Regrow Yirga Project

2022/23 Harvest

Experiment Report | Fermentation Trails

Prepared: March 2023

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Abstract

For these experiments, we focused on the effect of fermentation types, mainly dry, submerged and agitated, on cup scores and overall time to completion with the hopes of identifying a fermentation type(s) that reduce costs and promote cup quality.

We found that overall cup scores only varied significantly ($F(2,57) = [1.378]$, $p = 0.260$) at the high elevation site where agitated fermentation scored higher than that of both submerged and dry fermentation types. There was no significant difference in the time required to complete fermentation between any fermentation type at either site ($t(27) = [1.261]$, $p = 0.218$).

Exploring further the effects of fermentation on specific cup attributes as recognized by the Specialty Coffee Association of America (SCAA), we discovered that the body attribute of coffees processed with dry fermentation consistently scored higher than that of both sub and agitated fermentation at both high and low elevations. This could be used to the advantage of wet mills to improve coffees or to meet buyer demands. Additionally, the body attribute along with acidity, aftertaste, and balance consistently showed significant differences in the ANOVA tests which might highlight attributes that fermentation has greater influence over but further tests would be needed to confirm.

Although the choice of which fermentation type to use is highly dependent upon the working environment, wet mill goals, and wet mill capabilities, our data suggests that dry fermentation could be a suitable alternative to submerged fermentation at high elevation sites as well as both submerged and agitated fermentation at low elevation sites in the Gedio Zone of Ethiopia. It is cautioned however, that dry fermentation be managed carefully at lower elevations. If done correctly, wet mills could save on costs associated with water usage. Additionally, dry fermentation can also reduce the environmental impact of a wet mill as less water is used in preparing coffee and waste could be more easily managed and treated.

Introduction

In cooperation with Technoserve (TNS), we have undertaken a series of experiments to identify and address bottlenecks in coffee wet mill operations that could impact their profitability and to provide managers with data backed recommendations for mitigation. This is a long-term effort in which we will continually adapt and undertake new experiments as guided by TNS staff and/or data from previous experiments.

For this first season, our efforts were focused on the effect of fermentation types, mainly dry, submerged and agitated, on cup scores and overall time to completion. Through this we hoped to identify a fermentation type(s) that reduce costs, speed process times and promotes, or at least, maintains cup quality in an effort to boost wet mill profitability.

Although there are exceptions, many times, and especially with larger wet mills, maintaining profitability is a volumes game. The more coffee that can be processed in a given season, the lower the production costs and the greater the returns. To do this coffee needs to flow through the station into warehouses as quickly and efficiently as possible without compromising quality. One of the largest bottlenecks for wet mills operations in Ethiopia is fermentation. Currently, submerged fermentation is used extensively throughout the country, and the Gedio Zone, and fermentation times can take between 30 to 48 hours depending upon the site (*personal observations*). The number of fermentation tanks at any one site is limited and keeping parchment fermenting for 48 hours can impede the flow of coffee through a wet mill by reducing the quantity of cherry a wet mill can process in a given night.

Dry fermentation is thought to ease this bottleneck and provide several benefits as compared to submerged fermentation types. These benefits include faster fermentation times because water is not added to parchment, sugar concentrations remain higher thereby promoting microbial activity (i.e. fermentation). Savings in water consumption because water is not added during fermentation, less water is used during coffee processing which can reduce wet mill production costs. Finally, dry fermentation can also reduce waste storage, maintenance and treatment costs because less water is used in dry fermentation, less water needs to be treated and smaller lagoons need to be constructed and maintained. This can also help a wet mill more easily transition towards more environmentally friendly operations if proper protocols are put in place.

Although there are several benefits to dry fermentation, it has not been undertaken at scale in the Gedio Zone of Ethiopia. This study will hopefully provide key insights into dry fermentation and its application to promote its use if proven beneficial. Furthermore, we included several other analyses to observe the impacts of other variables in the wet mill process flow to identify new areas for continued research and further exploration.

Scope of Study

We established experimental sites at three locations of varying elevation within the Gedio Zone of Southern Nations Nationalities and Peoples Republic (SNNPR). To make cherry acquisition easier and to comply with local regulation, these sites were constructed within the compounds of partner wet mills or at TNS facilities.

The first experimental site was established at the TNS office in Dilla. This site represented our lowland (< 1,600 m.a.s.l.) facility with an elevation of ~1,500 m.a.s.l. The second experimental site was established in Wonango at the Finchewa Cooperative. This cooperative is a member of the Yirgachefe Union and represented our mid-elevation site (1,700 - 1,800 m.a.s.l.) with an elevation of about ~1,800 m.a.s.l. The final site was constructed at the Haptamu Getu Site in Gedeb and represented our highland site (>1,900 m.a.s.l.) with an elevation of ~2,000 m.a.s.l.

It is important to note that due to unforeseen setbacks and an unusually short harvest window, experiments were not able to be completed at the mid-elevation, FInchewa, site although it was readied for operations. Instead, attention was given to the lowland and highland sites. Although this represents a significant setback, results obtained at high and low elevation sites still capture variability occurring across the full elevational spectrum.

Objectives

In coordination with TNS, several research objectives were made for the coffee harvest season of 2022/23. As this was the first year of planned experimentation, we realized that there would likely be an operational learning curve and we set objectives accordingly. Where possible, we simplified goals and recorded as much information as possible to identify opportunities for future studies. Objectives from this season were derived from previous TNS experiments where greater robustness of results was desired. Alternative hypotheses were set as follows:

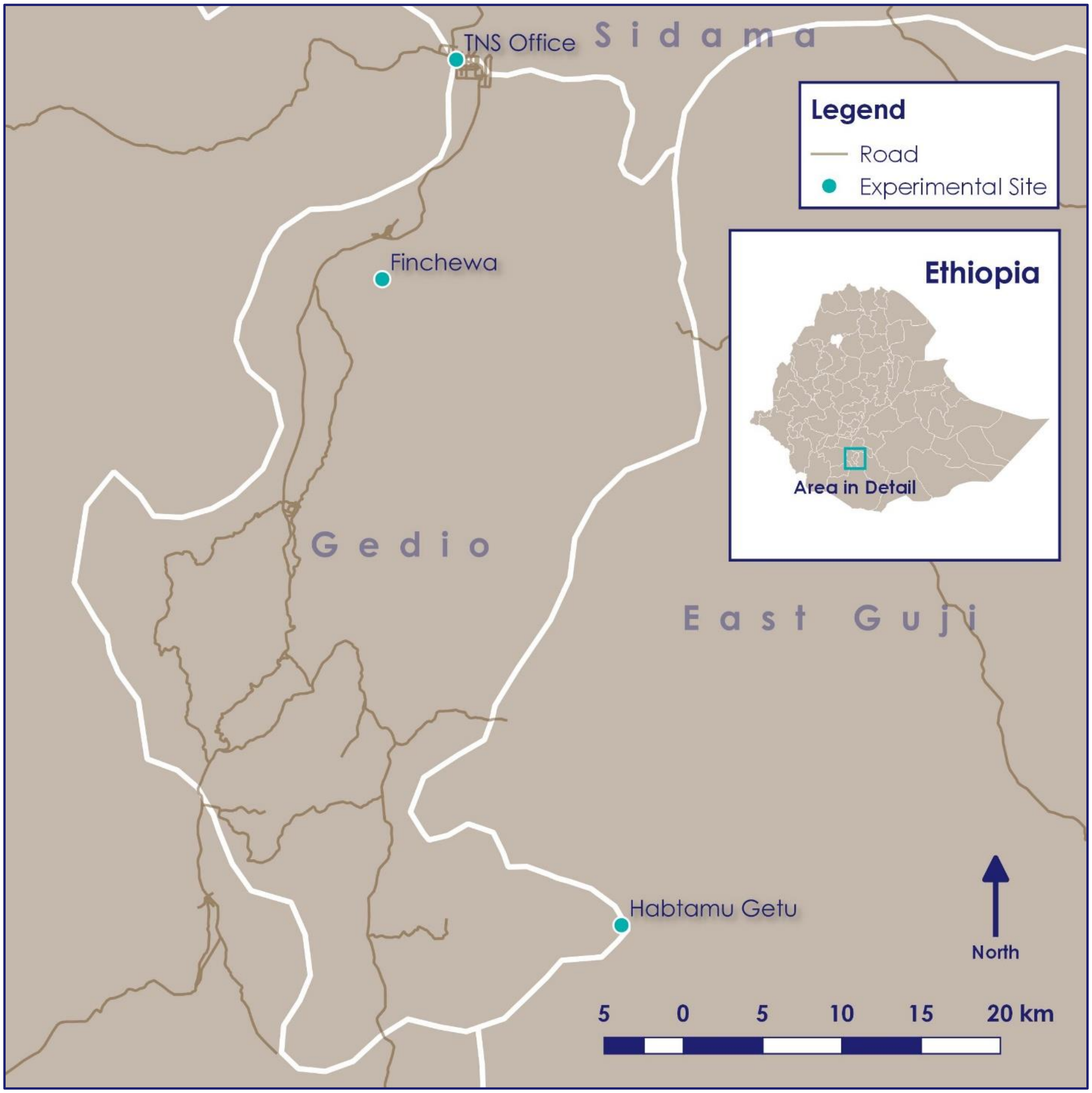

Figure 01. Locations of experimental sites established in Gedio Zone, SNNPR for the coffee harvest season of 2022/23.

