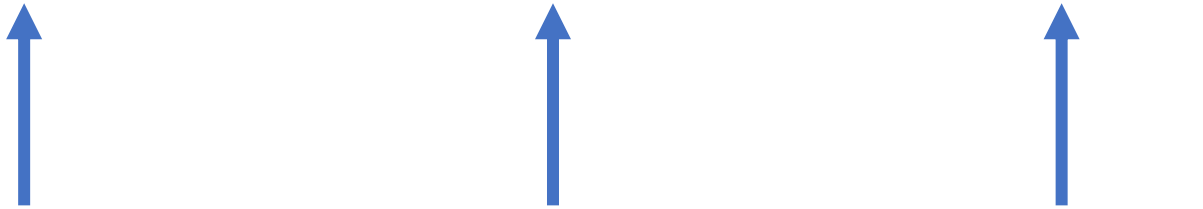


Sample Nomenclature

90-1.25-20



Brewing Temperature

Total Dissolved Solids

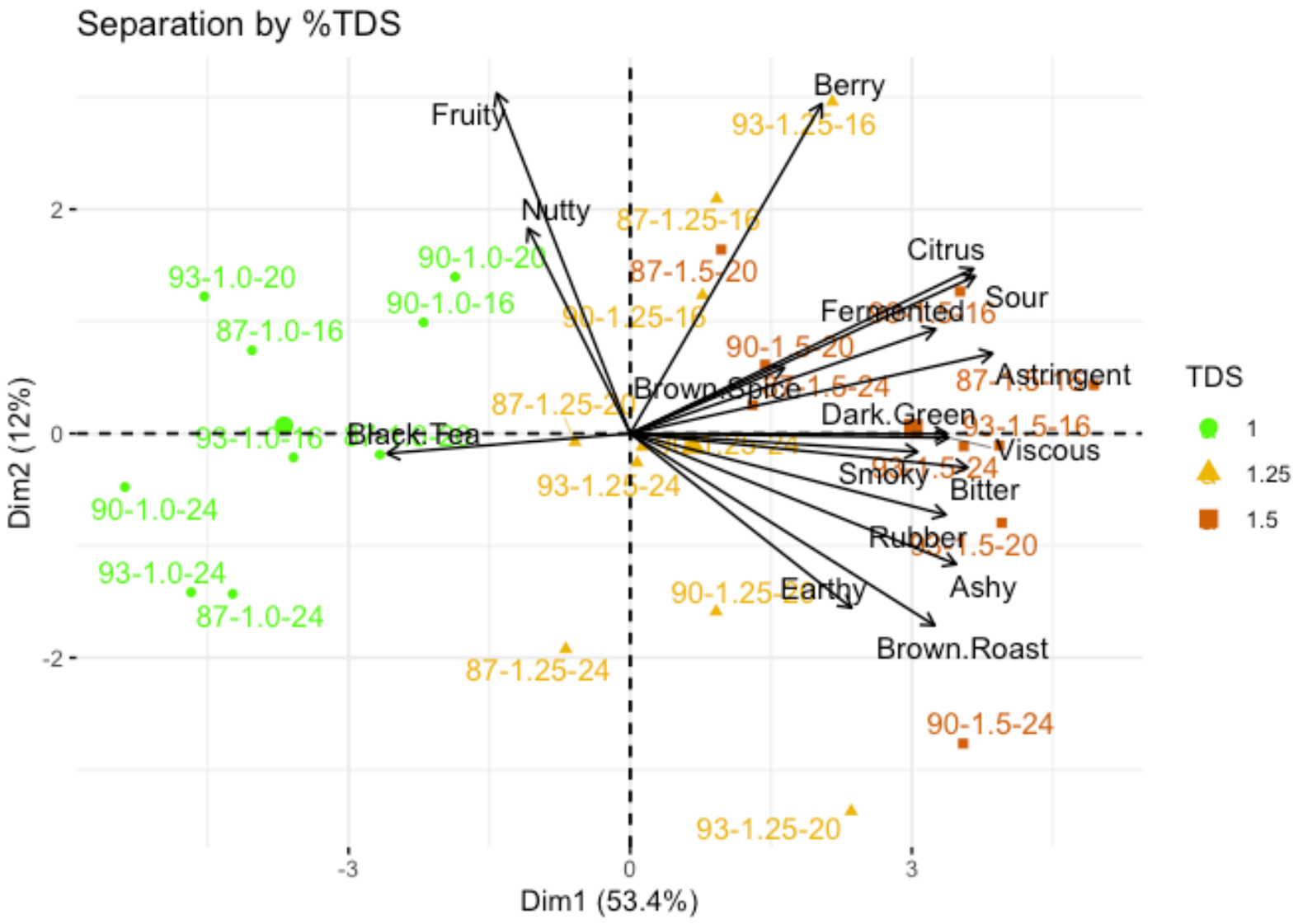
Percent Extraction

PCA by TDS

- The descriptive analysis scores separate the samples across PC1 by TDS, moving from left to right.

90-1.25-20

- Brewing Temperature
- Total Dissolved Solids
- Percent Extraction

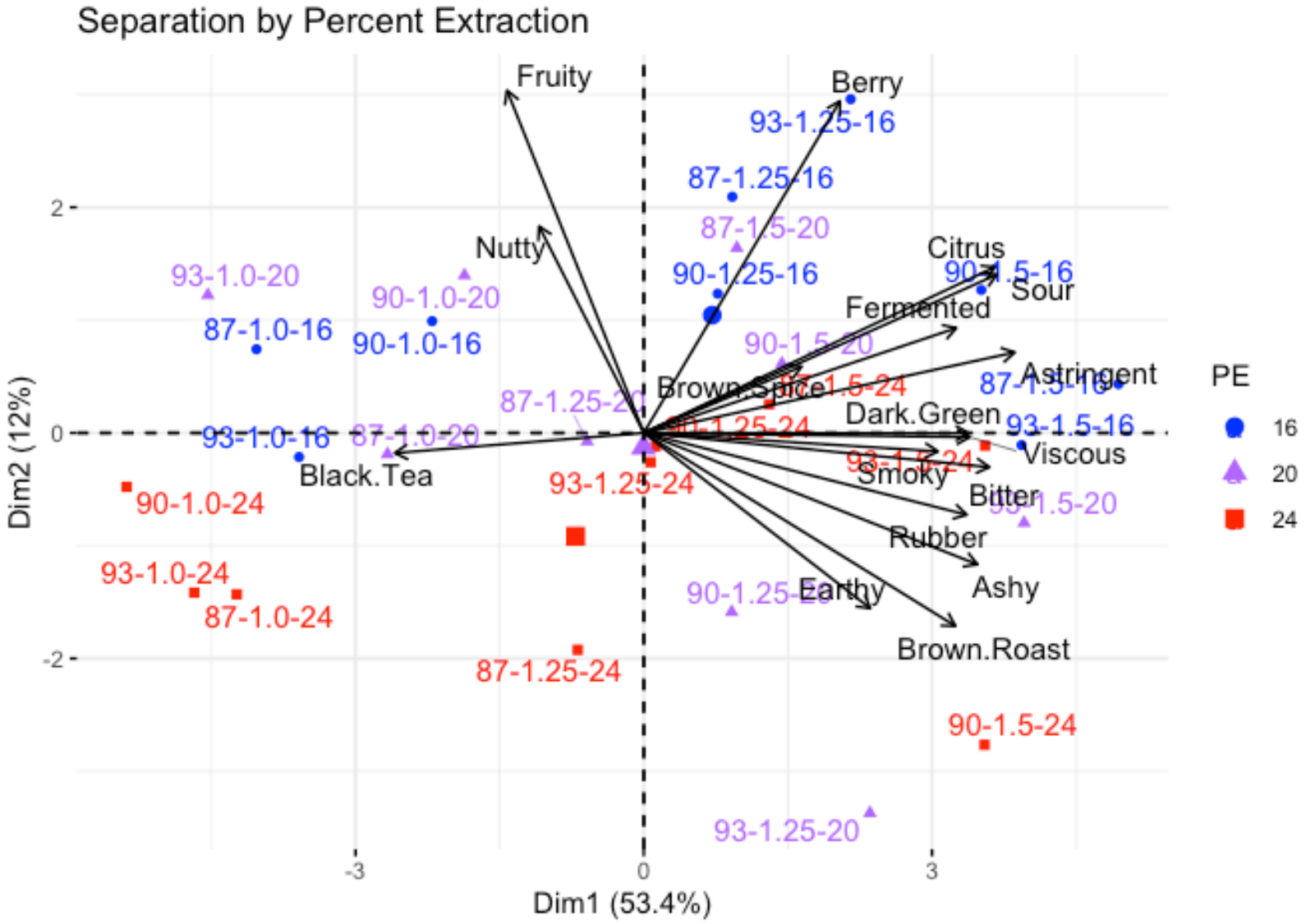


PCA by PE

- Attributes separate diagonally by percent extraction, going from high PE in the lower left quadrant to low PE in the upper right quadrant.

