The Crème de la Crema: Temperature & Pressure's Impact on Espresso Foam Index

Math 158 Final Project

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Introduction

The global espresso coffee market is expected to post a compound annual growth rate close to 7% during 2019-2023 according to market research (Technavio 2019). With espresso demand on the rise, researching ways to optimize espresso quality will improve the quality of product for coffee vendors and boost the growth of the espresso and coffee sectors.

Espresso is a coffee brewing method that uses hot, pressurized water to extract solid material from a cake of coffee grounds. In this way, espresso coffee differs from traditional filter, plunger, of mocha methods; the high pressures involved (typically up to 15 bar) enable faster brewing and a richer coffee flavor (Farah 2019).

The presence of foam (or crema) is an essential aspect of a good cup of espresso. Crema is a reddish brown froth that rests on the top of the espresso and is formed when air bubbles combine with the fine-ground coffee's soluble oils (Figure 1) (Goodwin 2019). Foam is a freshness marker that indicates the espresso's aroma, coffee quality, barrista skill, aesthetic appeal, and flavor. Foamability of espresso is typically measured as foam index (the ratio between the foam and liquid volume measured 30s after extraction). Factors like protein content, chemical composition, pH, and total solid material are known to influence foam index and persistance (Farah 2019).

Figure 1: Reddish espresso foam (or crema) is a critical component of the coffee's flavor, aroma, and aesthetic appeal

Masella et al. (2015) developed a new method of brewing expresso where the driving force for water flow through the grounds is the pressure differential between the chamber and surroundings (rather than the traditional method which uses motorized pump to pressurize steam). This method allowed for finer control of pressure and temperature. They generated data at 6 different combinationss of temperature and pressure to understand the impact of pressure and temperature on the foam index.

Methods

Table 1: Example data for each of the 6 treatment combinations

	foamIndx	trt_id	tempC	prssBar
1	94.21	1	75	15
10	134.84	2	75	20
19	95.84	3	85	15
28	143.38	4	85	20
37	75.63	5	95	15
46	120.10	6	95	20

In the experiment designed by Masella et al. (2015), six different espresso treatments were applied (Table 1): foam indexes were measured at combinations of three different water temperatures (levels: 75, 85, 95 C) and 2 different pressures (levels: 15, 20 bar). There were nine replicates at each of the six treatment combinations. The study design was balanced, permitting analysis using analysis of variance (ANOVA).

A two factor ANOVA was performed on the data to assess factor effects and interactions. While predictor variables (pressure and temperature) were in numerical units, these variables were encoded as categorical variables, since this avoids specification of a certain statistical relation between the predictor and response (ex a linear response). The validity of ANOVA assumptions were assessed using diagnostic plots.

Possible data transformations and additivity/interactivity of the model were assessed using interaction plots and Box-Cox method.

Analysis

First, I fit the full additive model, and assessed the significance of the main effects. Both factors- temperature and pressure- were found to be highly significant (p-values of 0.007 and 0.0004 for temperature and pressure respectively) (Table 2).

Table 2: Signficance of main effects

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
factor(tempC)	2	4003.852	2001.9262	5.549996	0.0066561
factor(prssBar)	1	5310.375	5310.3750	14.722102	0.0003507
Residuals	50	18035.384	360.7077	NA	NA

When an interaction plot of the two factors was examined, the lines denoting the 85 and 95 C levels intersected, indicating possible interactions of the factors (Figure 2). Model transformations were not amenable to this situation, as no cognizable function could transform-away an intersection and make the factors more additive.