• **H_{A1}:** There is a difference (p = 0.05) in the overall cup score of coffee lots produced via dry fermentation*, submerged fermentation^, and agitated fermentation⁰ regardless of site elevation;

• **H_{A2}:** There is a difference ($p = 0.05$) in the overall cup score of coffee lots produced via dry fermentation[*], submerged fermentation[^], and agitated fermentation[0] at the high elevation site;

• **H_{A3}:** There is a difference ($p = 0.05$) in the overall cup score of coffee lots produced via dry fermentation[*], submerged fermentation[^], and agitated fermentation[0] at the low elevation site;

• **H_{A4}:** There is a difference ($p = 0.05$) in the fermentation rates of coffee lots produced via dry fermentation[*], submerged fermentation[^], and agitated fermentation[0] regardless of site elevation;

• **H_{A5}:** There is a difference ($p = 0.05$) in the fermentation rates of coffee lots produced via dry fermentation[*], submerged fermentation[^], and agitated fermentation[0] at the high elevation site;

• **H_{A6}:** There is a difference ($p = 0.05$) in the fermentation rates of coffee lots produced via dry fermentation[*], submerged fermentation[^], and agitated fermentation[0] at the low elevation site;

Note: *[*]Dry fermentation is coffee that is fermented in fermentation tanks without the addition of water it is then washed and graded in washing channels; [^]submerged fermentation is classic washed coffee that is submerged in water for fermentation and is then washed and graded in washing channels; [0]Agitated fermentation is the same process as submerged fermentation but the coffee lot is agitated/stirred at predefined intervals when the lot is submerged in water.*

Methodology

Experiment Sites:

Experiment facilities were constructed in a similar fashion across all sites. Each included $62m^2$ of raised drying beds. Drying beds were comprised of eucalyptus poles for the bed framing. The bed surface was furnished of bamboo poles laid horizontally across the bed frames. Chicken wire was then tacked over this surface and a final layer of black plastic shade netting was placed over the chicken wire. This created a solid surface for coffee parchment to dry on and mimics common construction practices at partner wet mills thus ensuring representative results.

Each experimental site also included a small shade structure measuring 2m x 3m framed with eucalyptus poles and tin roofing. Jute was tacked to the side walls to create shade for fermentation which aided in controlling fermentation temperatures.

Highland experiment site at Habtamu Getu Wet Mill in Gedeb.

Dilla experiment site under construction at the TNS office.

Cherry Acquisition, Processing and Fermentation:

At the lowland site, coffee cherry was collected from Wonago and transported back to Dilla for experimental processing. At the high elevation site cherry was collected directly from the partner wet mill. New coffee cherry was purchased after the previous fermentation trial was completed. For each trial, 50kg of coffee cherry were purchased.

Upon receival, the cherry was placed onto a clean tarpaulin sheet. It was quickly rinsed with clean water and mixed to ensure an even distribution of ripe, immature and otherwise defect beans. From the mass, five (5) kg of cherry were measured and from this red ripe, over ripe, and immature cherry were sorted and weighed to account for differences in cherry quality upon fermentation and cupping results. This cherry was then reintroduced to the original mass and mixed again. Cherry was then floated in clean water and floaters were placed directly on the drying beds.

Remaining cherry was then pulped. Pulping machines varied. A drum pulper was used at the lowland site and a disc pulper was used at the highland site. Parchment with mucilage was then distributed equally, by eye, into three separate fermentation barrels. Barrels were blue in color and had a volume of 100lt. Barrels were labeled and prepared as per their fermentation type and immediately placed under the shade structure. For submerged and agitated fermentation, water was added to the barrels to a level of 10cm, or 1 finger length, above the level of parchment fill.

Fermentation and ambient conditions were then recorded throughout the fermentation process. These measurements included the date, time, atmospheric temperature (°C), the temperature of the parchment mass (°C), parchment mass pH, and Brix measurement (% sugar). These measurements were taken on an hourly basis during working hours and every two hours at night.

Fermentation was considered complete when the parchment reached a pH level of 4.6. At this point, parchment was removed from the barrels and washed by vigorously rubbing parchment by hand and using clean water. The parchment was washed several times until all mucilage was removed and was then transported to the drying beds.

Drying:

After washing coffee was placed onto the raised beds for drying. The parchment was heaped into a layer of ~5cm thickness. When drying, the mass was rotated or thoroughly mixed on an hourly basis during the day and every two hours at night which allowed for even drying. Parchment was covered by shade netting during the extreme heat of the day 1100 hours through 1400 hours. In the event of rain, parchment was covered with plastic sheeting. Parchment was covered by both shade netting and plastic sheeting at night.

Drying measurements were taken on an hourly interval during working hours and every two hours at night. These measurements included date, time, atmospheric temperature (°C), parchment temperature (°C), ambient humidity (%), moisture content of parchment (%), density (g/lt.), weather condition (sunny, partly cloudy, cloudy, raining), if the parchment was covered (Y/N), if the parchment was mixed (Y/N), and if the parchment depth on the drying bed was checked (Y/N).

These measurements were continued until the parchment reached a percent moisture content of 11% after which, the parchment was moved into a clean PP bag, labeled and put into a cool location for storage as provided by the partner wet mill staff. Parchment, if stored at a partner WET MILL site, was collected and transported to the TNS Dilla office for storage and curing upon next site visit by staff.

Cupping:

Parchment was allowed to rest for at least three weeks following completion of drying to allow for the coffee beans to cure and the free water molecules within the coffee beans to settle. Coffee from each lot was then roasted and cupped as per SCAA standard protocols in the TNS Dilla Coffee Lab. Each coffee was roasted and cupped on three separate occasions.

Cupping with TNS staff at the TNS Dilla Coffee Lab.

Analysis:

After cupping collection, fermentation, drying and cupping information was gathered, cleaned and prepared for analysis. Cupping results were compiled and overall cup scores as well as individual cup attributes as recognized by the SCAA (i.e. body, flavor, acidity, etc.) were analyzed using ANOVA tests, t-tests and regression analyses.

Results

Site Trends

In total, 11 fermentation trials were conducted across all experimental sites (7 lowland and 4 highland). Each trial consisted of three different fermentation types (i.e. dry, submerged, agitation) thus totaling 33 (21 lowland and 12 highland) unique fermentation tests.

Fermentation at the lowland site (SD = 9.941) took on average 27.86 hours (SD = 9.941) to complete but was not statistically different ($t(27) = [1.261]$, $p = 0.218$) from highland sites with an average of 23.83 hours (SD = 8.108) to complete. In addition, fermentation times between fermentation treatements within both lowland ($F(2, 18) = [0.036]$, $p = 0.964$) and highland ($F(2, 9) = [0.209]$, $p = 0.815$) sites were not significantly different.

Mean ambient temperatures at the lowland sites (SD = 1.642) proved significantly different (t(16) = [6.05], p = < 0.000) from the mean ambient temperatures at the highland site (SD = 0.851). This temperature difference was also observed in the temperatures of parchment mass (dry fermentation) and water (submerged and agitated fermentation) where mean lowland site (SD = 0.766) temperatures were significantly different from mean highland site (SD = 1.050) temperatures.

Mean temperatures of parchment mass/water however, did not significantly differ between fermentation types at any particular site. ANOVA tests of mean parchment/water temperatures at the lowland site showed no significant difference (F(2, 18) = [0.036], p = 0.964) between fermentation treatments. This was similar to the highland site where the ANOVA test again showed no significant difference between fermentation treatments (F(2, 9) = [0.209], p = 0.814).