90-1.25-20

- Brewing Temperature
- Total Dissolved Solids
- Percent Extraction

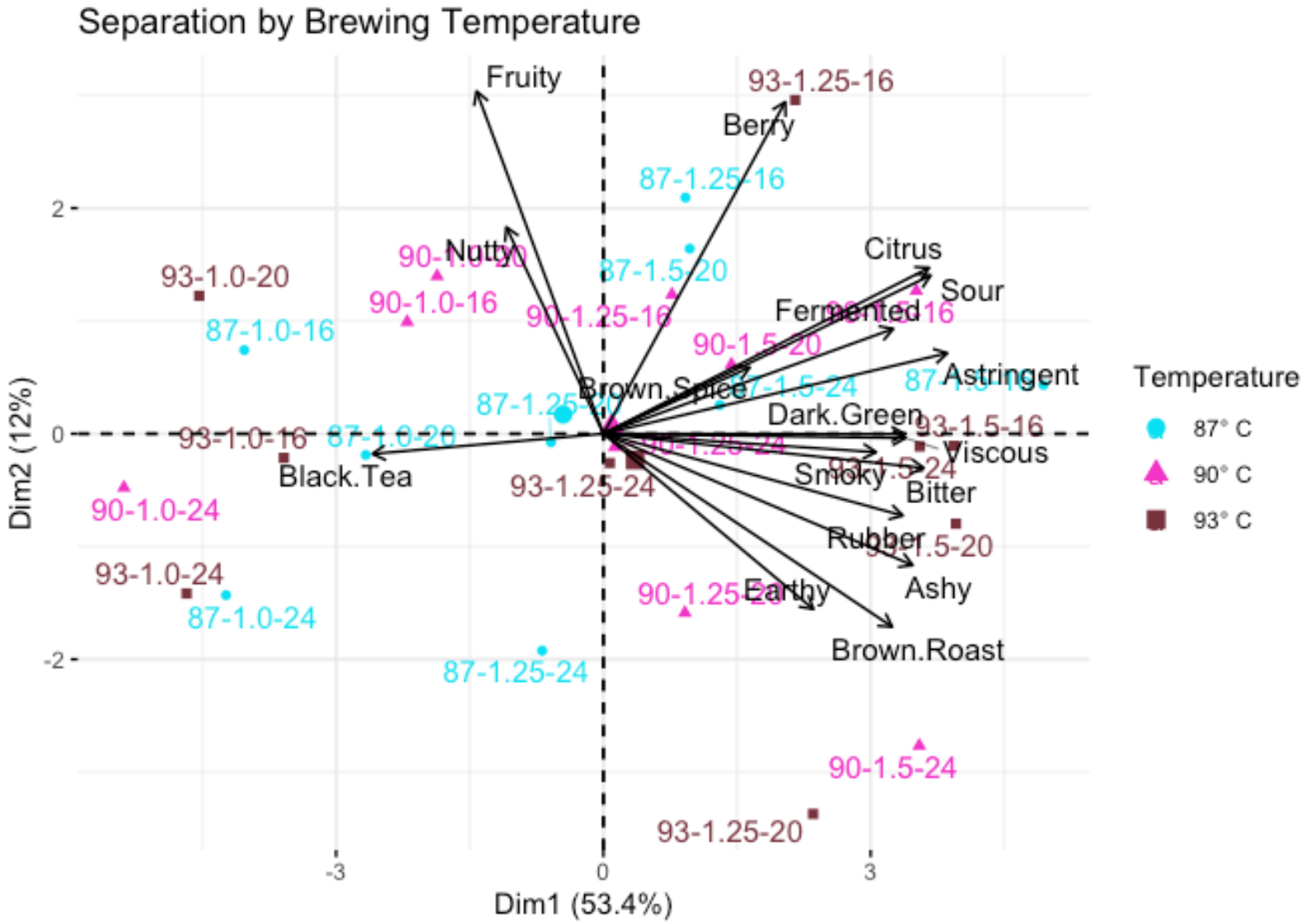


PCA by Temperature

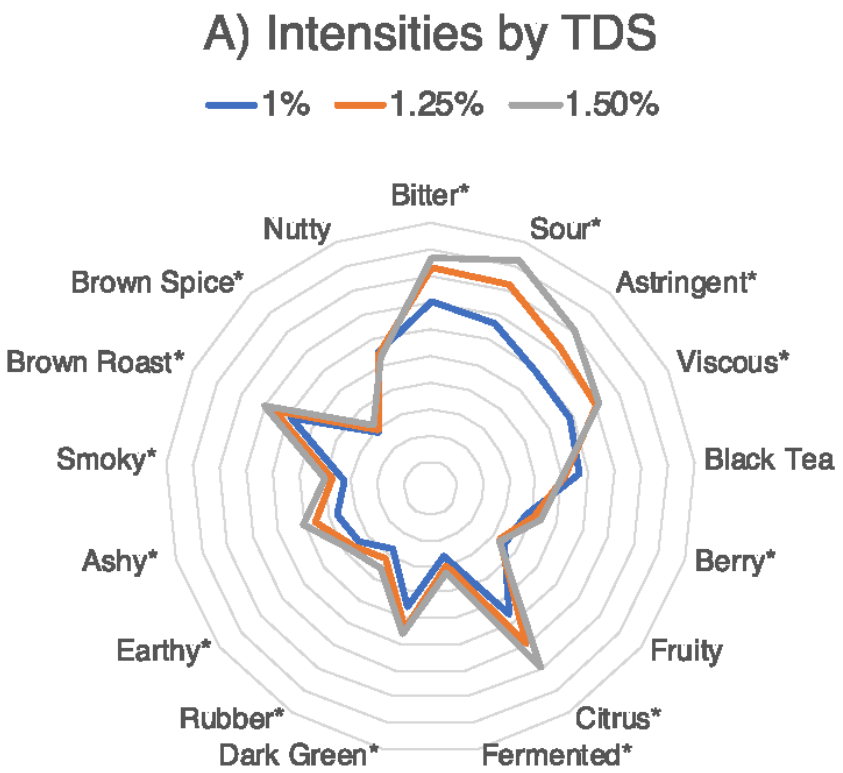
- The ANOVA indicated almost no significant differences between sensory attributes based on brewing temperature.
- Temperatures are scattered across the PCA

90-1.25-20

- 90 — Brewing Temperature
- 1.25 — Total Dissolved Solids
- 20 — Percent Extraction



Simplifying by variable…(TDS, PE, and Brew Temp)