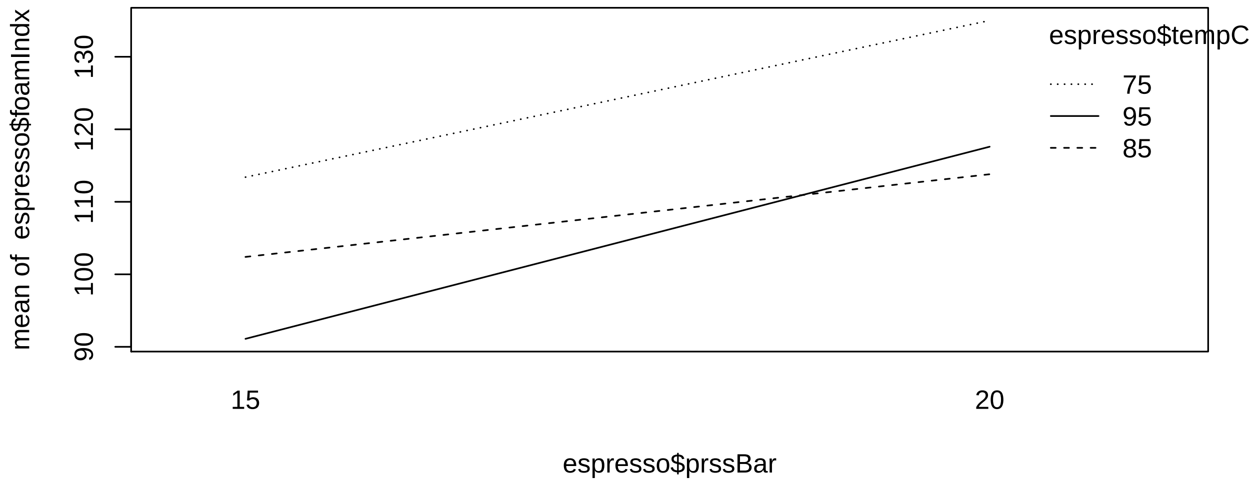

Figure 2: Interaction plot of factor level means indicated possible interaction between factors.

When the interactive model was fit, the interaction term was not statistically significant (p=0.49), suggesting that any interactions were explainable by noise in the data (Table 3). Indeed, examination of the interaction plot showed that the factors appeared additive for the 75 and 95 C levels. There is no rationale for why the 75 and 95 C would behave additively, but 85 C would not. Given these results and prizing model interpretability, interactions were disregarded for further analysis.

Table 3: Signficance of main effects and interactions in interactive model

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
factor(tempC)	2	4003.852	2001.9262	5.4905763	0.0071231
factor(prssBar)	1	5310.375	5310.3750	14.5644826	0.0003876
factor(tempC):factor(prssBar)	2	534.041	267.0205	0.7323429	0.4860753
Residuals	48	17501.343	364.6113	NA	NA

Additionally, possible transformations of the response variable as suggested by the Box-Cox method were considered but ultimately eschewed for two reasons. First, the inability to backtransform the response meant that the interpretability of local inference (Tukey intervals) would be limited. For the purposes of informing future coffee-brewing methods, intervals that represented mean changes in foam index would be preferable to intervals that represesnted reciprocal square roots of mean foam index changes (the transformation suggested by Box-Cox). Second, the additive model with an untransformed response variable appeared permissable, as it did not appear to violate the ANOVA asssumptions.