Fermentation (General Trends)

The first objective of data analysis was to determine if there was a significant difference in cup scores between different fermentation types regardless of site elevation (Figure 02). These tests revealed that there was a statistically significant difference in the mean cupping scores between at least two fermentation types for acidity (F(2, 93) = [7.57], p = 0.0008), aftertaste (F(2,93) = [5.54], p = 0.0005), balance (F(2,93) = [5.54], p = 0.005), body (F(2,93) = [3.09], p = 3.24×10^{-7}) and uniformity (F(2,93) = [8.05], p = 0.001) attributes. There was however, no significant difference found between any fermentation type and their total cup score (F(2,93) = [1.86], p = 0.161). Other non-significant ANOVA analyses can be found in Appenix I.

Tukey's HSD tests for multiple comparisons found that the mean scores for dry fermentation as compared to submerged and agitated were significantly less for aftertaste, and uniformity cup attributes but scored significantly higher in the body attribute score. The mean score for dry fermentation was also found to be significantly less than the mean scores for agitated fermentation for acidity and balance cup attributes (Table 01).

Figure 02. Cup attribute scores for different fermentation types across all sites.

Table 01. Post Hoc results for Tukey's HSD Test for multiple comparisons (fermentation dependent).

Cup Attribute	Tested Group Pairs	Absolute Difference	Standard Error	Q Tukey Score	$Q_{0.05}$ Tukey Critical Value	Significant Result
Acidity	Dry v. Submerged	0.203	0.078	2.601	3.37	Not Significant
	Dry v. Agitated	0.430	0.078	5.503	3.37	Significant
	Submerged v. Agitated	0.227	0.078	2.901	3.37	Not Significant
Aftertaste	Dry v. Submerged	0.281	0.077	3.656	3.37	Significant
	Dry v. Agitated	0.430	0.077	5.586	3.37	Significant
	Submerged v. Agitated	0.148	0.077	1.930	3.37	Not Significant
Balance	Dry v. Submerged	0.242	0.078	3.111	3.37	Not Significant
	Dry v. Agitated	0.359	0.078	4.616	3.37	Significant
	Submerged v. Agitated	0.117	0.078	1.505	3.37	Not Significant

Body	Dry v. Submerged	0.414	0.065	6.364	3.37	Significant
	Dry v. Agitated	0.516	0.065	7.925	3.37	Significant
	Submerged v. Agitated	0.102	0.065	1.561	3.37	Not Significant
Uniformity	Dry v. Submerged	0.219	0.056	3.882	3.37	Significant
	Dry v. Agitated	0.297	0.056	5.270	3.37	Significant
	Submerged v. Agitated	0.078	0.056	1.387	3.37	Not Significant

Fermentation (Site Specific)

Our second objective of data analysis was to determine if fermentation types exhibited site or elevation specific trends on cup scores. For this, a series of one-way ANOVA test were completed to compare the effect of fermentation type on cup attributes and overall score for both the lowland and highland sites respectively.

For the lowland site, these tests revealed that there was a statistically significant difference in the mean cupping scores between at least two fermentation types for acidity ($F(2, 57) = [7.19]$, $p = 0.002$), body ($F(2,57) = [13.94]$, $p = 1.18x10^{-5}$), balance (($F(2,57) = [3.94$, $p = 0.025$) and uniformity ($F(2,57) = [6.25]$, $p = 0.003$) attributes (Figure 03). There was however, no significant difference found between any fermentation type and their total cup score ($F(2,57) = [1.378]$, $p = 0.260$)(Appendix II).

Tukey's HSD tests for multiple comparisons found that the mean scores for dry fermentation as compared to submerged and agitated fermentation scored significantly less for acidity and uniformity but had a significantly higher mean body score. The mean scores for balance and aftertaste were found to be significantly less in dry fermentation trials as compared to agitated fermentation trials (Table 02).

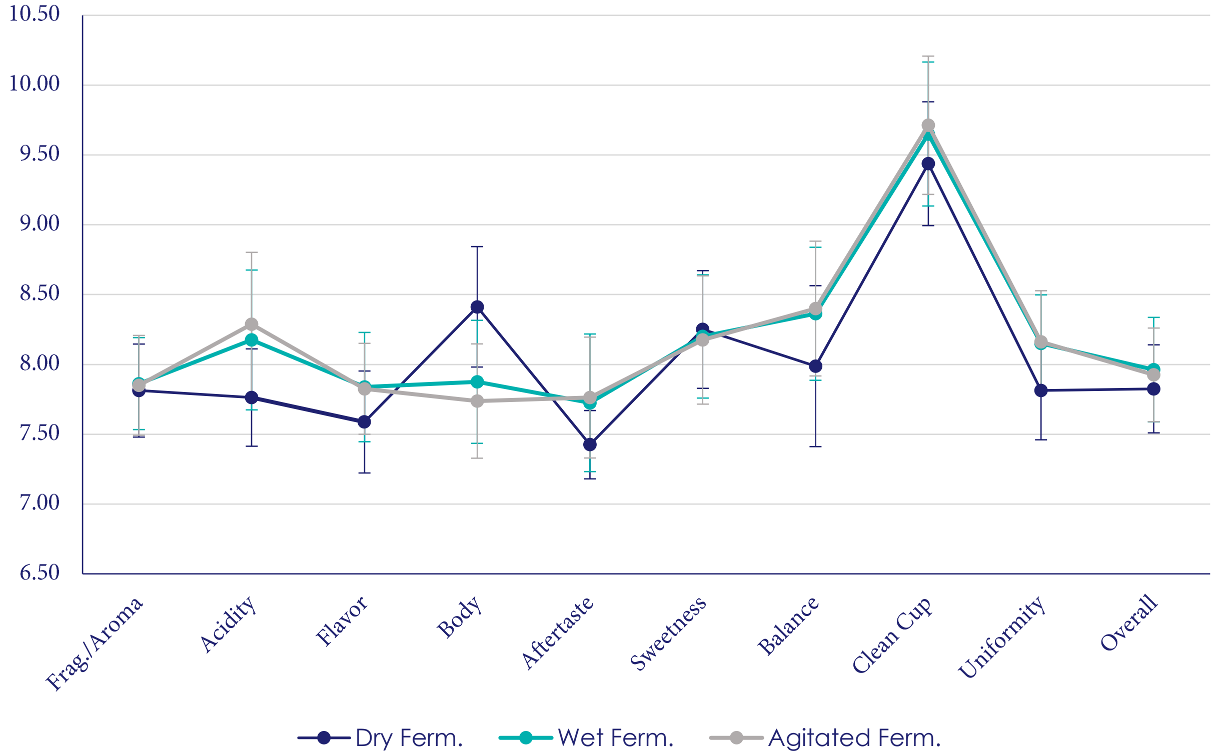

Figure 03. Cup attribute scores for different fermentation types at lowland site.

One-way ANOVA tests were then completed to compare the effect of fermentation type on cup attributes and overall score for the highland site. It was revealed that there was a statistically significant difference in the mean cupping scores (Figure 04) between at least two fermentation types for acidity (F(2, 33) = [4.58], p = 0.017), aftertaste (F(2, 33) = [11.79], p = 0.0001), balance (F(2, 33) = [3.74], p = 0.034), body (F(2, 33) = [5.015], p = 0.013), flavor (F(2, 33) = [4.58], p = 0.017) and overall (F(2,33) = [3.392], p = 0.045. In addition, there was a significant difference found between the total cup scores of at least two fermentation types (F(2,57) = [1.378], p = 0.260)(Appendix III).

Table 02. Post Hoc results for Tukey's HSD Test for multiple comparisons for the lowland site.

Cup Attribute	Tested Group Pairs	Absolute Difference	Standard Error	Q Tukey Score	$Q_{0.05}$ Tukey Critical Value	Significant Result
Acidity	Dry v. Submerged	0.413	0.103	4.003	3.40	Significant
	Dry v. Agitated	0.525	0.103	5.094	3.40	Significant
	Submerged v. Agitated	0.112	0.103	1.092	3.40	Not Significant
Aftertaste	Dry v. Submerged	0.300	0.090	3.320	3.40	Not Significant
	Dry v. Agitated	0.038	0.090	3.735	3.40	Significant
	Submerged v. Agitated	0.338	0.090	0.415	3.40	Not Significant
Balance	Dry v. Submerged	0.375	0.115	3.264	3.40	Not Significant
	Dry v. Agitated	0.413	0.115	3.591	3.40	Significant
	Submerged v. Agitated	0.037	0.115	0.326	3.40	Not Significant
Body	Dry v. Submerged	0.538	0.095	5.626	3.40	Significant
	Dry v. Agitated	0.675	0.095	7.065	3.40	Significant
	Submerged v. Agitated	0.138	0.095	1.439	3.40	Not Significant
Uniformity	Dry v. Submerged	0.338	0.079	4.249	3.40	Significant
	Dry v. Agitated	0.350	0.079	4.406	3.40	Significant
	Submerged v. Agitated	0.012	0.079	0.157	3.40	Not Significant

Tukey's HSD tests for multiple comparisons were run and found that the mean scores for acidity and flavor of submerged fermentation were significantly lower than that of agitated fermentation. The mean score for aftertaste for dry fermentation was significantly less than the means scores for both submerged and agitated fermentation types. The mean score for balance for dry fermentation was significantly less than that of agitated fermentation. The mean score for the overall cup attribute although shown to have a significant difference from our ANOVA test has proven not significant in the Tukey HSD test. The mean score of body for dry fermentation was significantly greater than both submerged and agitated fermentation types. Finally, the mean total cup score for agitated fermentation was proven significantly greater than the same scores for dry and submerged agitation (Table 03).