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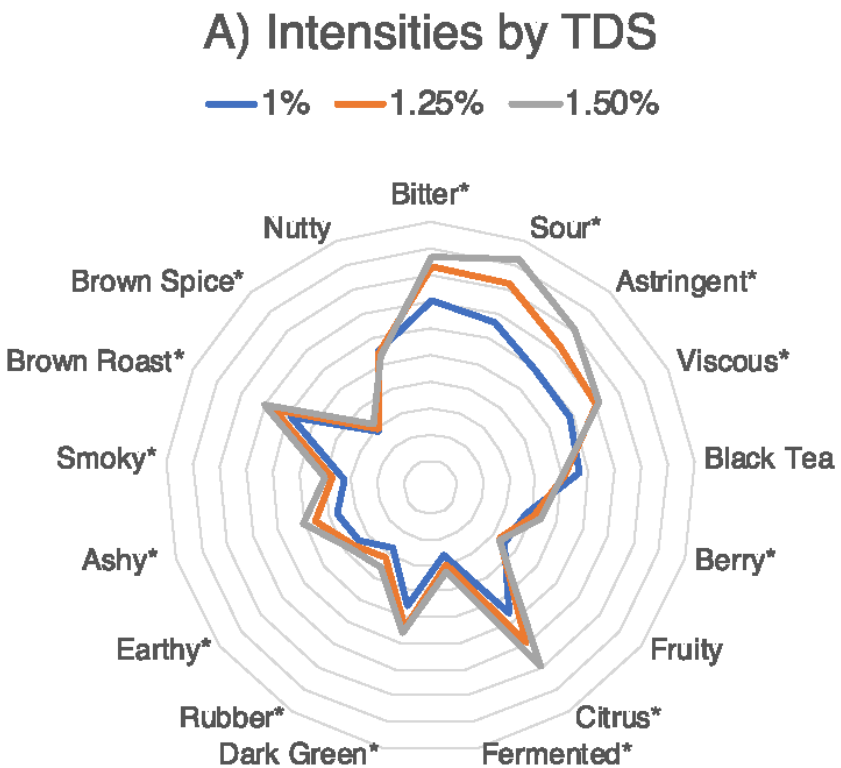
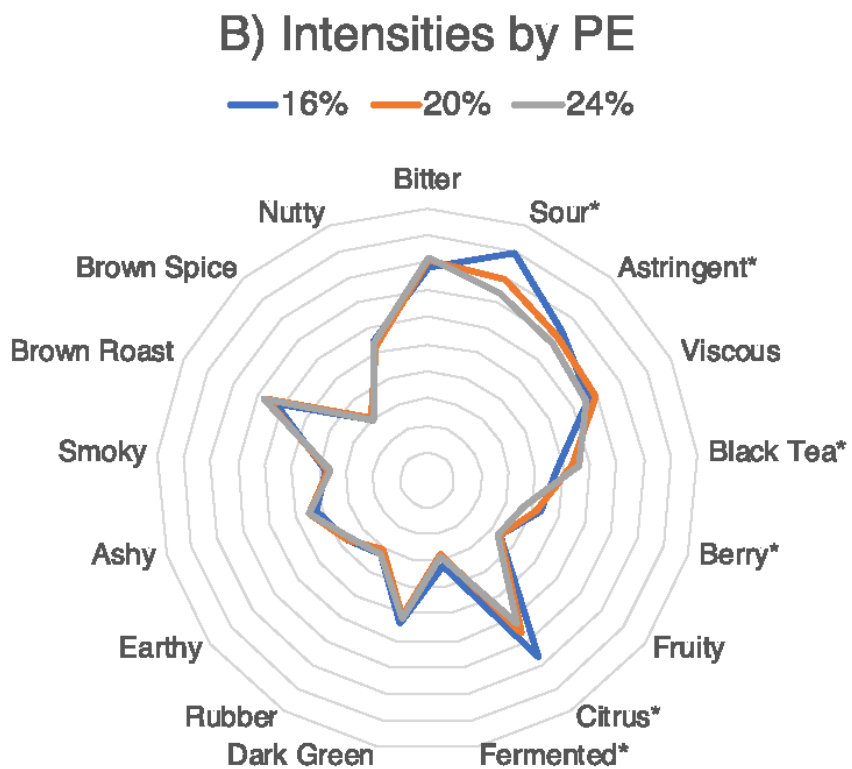
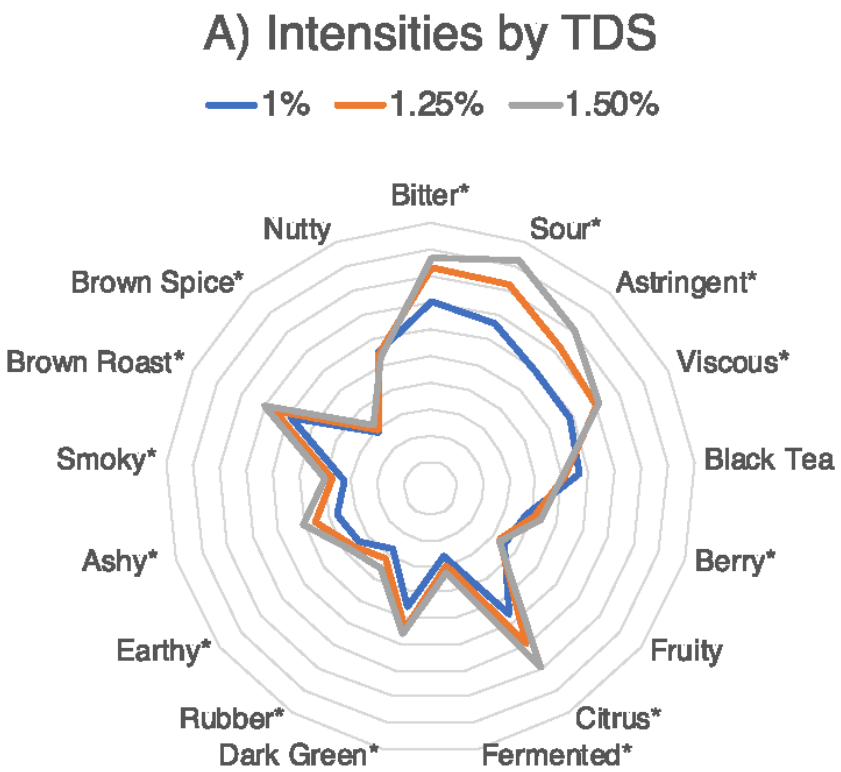
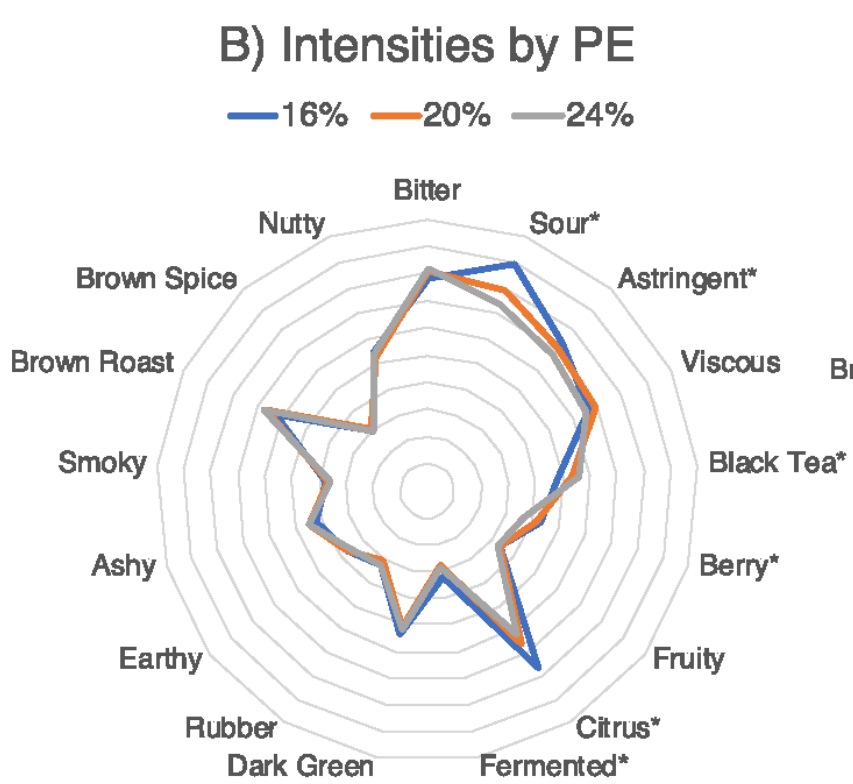
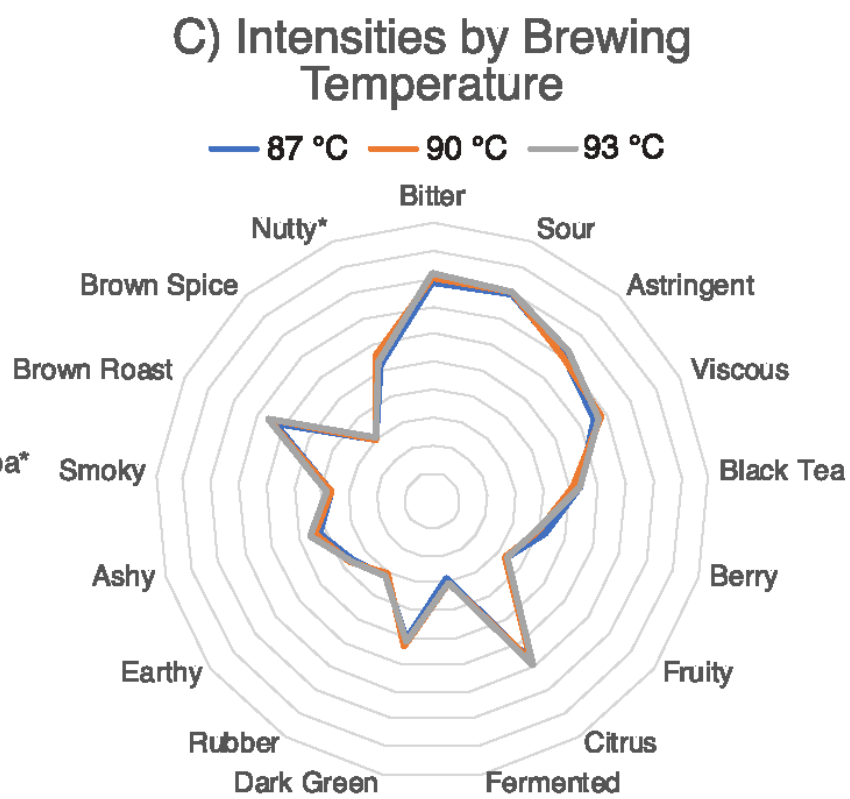




Simplifying by variable…(TDS, PE, and Brew Temp)