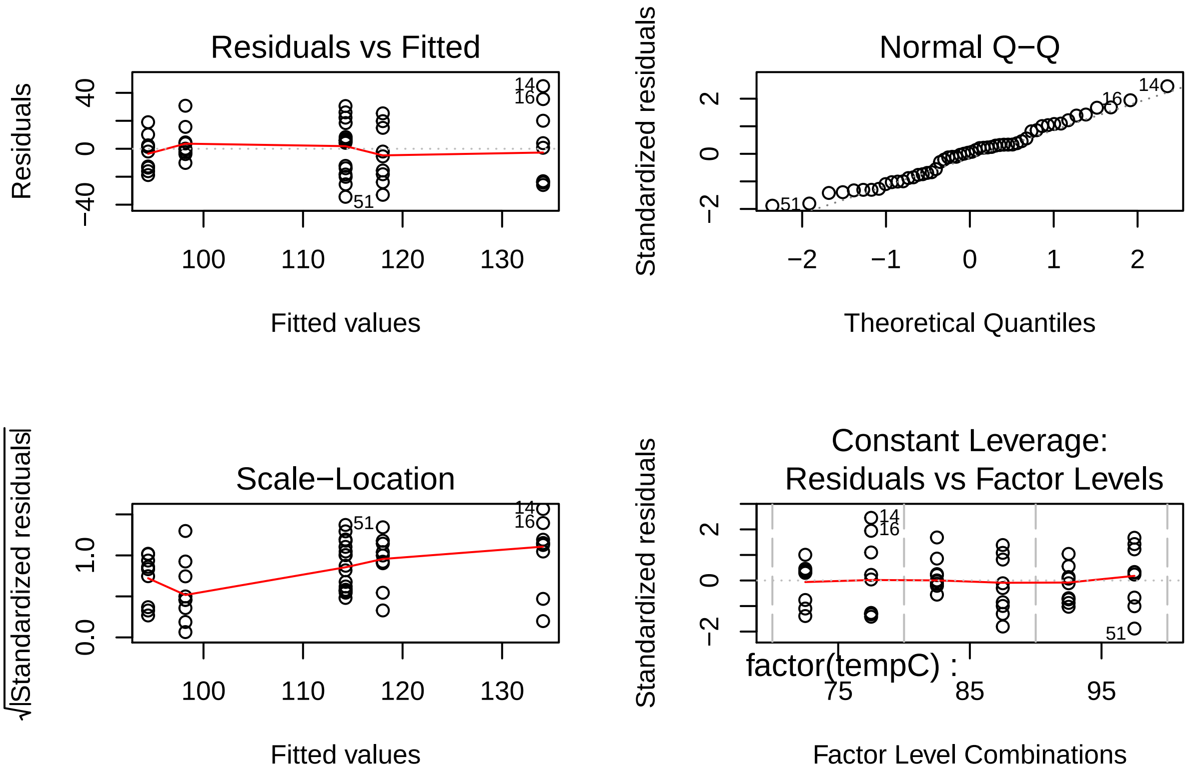

Figure 3: Diagnostic plots to check ANOVA assumptions

Diagnostic plots of the additive model were generated to asssess concordance with the ANOVA assumptions of normality and constant variance (Figure 3). The third ANOVA assumption, the Random Sample assumption, was addressed during the experiment's design and execution and will be excluded from further discussion here. The Q-Q plot indicated that the studentized residuals were sufficiently normally distributed about the signal, supporting the assumption of normality. And the absence of extreme trends in residuals in the residual vs fitted plot, scale-locatioon plot, and residuals vs factor level plots indicated that the data was relatively homoskedastic, and that there were no readily apparent outliers influencing the model. Thus, all ANOVA assumptions appeared appropriately satisfied.

Table 4: Tukey intervals for pairwise comparisons of temperatures

	diff	lwr	upr	p adj
85-75	-16.100556	-31.39202	-0.8090869	0.0369700
95-75	-19.850000	-35.14147	-4.5585313	0.0079446
95-85	-3.749444	-19.04091	11.5420243	0.8248954

Local inference using Tukey intervals identified that espresso foam index was significantly lower in the 85 and 95 C temperature groups as compared to the 75 C group (p_adj=0.04 and 0.008 respectively) (Table 4). Espresso generated at 75 C had a 16% and 20% higher foam index compared to espresso generated at 85 and 95 C respectively. No significant difference in foam index was observed between 85 and 95 C (p_adj=0.824).

Table 5: Tukey interval for pairwise comparison of pressures

	diff	lwr	upr	p adj
20-15	19.83333	9.450989	30.21568	0.0003507

The effect of pressure was also highly significant (p_adj=0.0004) (Table 5), as 20 bar of pressure generated a 20% higher espresso foam index than the 15 bar method.

Conclusion

Analysis of data by Masella et al (2015) demonstrated that temperature and pressure have significant effects on the foam index of espresso coffee. In particular, temperatures of 75 C resulted in a higher foam index than espressos made at 85 and 95 C (p_adj=0.04 and 0.008 respectively). 75 C generated 16% and 20% higher foam index than these higher temperatures. No significant difference in foam index was seen between 85 and 95 C (p_adj=0.824). High pressure (20 bar) resulted in significantly higher foam index than that for espresso made under a lower pressure of 15 bar (p_adj=0.0004). 20 bar of pressure generated on average a 20% higher espresso foam index than the 15 bar method.

Thus, Masella et al's hypothesis that temperature and pressure influence espresso foam index was confirmed. This analysis also suggested actionable ways to brew higher-foam coffee. These results indicated that lower temperatures (75 C) generated larger amounts of foam than compared to higher temperatures (85, 95 C). Second, higher pressures (20 bar) generating more foam compared to traditional espresso-making pressures (15 bar). Thus, new espresso-making techniques aiming to make foamier espressos should employ lower temperature, higher pressure methods.

In reality, customers have different foam preferences, and the ability to adapt the foam quantities to individual customers could be beneficial for coffee vendors. New brewing methods as proposed by Masella et al (2015) that allow for finer control of temperature and pressure will afford finer control over amount of crema in a customer's espresso.

There are some next steps that warrant investigation. Foam index measures the *quantity* of foam in a drink, but a similarly designed study could explore whether *foam persistance* differs between different temperature and pressure treatments. Foam should persist long enough to be enjoyed by the customer (2 mins), so studying effects on foam persistance may help tailor brewing conditions to customer preference.

Additionally, various other factors are known to impact foam quantity and quality, and these should be investigated in future experiments. Namely, coarseness of the grind, the darkness of the roast, the freshness of the bean, and the type of machine all impact the amount of crema generated (Goodwin 2019). The significance and effect size of these factors should be assessed in order to provide more information to espresso vendors, enable personalization of espressos to individuals, and refine the art brewing espresso.

References

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