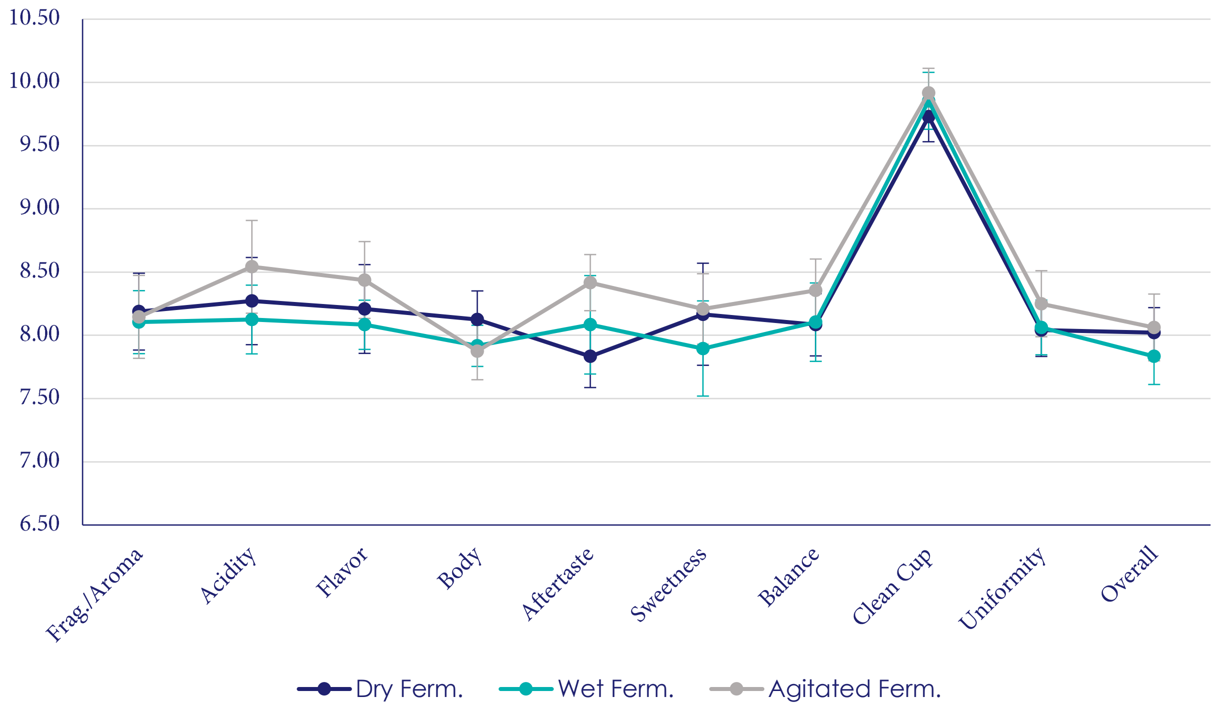

Figure 04. Cup attribute scores for different fermentation types at highland site.

Table. 03 Post Hoc results for Tukey's HSD Test for multiple comparisons for the highland site.

Cup Attribute	Tested Group Pairs	Absolute Difference	Standard Error	Q Tukey Score	$Q_{0.05}$ Tukey Critical Value	Significant Result
Acidity	Dry v. Submerged	0.146	0.095	1.530	3.47	Not Significant
	Dry v. Agitated	0.271	0.095	2.841	3.47	Not Significant
	Submerged v. Agitated	0.417	0.095	4.371	3.47	Significant
Aftertaste	Dry v. Submerged	0.250	0.085	2.934	3.47	Not Significant
	Dry v. Agitated	0.583	0.085	6.846	3.47	Significant
	Submerged v. Agitated	0.333	0.085	3.912	3.47	Significant
Balance	Dry v. Submerged	0.021	0.078	0.267	3.47	Not Significant
	Dry v. Agitated	0.271	0.078	3.474	3.47	Significant
	Submerged v. Agitated	0.250	0.078	3.207	3.47	Not Significant

Body	Dry v. Submerged	0.208	0.060	3.483	3.47	Significant
	Dry v. Agitated	0.250	0.060	4.180	3.47	Significant
	Submerged v. Agitated	0.042	0.060	0.697	3.47	Not Significant
Flavor	Dry v. Submerged	0.125	0.084	1.490	3.47	Not Significant
	Dry v. Agitated	0.354	0.084	4.222	3.47	Significant
	Submerged v. Agitated	0.229	0.084	2.732	3.47	Not Significant
Overall	Dry v. Submerged	0.188	0.066	2.829	3.47	Not Significant
	Dry v. Agitated	0.042	0.066	0.629	3.47	Not Significant
	Submerged v. Agitated	0.229	0.066	3.458	3.47	Not Significant
Total	Dry v. Submerged	0.604	0.441	1.371	3.47	Not Significant
	Dry v. Agitated	1.542	0.441	4.869	3.47	Significant
	Submerged v. Agitated	2.146	0.441	3.498	3.47	Significant

Fermentation (Between Sites/Elevation Specific)

A series of t-tests were conducted to compare the cupping scores of each fermentation trial across sites to see if there was a significant difference between lowland and highland sites. Dry fermentation displayed the greatest significant difference between sites (Figure 05) with cup attributes including fragrance/aroma (M Highland = [8.19], SD Highland = [0.304] and M Lowland [7.81], SD Lowland = [0.333]; t(25) = [-3.258], p = 0.003), acidity (M Highland = [8.27], SD Highland = [0.345] and M Lowland [7.76], SD Lowland = [0.349]; t(20) = [-4.021], p = < 0.000), body (M Highland = [8.12], SD Highland = [0.226] and M Lowland [8.41], SD Lowland = [0.431]; t(30) = [2.469], p = < 0.000), flavor (M Highland = [8.21], SD Highland = [0.351] and M Lowland [7.59], SD Lowland = [0.365]; t(24) = [-4.772], p = < 0.000), aftertaste (M Highland = [7.83], SD Highland = [0.345] and M Lowland [7.42], SD Lowland = [0.349]; t(23) = [-4.553], p = < 0.000), clean cup (M Highland = [9.73], SD Highland = [0.198] and M Lowland [9.43], SD Lowland = [0.443]; t(28) = [-2.548], p = 0.017), uniformity (M Highland = [8.04], SD Highland = [0.209] and M Lowland [7.81], SD Lowland = [0.352]; t(30) = [-2.310], p = 0.028), overall (M Highland = [8.02], SD Highland = [0.198] and M Lowland [7.82], SD

Lowland = [0.315]; t(30) = [-2.157], p = 0.039), total cup score (M Highland = [82.67], SD Highland = [1.400] and M Lowland [80.31], SD Lowland = [2.741]; t(29) = [-3.207], p = 0.003)(Appendix IV).

Submerged fermentation showed significant difference in four cup attributes (Figure 06) including fragrance/aroma (M Highland = [8.10], SD Highland = [0.249] and M Lowland [7.86], SD Lowland = [0.329]; t(28) = [-2.349], p = 0.026), flavor (M Highland = [8.08], SD Highland = [0.194] and M Lowland [7.84], SD Lowland = [0.391]; t(29) = [-2.364], p = 0.025), aftertaste (M Highland = [8.08], SD Highland = [0.389] and M Lowland [7.72], SD Lowland = [0.493]; t(28) = [-2.277], p = 0.031), and sweetness (M Highland = [7.90], SD Highland = [0.376] and M Lowland [8.20], SD Lowland = [0.441]; t(26) = [2.073], p = 0.048) (Appendix IV).