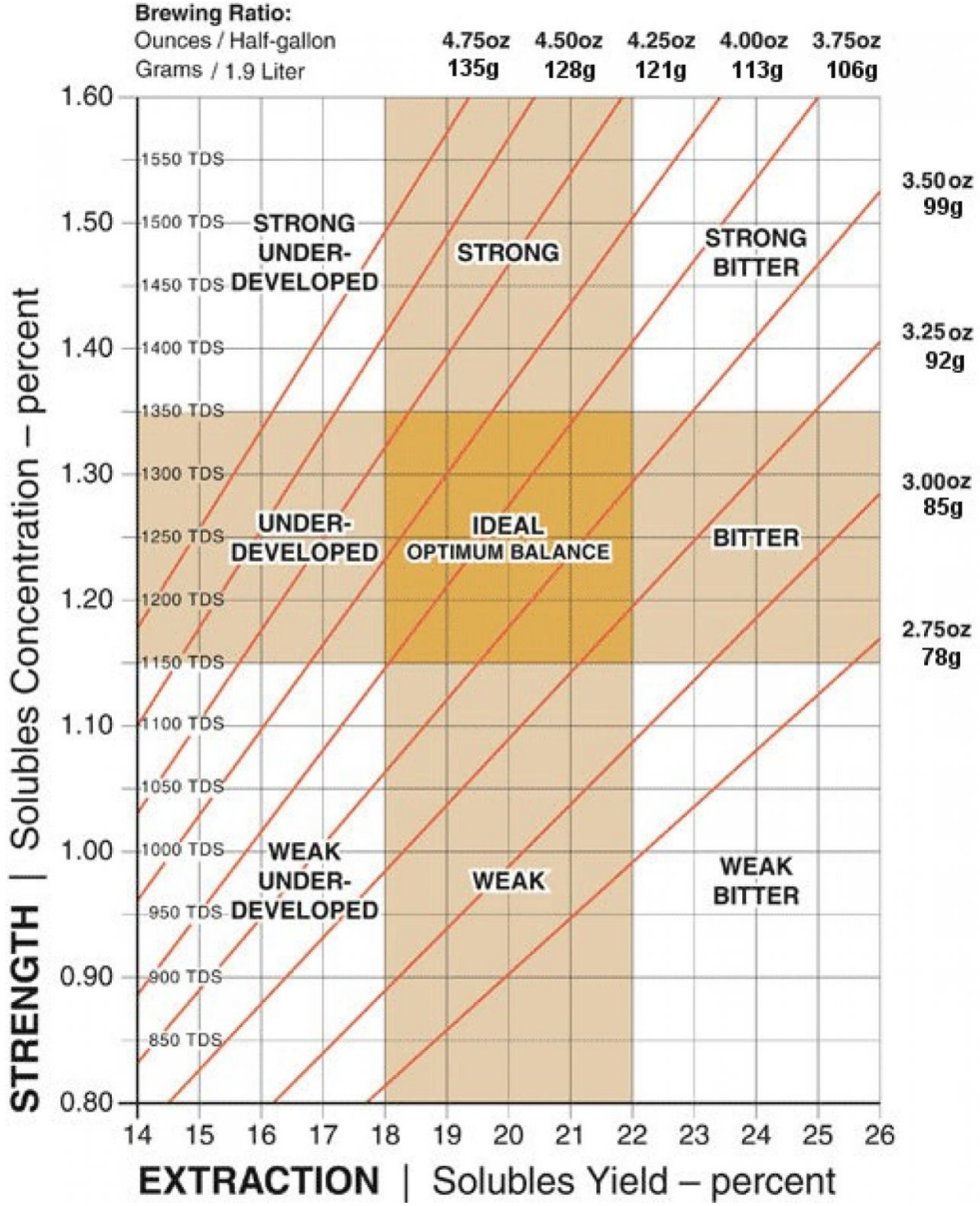


In conclusion…

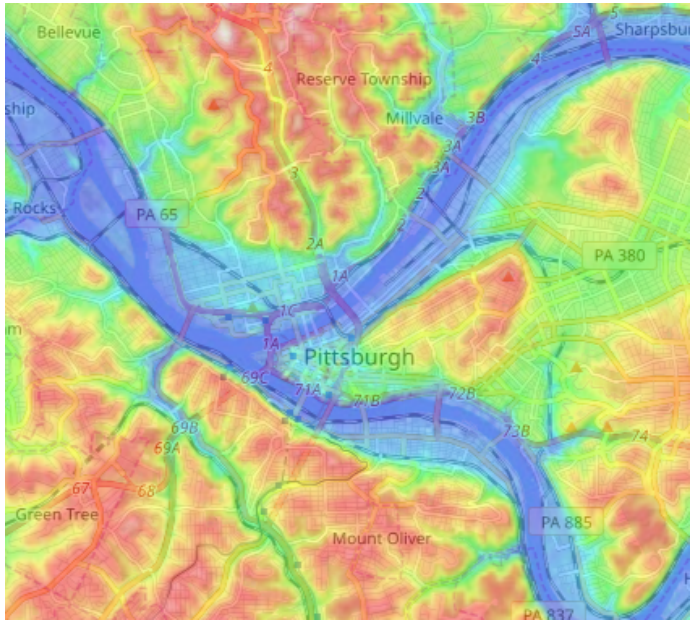
- Of the three independent variables (TDS, PE, and brew temperature), TDS is the most significant driver of sensory differences, followed by PE.
- Brew temperature has limited impact on the sensory quality of coffee at fixed extraction, within the range measured.

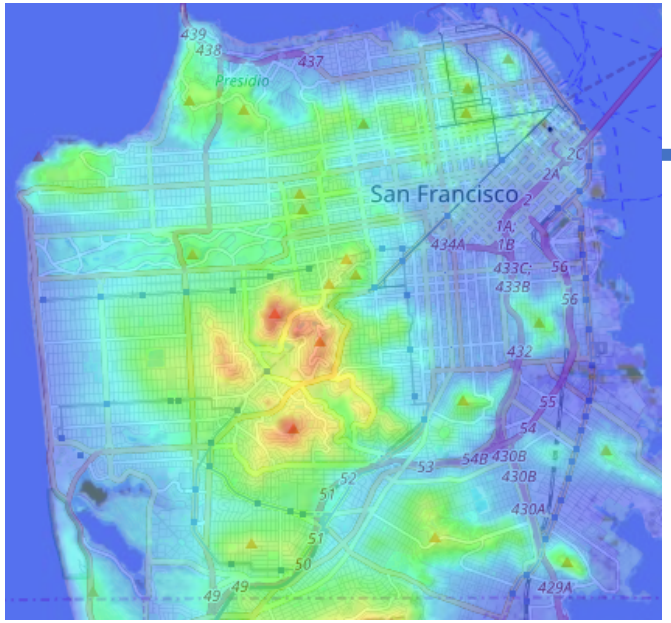
How do we put this back on the coffee brewing control chart?

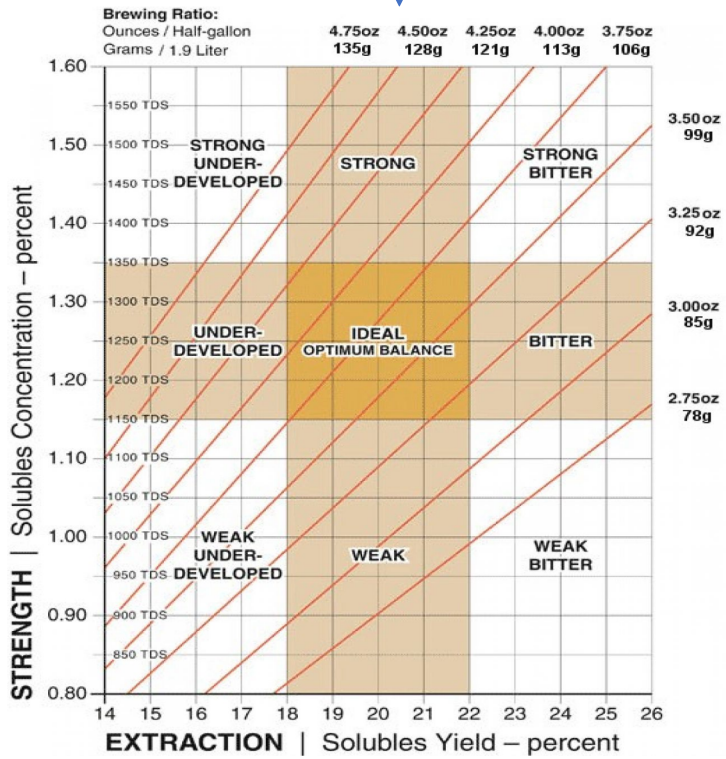
?



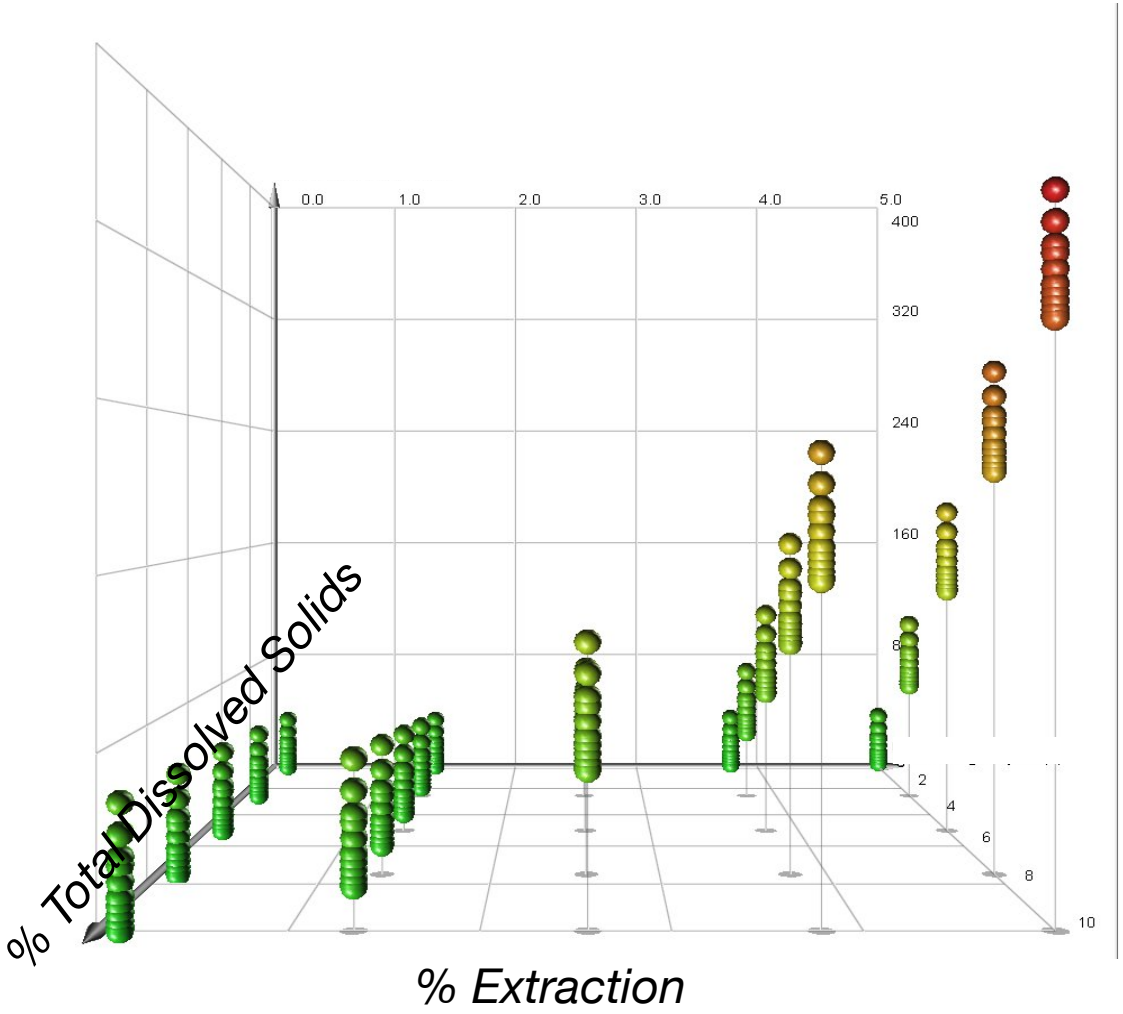
Three dimensional mapping method

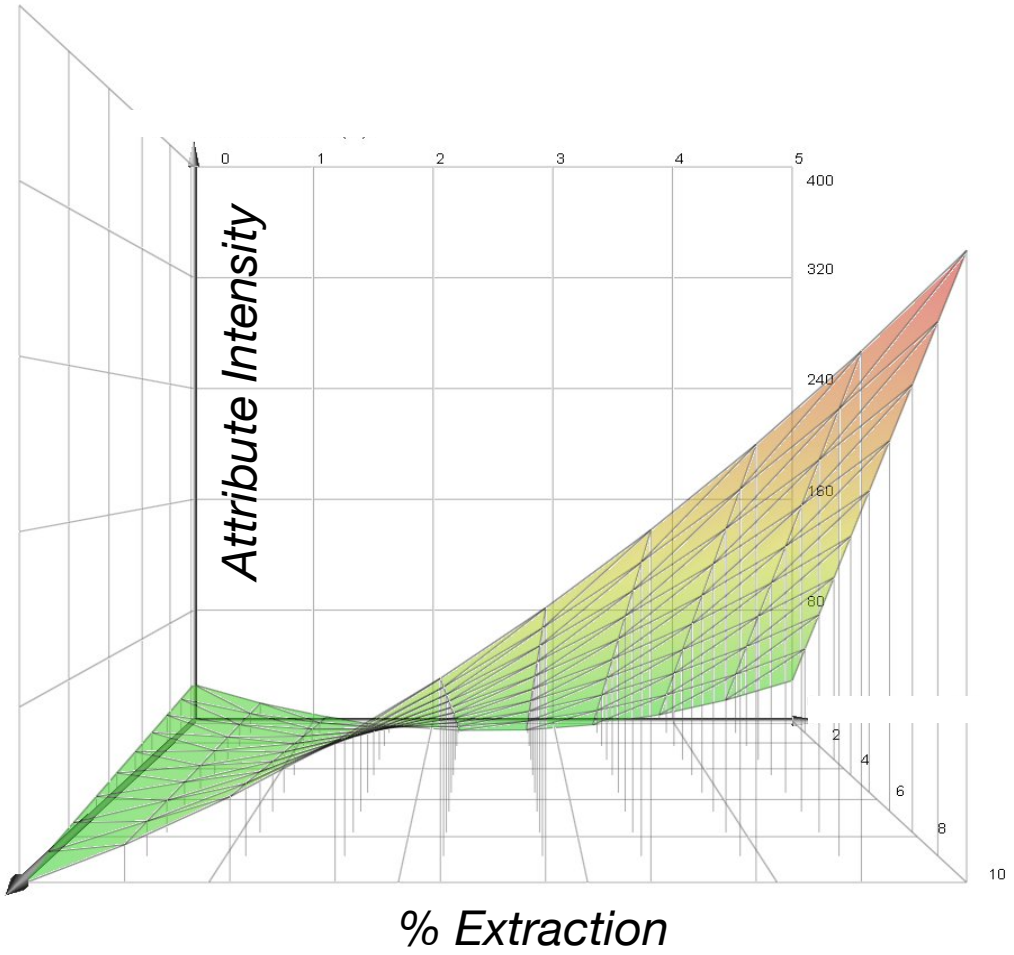


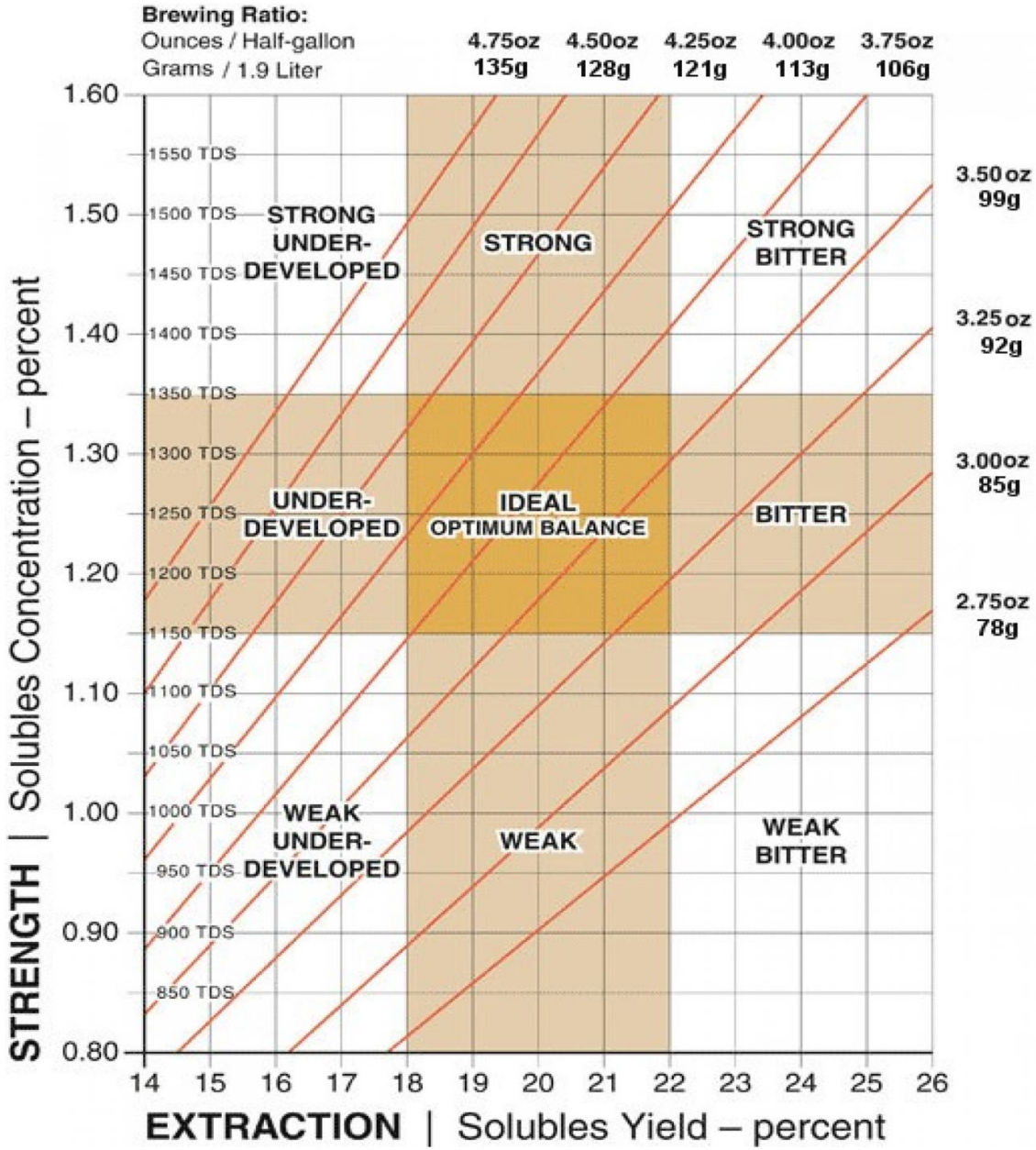


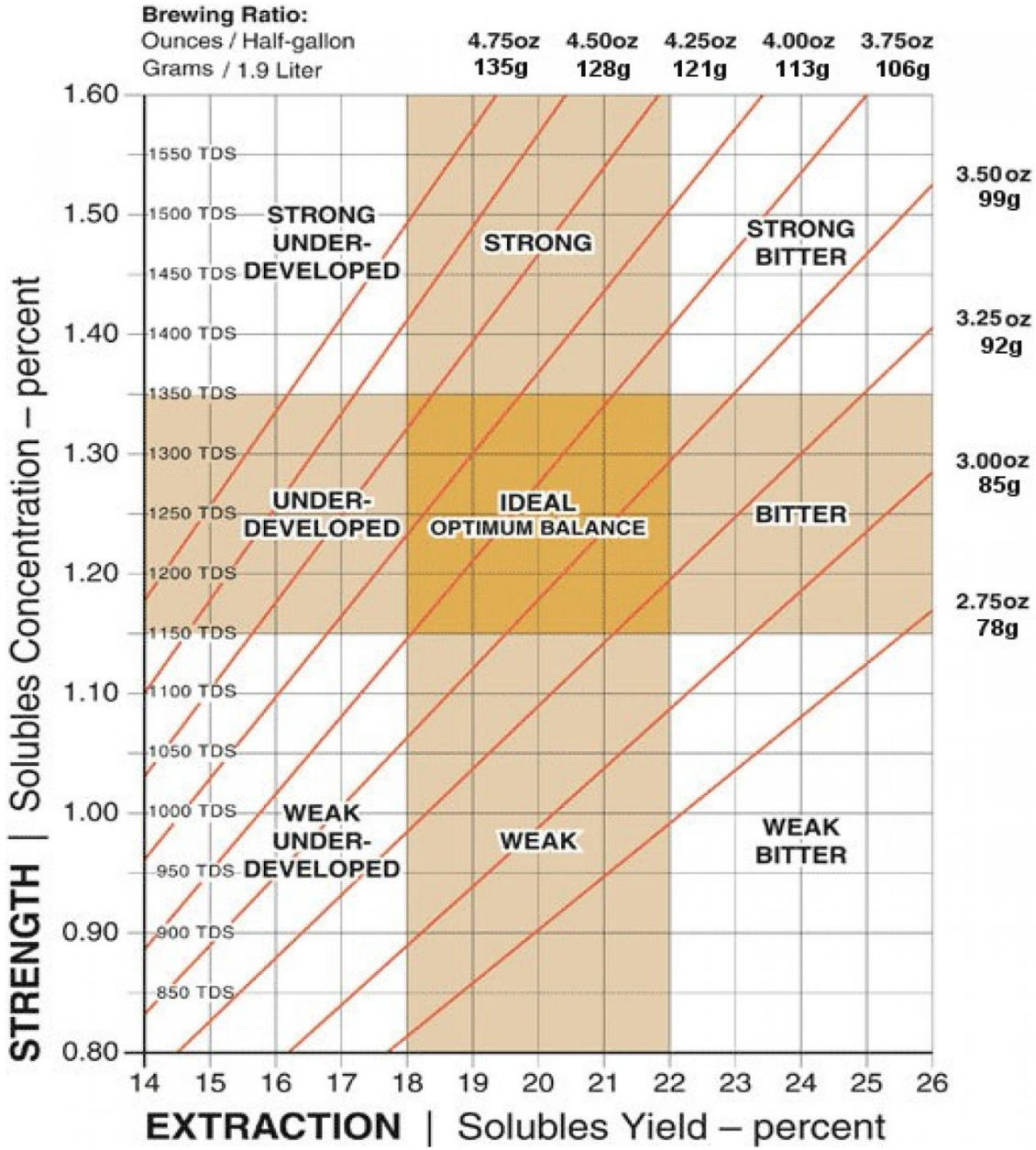


Response Surface Methodology






Brewing Ratio:
Ounces / Half-gallon
Grams / 1.9 Liter
4.75oz 135g
4.50oz 128g
4.25oz 121g
4.00oz 113g
3.75oz 106g
3.50oz 99g
3.25oz 92g
3.00oz 85g
2.75oz 78g
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
1550 TDS
1500 TDS
1450 TDS
1400 TDS
1350 TDS
1300 TDS
1250 TDS
1200 TDS
1150 TDS
1100 TDS
1050 TDS