Agitated fermentation also showed significant difference in four cup attributes as well (Figure 07) including fragrance/aroma (M Highland = [8.15], SD Highland = [0.328] and M Lowland [7.85], SD Lowland = [0.357]; t(25) = [-2.389], p = 0.025), flavor (M Highland = [8.44], SD Highland = [0.304] and M Lowland [7.82], SD Lowland = [0.325]; t(25) = [-5.374], p = < 0.000), aftertaste (M Highland = [8.42], SD Highland = [0.223] and M Lowland [7.76], SD Lowland = [0.433]; t(30) = [-5.636], p = < 0.000), total cup score (M Highland = [84.21], SD Highland = [1.598] and M Lowland [81.47], SD Lowland = [3.077]; t(30) = [-3.300], p = 0.003)(Appendix IV).

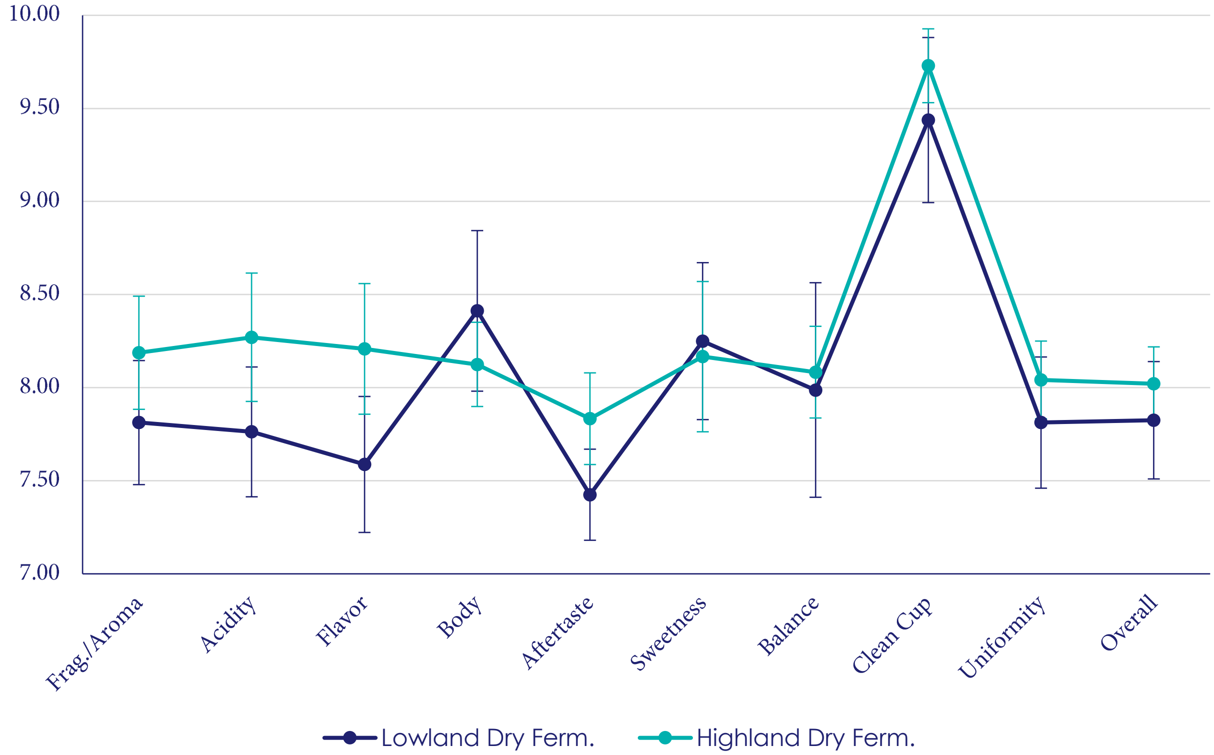

Figure 05. Cup attribute scores for dry fermentation at lowland and highland sites.

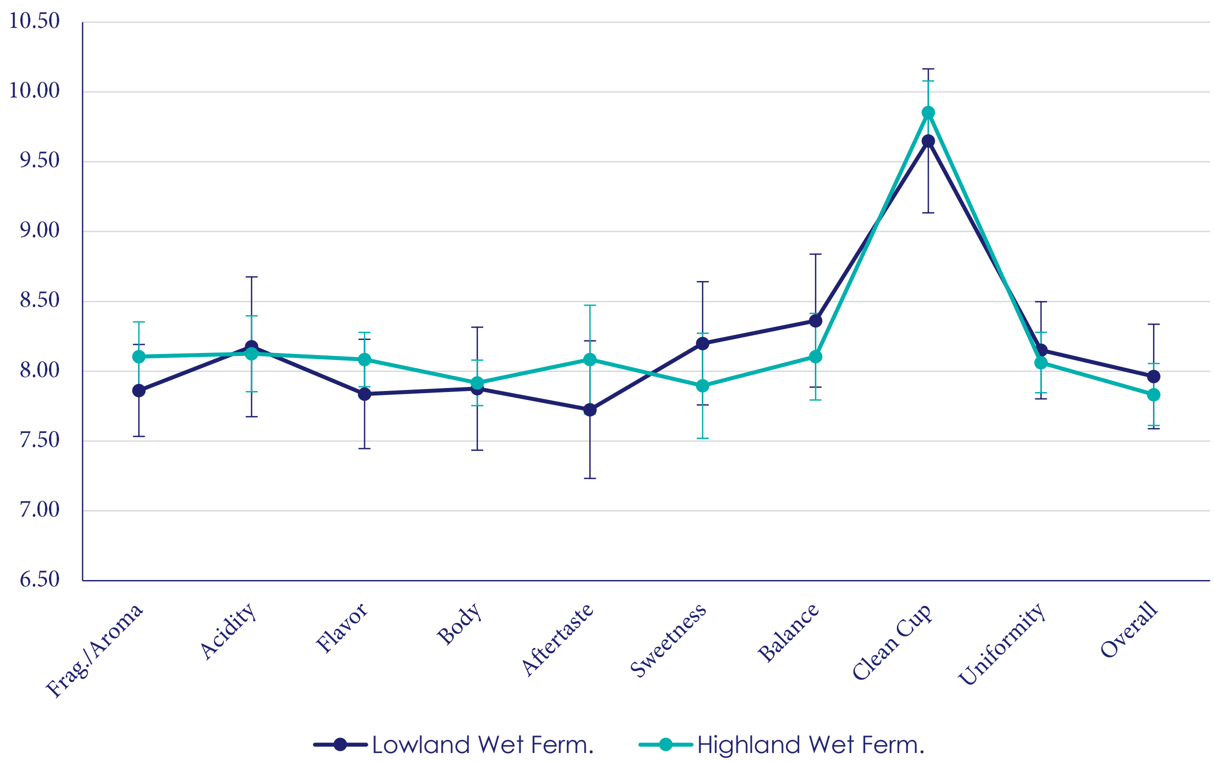

Figure 06. Cup attribute scores for submerged fermentation at lowland and highland sites.

Figure 07. Cup attribute scores for agitated fermentation at lowland and highland sites.

External Factors

A series of regression analyses were completed to analyze the impacts of external factors on cup quality. The first regression analyses was used to test if percent ripe cherry (Figure 08), percent immature cherry (Figure 09) and percent overripe cherry (Figure 10) significantly predicted the total cup score for all experimental sites.

The fitted regression model was: Total Cup Score = 81.48 + 0.04*(% ripe cherry) - 0.12*(% immature cherry) - 0.02*(% overripe cherry). Although the overall regression was statistically significant ($R^2 = 0.24$, $F(3, 89) = 9.42$, p = < 0.00), it was found that percent ripe cherry (β = 0.04, p = 0.73), percent immature cherry (β = -0.12, p = 0.39) and percent overripe cherry (β = -0.02, p = 0.88) did not significantly predict total cup score.

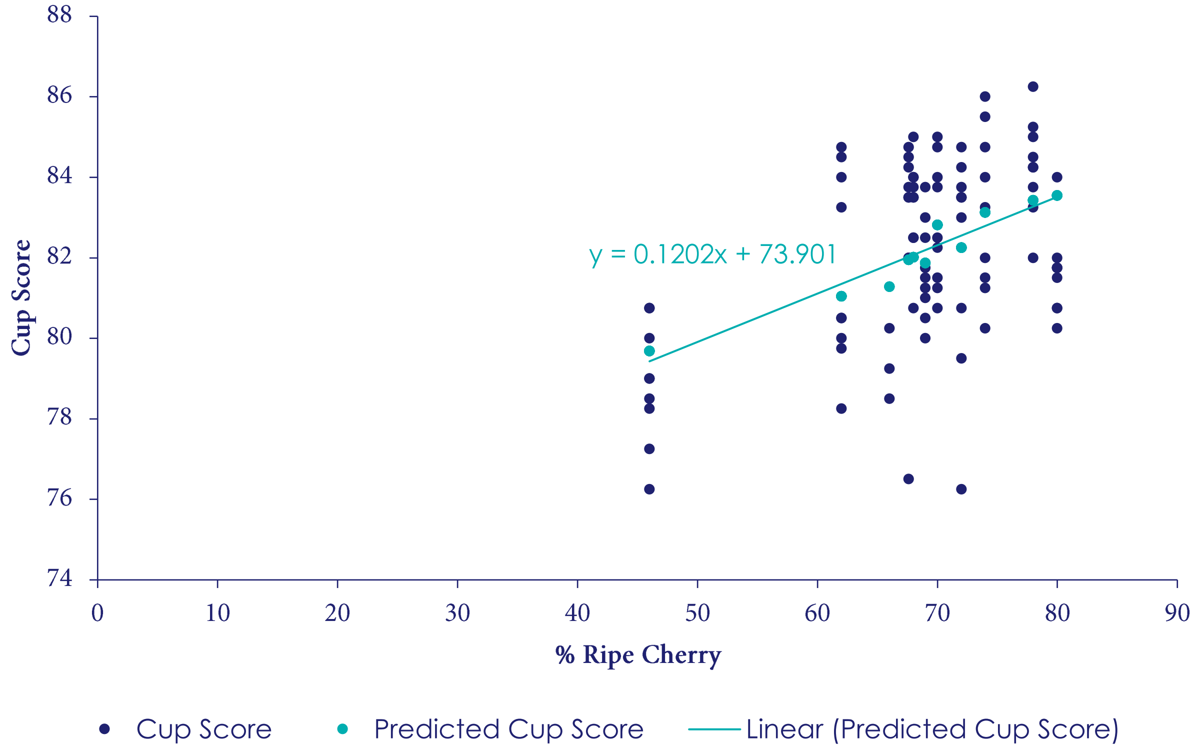

Figure 08. Regression plot of percent ripe cherry as predictor of cup score.

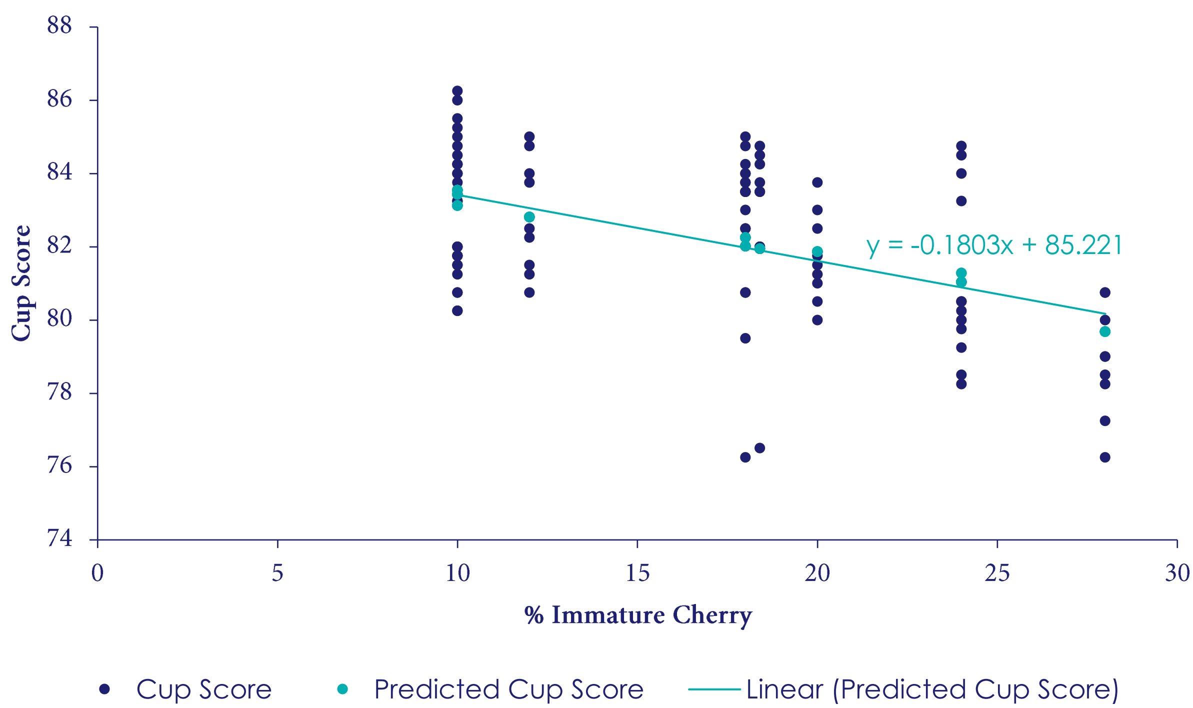

Figure 09. Regression plot of percent immature cherry as predictor of cup score.

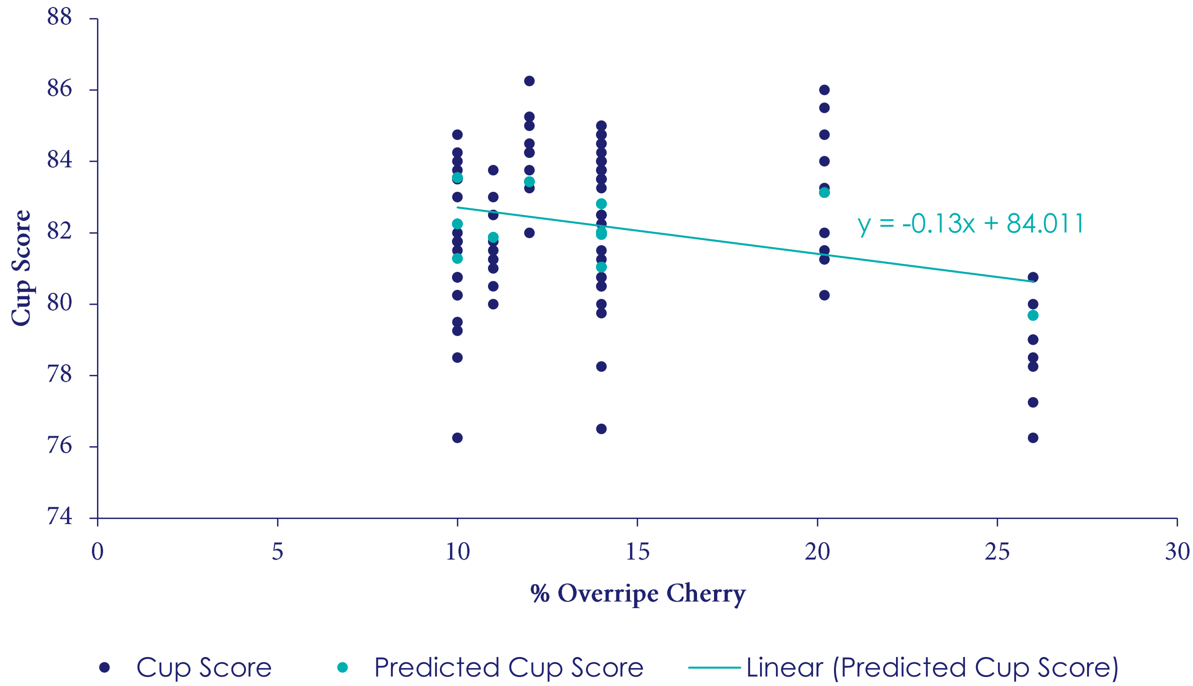

Figure 10. Regression plot of percent immature cherry as predictor of cup score.

The second multiple regression analyses was used to determine if ambient (Figure 11) and parchment mass/water temperature (°C)(Figure 12) significantly predicted the total cup score for all experimental lots. The fitted regression model was: Total Cup Score = 88.21 - 0.60*(atmospheric temperature (°C)) + 0.01*(water/mass temperature (°C)). The overall regression was found to be statistically significant (R^2 = 0.19, $F(2, 90) = 10.23$, p = < 0.00). It was found that atmospheric temperature (°C) (β = -0.06, p = <0.00) significantly predicted total cup score. Water/mass temperature (°C) (β = 0.01, p = 0.90) was found to not significantly impact total cup score.