1000 TDS
950 TDS
900 TDS
850 TDS
STRONG UNDER-DEVELOPED
STRONG
STRONG BITTER
UNDER-DEVELOPED
IDEAL
OPTIMUM BALANCE
BITTER
WEAK UNDER-DEVELOPED
WEAK
WEAK BITTER
STRENGTH | Solubles Concentration – percent
14 15 16 17 18 19 20 21 22 23 24 25 26
EXTRACTION | Solubles Yield – percent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3.50oz 99g
3.25oz 92g
3.00oz 85g
2.75oz 78g
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
1550 TDS
1500 TDS
1450 TDS
1400 TDS
1350 TDS
1300 TDS
1250 TDS
1200 TDS
1150 TDS
1100 TDS
1050 TDS
1000 TDS
950 TDS
900 TDS
850 TDS
STRONG UNDER-DEVELOPED
STRONG
STRONG BITTER
UNDER-DEVELOPED
IDEAL OPTIMUM BALANCE
BITTER
WEAK UNDER-DEVELOPED
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STRENGTH | Solubles Concentration – percent
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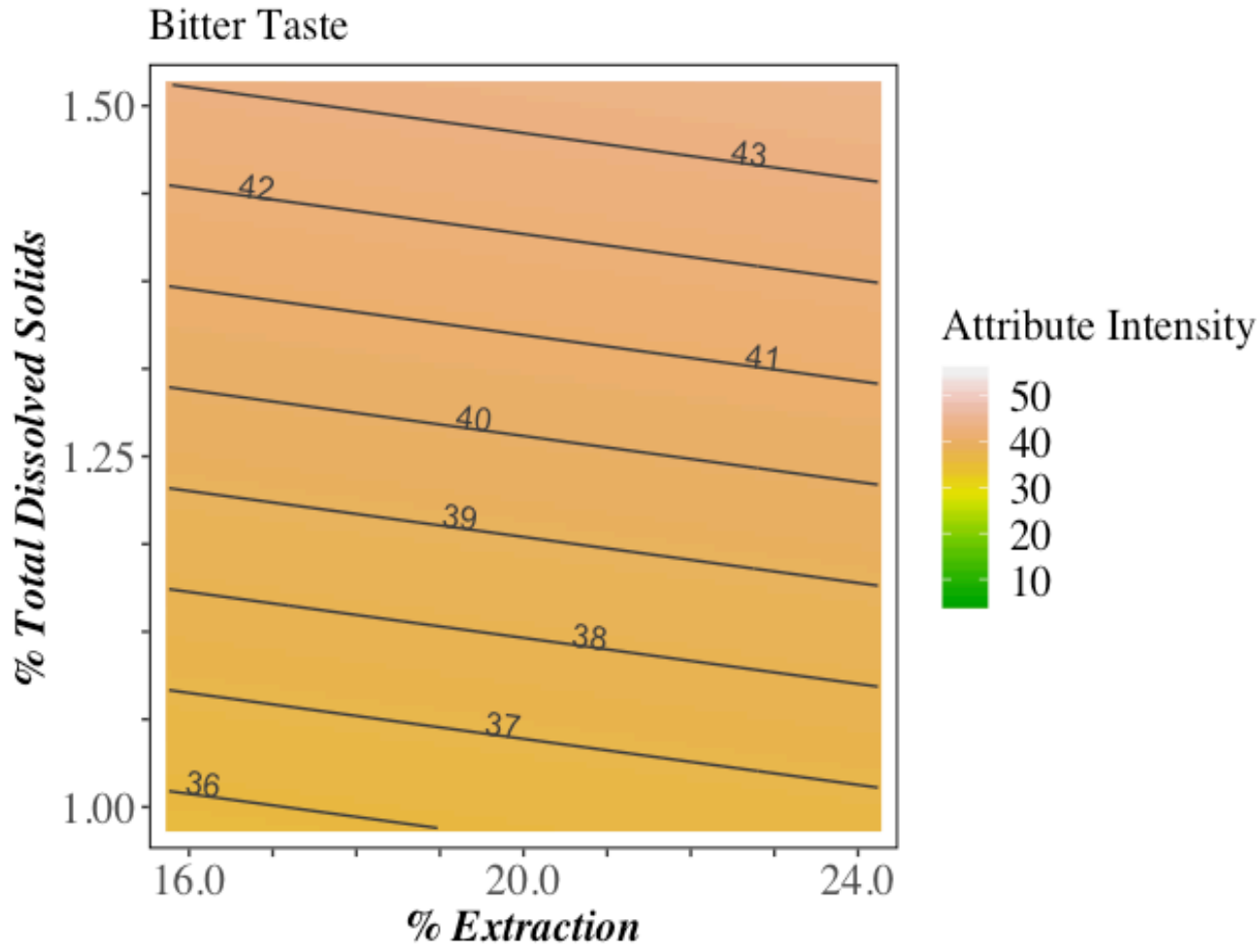
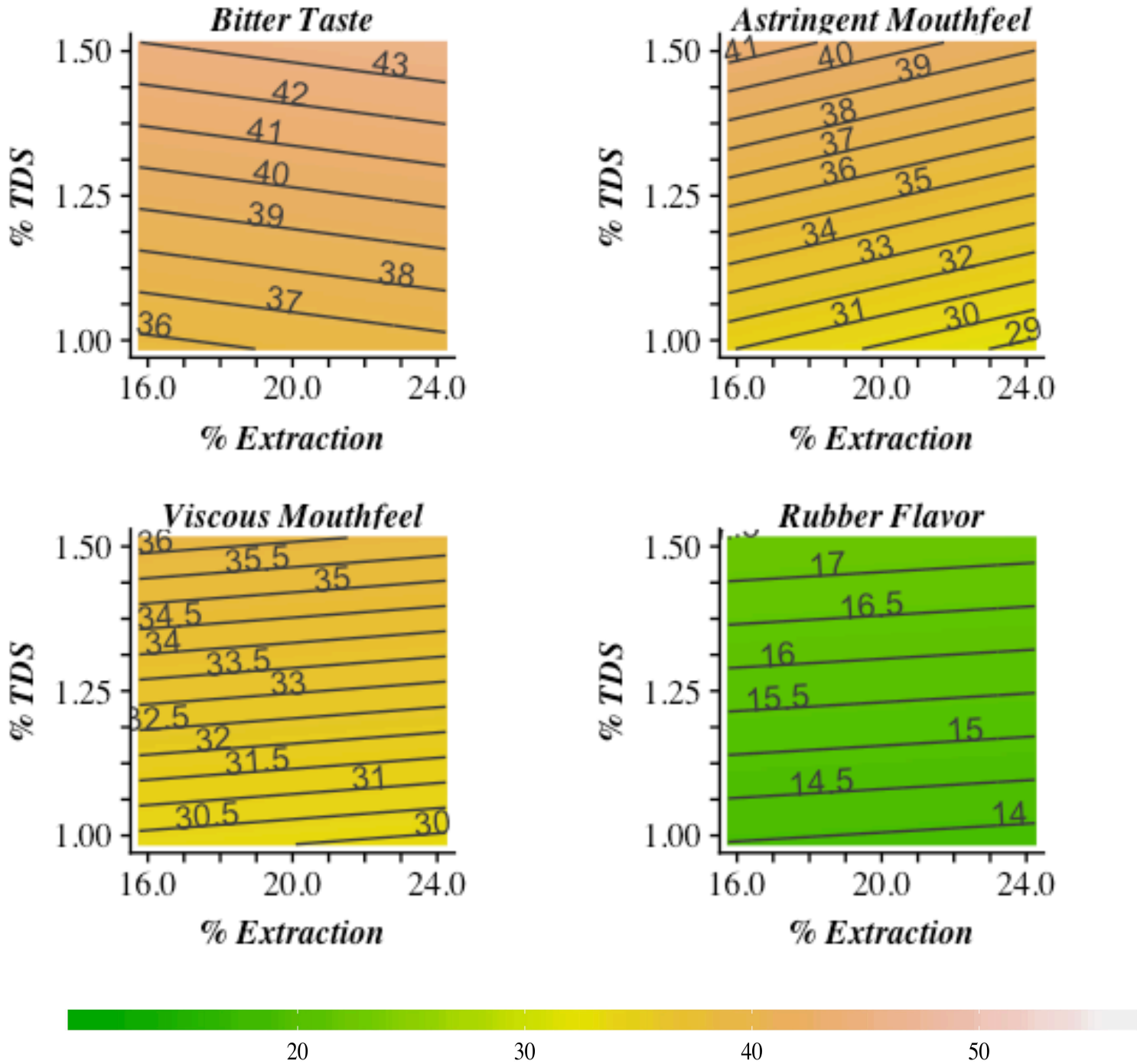
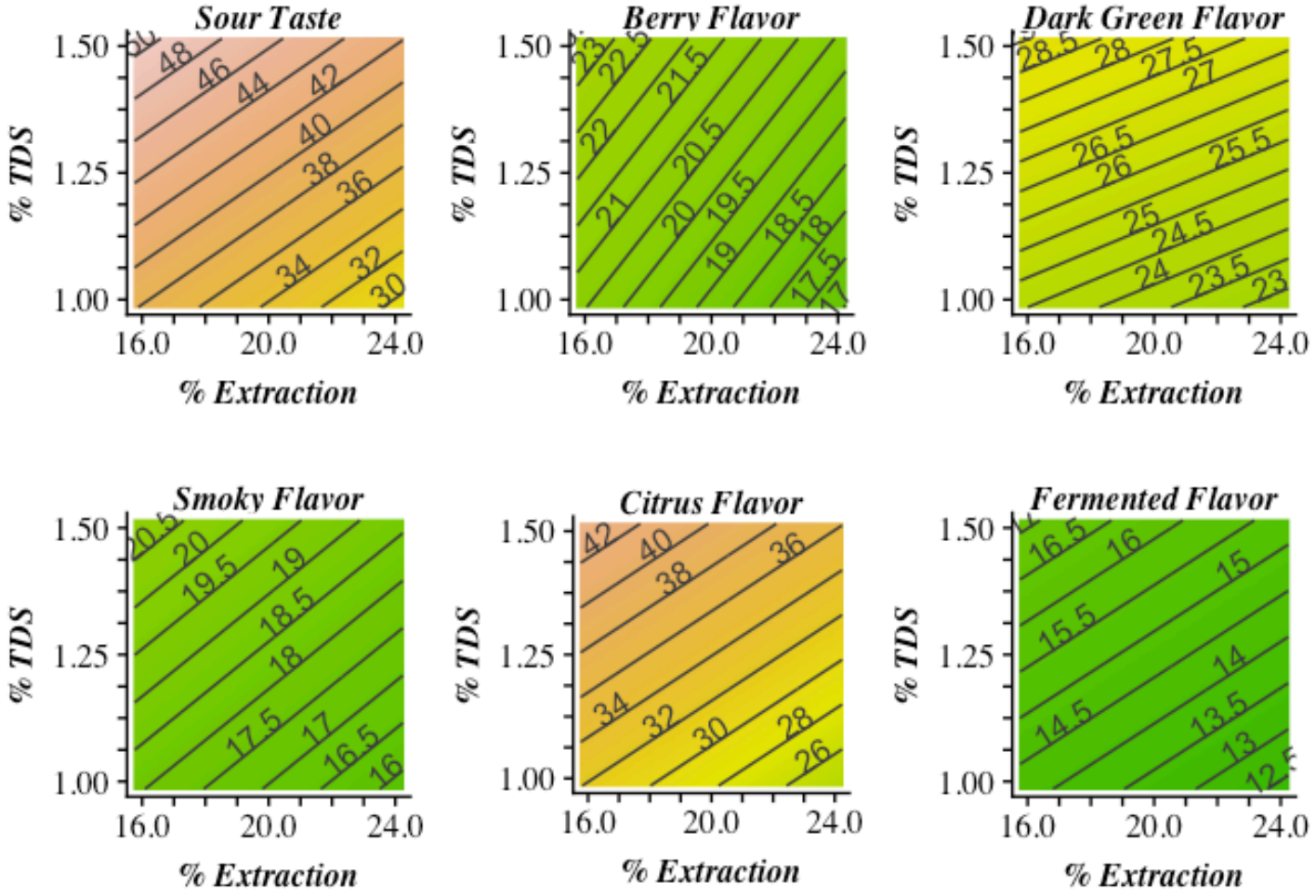

Bitter Taste
1.50
1.25
1.00
% Total Dissolved Solids
43
42
41
40
39
38
37
36
16.0
20.0
24.0
% Extraction
Attribute Intensity
50
40
30
20
10