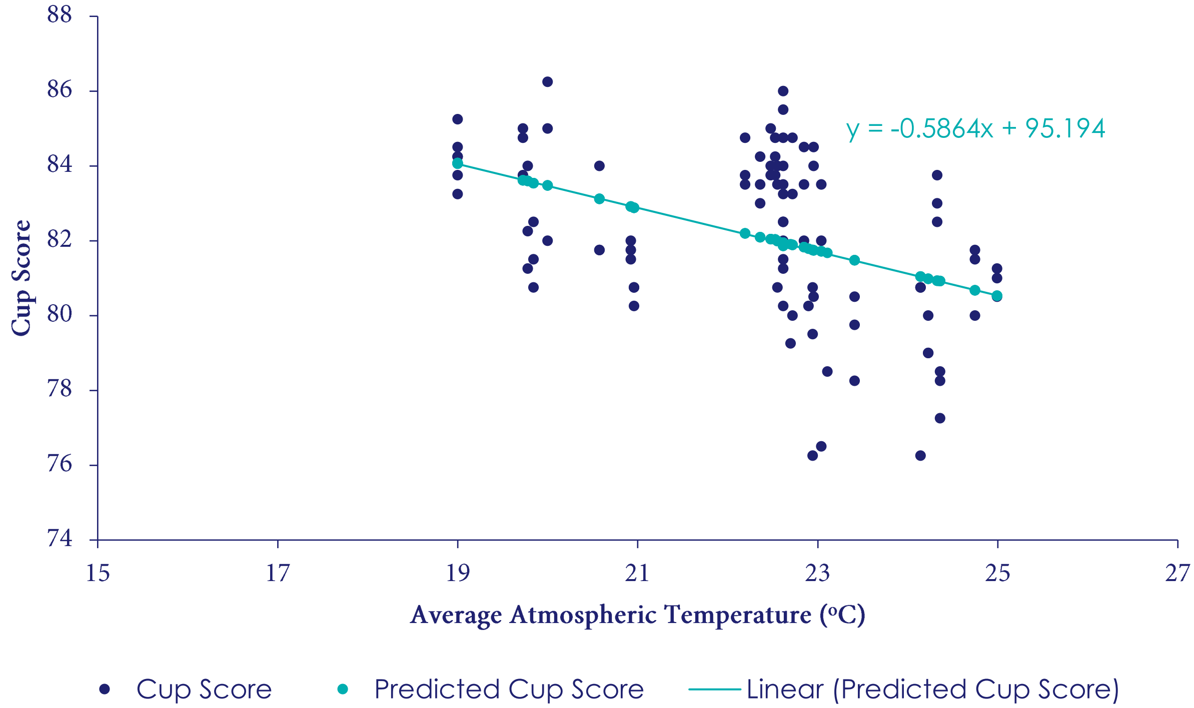

Figure 11. Regression plot of mean atmospheric temperature (ᵒC) as a predictor of cup score.

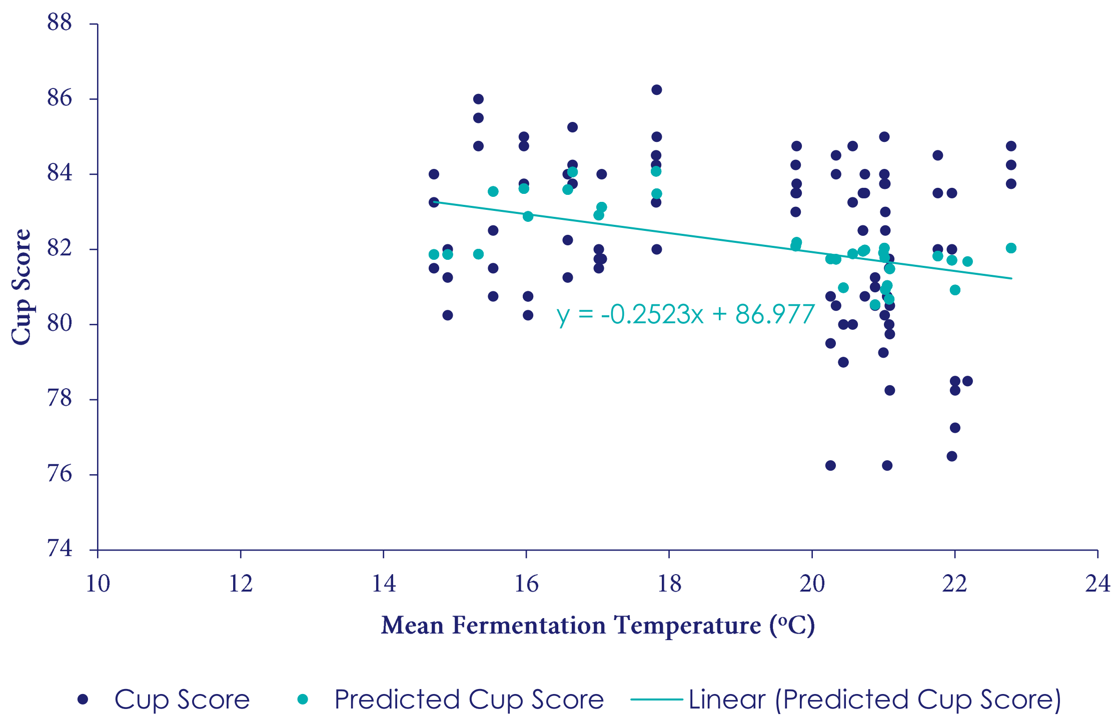

Figure 12. Regression plot of parchment mass/water fermentation temperature (ᵒC) as a predictor of cup score.

Conclusion

Fermentation and Cup Quality

The effect of fermentation type on overall cup scores was limited. When data from all sites was compiled, there was no significant difference in the total cup score between any of the three fermentation trails. This same trend was also observed at the low elevation site. Only agitated fermentation at the highland site returned a significantly higher difference in its total cup score as compared to both dry and submerged fermentation which can be attributed to its significantly higher scores in acidity, aftertaste, flavor and balance cup attributes. It is our assumption that stirring the parchment mass creates an equilibrium in the fermentation environment which allows for key processes (i.e. leaching, fermentation, etc.) to occur at consistent levels across the mass and individual coffee beans which results in the better attribute scores.

Interestingly, acidity, aftertaste, balance and body, returned significant differences across all ANOVA tests, even when total cup scores showed no significant difference. We believe this begins to highlight the specific effects of fermentation on cup profiles. In addition, the body attribute scored significantly higher for dry fermentation in all analyses. Although not conclusive, possible reasons for better a body attribute could be related to the impact of exposure to higher concentrations of sugar, the types and concentrations of various microbe populations supported by dry fermentation, or the leaching of certain compounds and/or elements from parchment coffee when submerged in water as per the agitated and submerged trials. From these experiments, dry fermentation could be considered a useful tool to boost the body attribute of washed coffees if desired by submerged mill owners or managers or if desired by coffee buyers.

The mean score for uniformity for dry fermentation at the lowland site and across sites proved significantly lower than both submerged and agitated trials which should be viewed with caution. Although expected, as dry fermentation has higher concentrations of sugars as compared to submerged fermentation types where water is added, and sugar concentrations are diluted. More sugar and higher temperatures commonly found at lowland areas creates ideal conditions for the microbes responsible for fermentation. Here they can quickly expand making the fermentation process difficult to control. In addition, it is our belief that fermentation will occur at different rates throughout the parchment mass in dry fermentation. It is likely that certain micro-environments are present which amplify fermentation in portions of the mass resulting in uneven fermentation and a lack of uniformity in the cup.

It is common knowledge that coffee grown at higher elevations, usually attains higher cup scores as compared to coffee grown at low elevations. Although we did not set a specific hypothesis to test for this, we did run a series of tests to see if our results ran parallel with industry standards. For our trials, we found that coffees processed at higher elevations scored higher than those processed at low elevations following industry norms and supporting the validity of our results.

Overall we failed to reject our null hypotheses H_{O1} and H_{O3} but we successfully reject H_{O2} as agitated fermentation had a significantly better mean cup score as compared to dry and submerged fermentation.

- **H_{O1}:** There is no difference ($p = 0.05$) in the overall cup score of coffee lots produced via dry fermentation*, submerged fermentation^, and agitated fermentation⁰ regardless of site elevation.
- **H_{A2}:** There is a difference ($p = 0.05$) in the overall cup score of coffee lots produced via dry fermentation*, submerged fermentation^, and agitated fermentation⁰ at the high elevation site.
- **H_{O3}:** There is no difference ($p = 0.05$) in the overall cup score of coffee lots produced via dry fermentation*, submerged fermentation^, and agitated fermentation⁰ at the low elevation site.