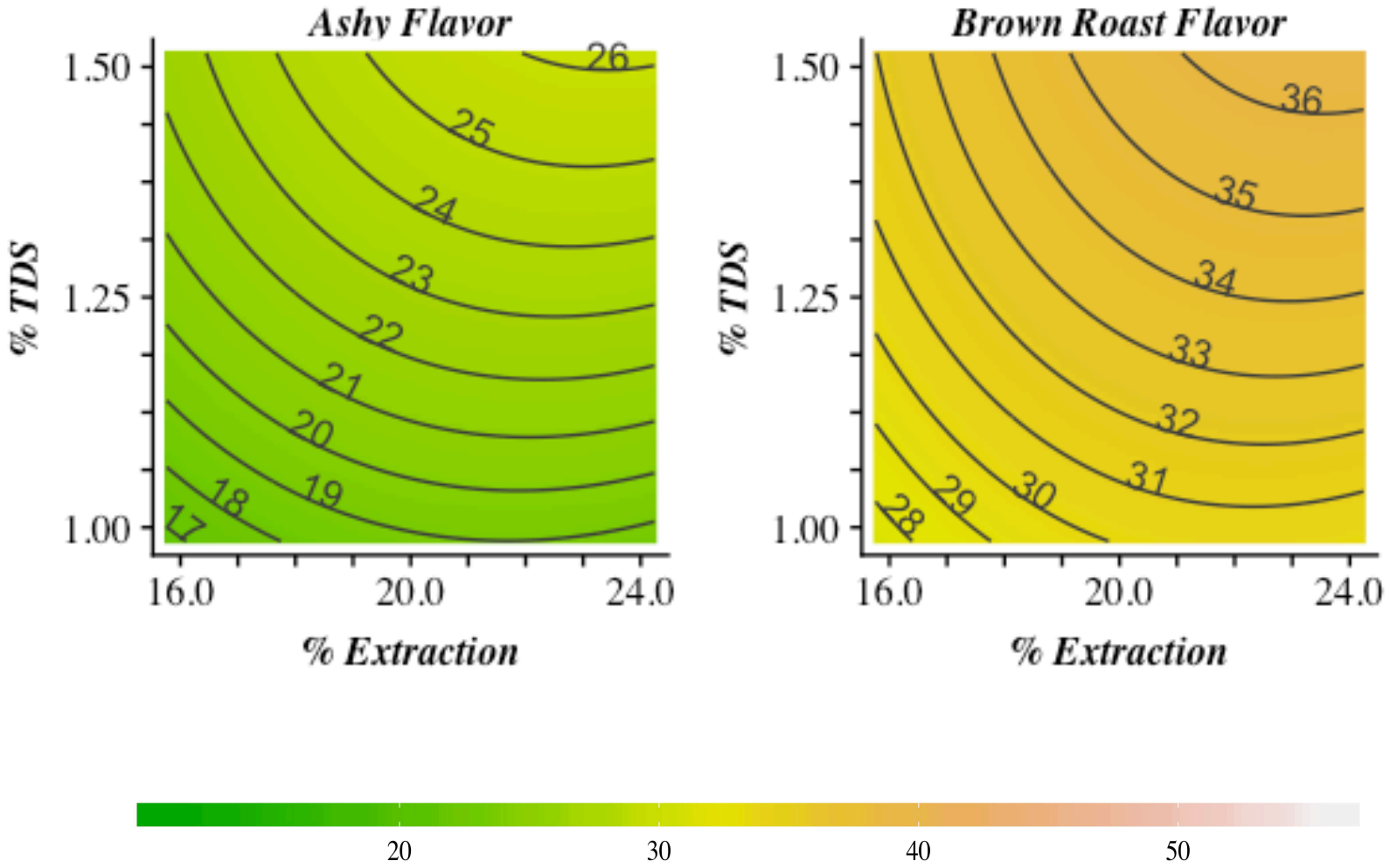
Attributes scaling with TDS



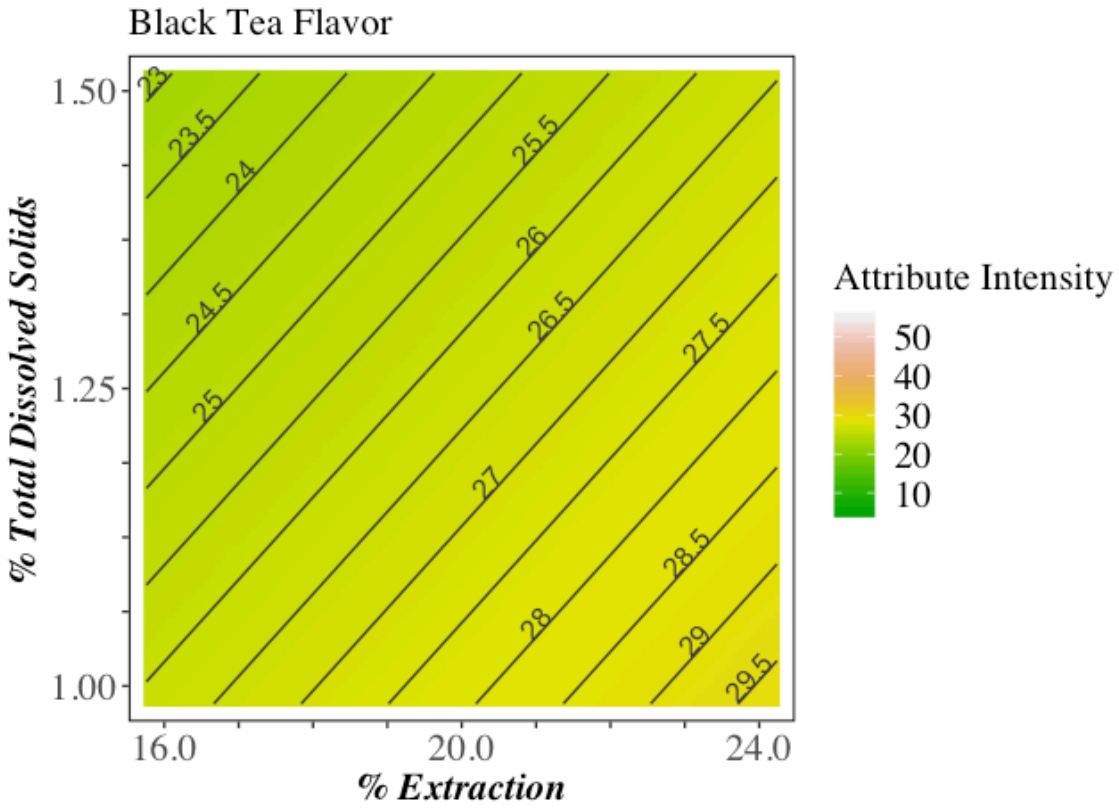
Increasing with TDS, decreasing with PE

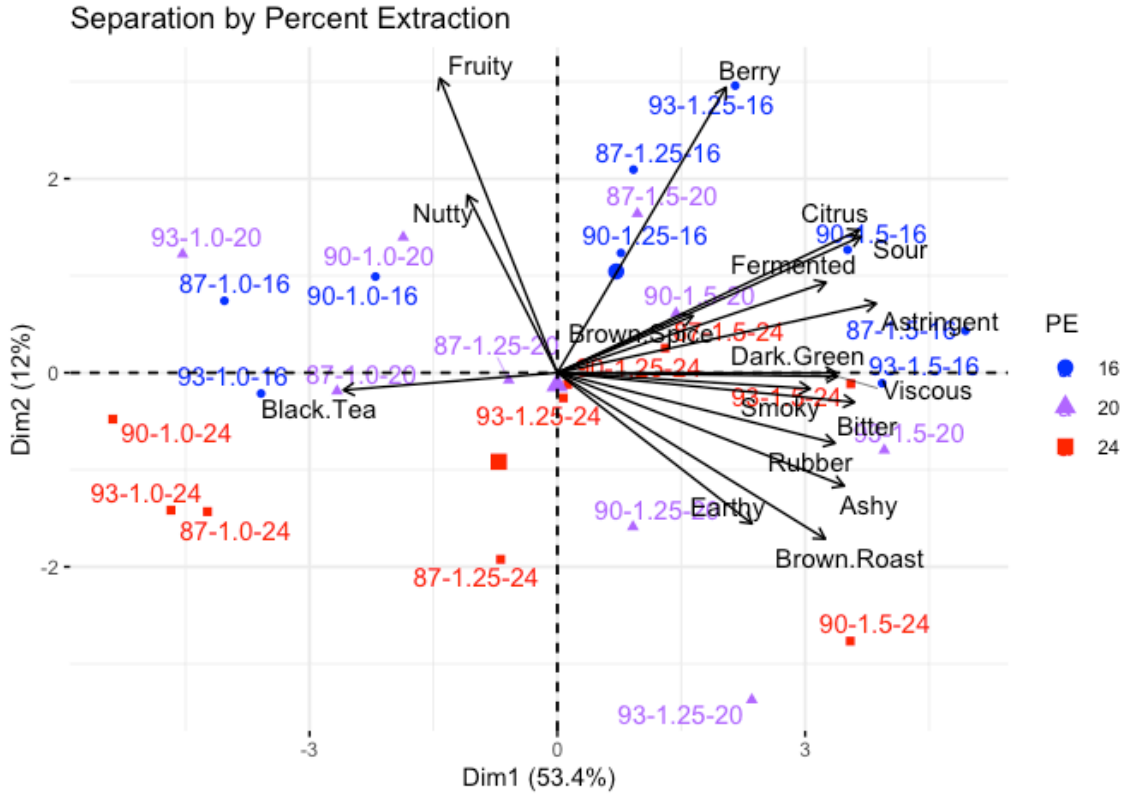


Increasing with TDS and PE, second order fit



As predicted from PCA, only one attribute correlates with low TDS, high PE



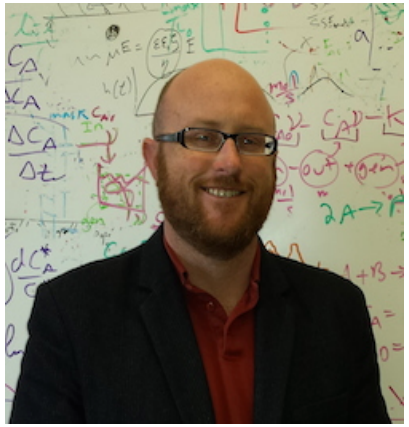


Summary

- Temperature at this range does not substantially impact coffee sensory quality
  - At what range does it matter? Next up, cold versus hot brew.
- Extraction does play a substantial role – how can we use this to update and expand the Coffee Brewing Control Chart
  - We’re starting to recognize trends – what do we do with that?
- Chemical measures of titratable acidity can predict perceptible sourness at fixed extraction.

Acknowledgements

Prof. Jean-Xavier Guinard



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