Fermentation Times

Although we expected to find a difference in the time required to complete fermentation between trials, none were found and we failed to reject all null hypotheses as follows:

- **H_{O4}:** There is no difference ($p = 0.05$) in the fermentation rates of coffee lots produced via dry fermentation*, submerged fermentation^, and agitated fermentation⁰ regardless of site elevation;
- **H_{O5}:** There is no difference ($p = 0.05$) in the fermentation rates of coffee lots produced via dry fermentation*, submerged fermentation^, and agitated fermentation⁰ at the high elevation site;

• **H_{O6}:** There is no difference ($p = 0.05$) in the fermentation rates of coffee lots produced via dry fermentation*, submerged fermentation^, and agitated fermentation⁰ at the low elevation site.

This was surprising to us as first as we expected dry fermentation, without water, to be quicker as it was exposed to higher daytime temperatures which would accelerate microbial activity. And although higher temperatures were observed, what was not accounted for was that at night the dry fermentation mass also experienced colder temperatures. Fermentation types where water has added were buffered against extreme cold and extreme hot temperatures. We believe this helps to explain why fermentation times did not vary significantly but further tests would need to be completed to verify this. It is our recommendation that tests on larger parchment masses also be considered to confirm if these same trends are present at scales that submerged mills operate.

External Factors

During fermentation trials, several independent variables were measured. These variable were fitted to regression curves as a predictor of cup quality with the hope that we could identify, or begin to identify, other factors that contribute to cup quality and merit further study in the future.

Our first regression looked at the composition of cherry deliveries in terms of ripe, immature and overripe as a predictor of cup quality. Although the overall model was proven significant, no individual variable (Figures 08, 09 and 10) proved to be a significant predictor. This however, was expected because cup quality relies on many factors and not simply the quality of cherry. Regardless, our model predicted that 24% of cup quality could be explained by the composition of cherry delivery with percent ripe cherry having a positive correlation with cup score and percent immature and overripe cherry having a negative correlation with cup scores which is to be expected and further verifies the model.

Our second regression analysis plotted the impact of both atmospheric temperature (°C) and fermentation time as a predictor of cup score. The regression model predicted that 20% of cup quality could be attributed to these two factors and both had a negative correlation with cup score. Interestingly, overall fermentation time has a negative correlation with cup quality meaning that the longer a coffee ferments, the lower its score. This goes against local coffee processing customs in Ethiopia where coffees are sometime fermented for 48 hours as it is seen as boosting quality. Before any recommendations could be given, further tests would be required.

Atmospheric temperature also displayed a negative correlation with cup score. Although this relationship was statistically significant, we are skeptical in the interpretation of this result as we believe this is highlighting the difference in inherent quality of highland vs lowland coffee and not necessarily related to higher temperatures resulting in lower cup scores.

Moving Forward

Recommendations

Our results showed that there is no difference in the fermentation times required by dry, submerged and agitated fermentation types. Furthermore, cup scores were also largely found to be statistically similar. Without a significant difference in either fermentation time nor cup score, dry fermentation could be considered a viable, cost saving and environmentally friendly option for submerged mill managers that are looking to reduce their costs on water procurement, treatment and usage. Additionally, for those looking for environmental certifications, dry fermentation could prove a reliable option as the process produces less wastewater which is easier and cheaper to manage and treat.

There should be caution given to submerged mill owners and managers at low elevations however, as we noticed uniformity scored significantly lower than other fermentation types at the same elevation. We believe this is a result of the higher temperatures found at lower elevations making dry fermentation harder to control. Without closely monitoring parchment masses or using a demucilager to control mucilage levels, fermentation could quickly spiral out of control and ruin entire lots of coffee making submerged mill operations unprofitable.

A final note, dry fermentation resulted in better body attributes in the cup profiles across all sites. For submerged mill owners and managers looking to boost this cup attribute, dry fermentation could be recommended as a means to do so.

The only significant total cup score difference in our trials occurred at the highland site where agitated fermentation resulted in higher cupping scores and improvement in several cup attributes as compared to dry and submerged fermentation. This suggests that agitated fermentation could be recommended to wet mill owners and managers that are looking to maximize the quality of their coffee at high elevations. This could be beneficial for highland submerged mills as cherry sold here is usually more costly and maintaining better cupping scores will help capture better sales prices, in turn keeping submerged mills profitable.

Results from this experiment, demonstrate that a diversity of fermentation options to boost quality, cost savings, environmental friendliness or specific cup attributes exist. Choosing a fermentation type needs to be made carefully however and in consideration of the goals of the submerged mill owner and manager, the local working environment, client expectations, etc. Fermentation may not be the only option for meeting specific submerged mill goals or even the best option and as such should be approached with cautious optimism.

Future Research

These trials exposed several new avenues for possible research as listed below:

1.) How does fermentation time impact cup quality and score in the Gedio Zone;

2.) How does cherry composition (ripe, overripe, immature) impact cup quality and score in the Gedio Zone;

3.) Why does dry fermentation boost the body of coffee profiles;

4.) How does percent mucilage removal impact cup quality and score in the Gedio Zone;

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Appendix I. ANOVA tests results for compiled cup results from both the lowland and highland site.

						df between groups	2
						df within group	93
Groups	***Count***	***Sum***	***Average***	***Var.***	***F***	***P-value***	***F crit.***
DRY Frag./Aroma	32	254.5	7.953	0.135			
SUB Frag./Aroma	32	254.5	7.953	0.103			
AGI Frag./Aroma	32	254.75	7.961	0.138			
ANOVA Result					**0.005**	**0.995**	**3.094**
DRY Acidity	32	254.5	7.953	0.179			
SUB Acidity	32	261	8.156	0.180			
AGI Acidity	32	268.25	8.383	0.226			
ANOVA Result					**7.577**	**0.001**	**3.094**
DRY Flavor	32	250.25	7.820	0.219			
SUB Flavor	32	253.75	7.930	0.122			
AGI Flavor	32	257.75	8.055	0.188			
ANOVA Result					**2.496**	**0.088**	**3.094**
DRY Body	32	265.75	8.305	0.152			
SUB Body	32	252.5	7.891	0.129			
AGI Body	32	249.25	7.789	0.125			
ANOVA Result					**17.624**	**0.000**	**3.094**
DRY Aftertaste	32	242.5	7.578	0.099			
SUB Aftertaste	32	251.5	7.859	0.234			
AGI Aftertaste	32	256.25	8.008	0.236			
ANOVA Result					**8.050**	**0.001**	**3.094**
DRY Sweetness	32	263	8.219	0.168			
SUB Sweetness	32	258.75	8.086	0.192			
AGI Sweetness	32	262	8.188	0.157			
ANOVA Result					**0.894**	**0.412**	**3.094**
DRY Balance	32	256.75	8.023	0.227			
SUB Balance	32	264.5	8.266	0.189			
AGI Balance	32	268.25	8.383	0.165			
ANOVA Result					**5.543**	**0.005**	**3.094**
DRY Clean Cup	32	305.5	9.547	0.155			
SUB Clean Cup	32	311.25	9.727	0.191			
AGI Clean Cup	32	313.25	9.789	0.174			
ANOVA Result					**2.920**	**0.059**	**3.094**
DRY Uniformity	32	252.75	7.898	0.104			
SUB Uniformity	32	259.75	8.117	0.093			
AGI Uniformity	32	262.25	8.195	0.108			
ANOVA Result					**7.460**	**0.001**	**3.094**
DRY Overall	32	252.75	7.898	0.084			
SUB Overall	32	253.25	7.914	0.107			
AGI Overall	32	255.25	7.977	0.098			
ANOVA Result					**0.566**	**0.569**	**3.094**
DRY Cup Score	32	2598.25	81.195	6.640			
SUB Cup Score	32	2620.75	81.898	6.806			
AGI Cup Score	32	2640.00	82.500	8.516			
ANOVA Result					**1.864**	**0.161**	**3.094**

Appendix II. ANOVA tests results for cup scores from the lowland site.

ANOVA Tests					df between groups		2
SUMMARY					df within group		57
Groups	**Count**	**Sum**	**Average**	**Var.**	**F**	**P-value**	**F crit.**
DRY Frag./Aroma	20	156.25	7.813	0.111			
SUB Frag./Aroma	20	157.25	7.863	0.108			
AGI Frag./Aroma	20	157.00	7.850	0.128			
ANOVA Result					**0.117**	**0.890**	**3.159**
DRY Acidity	20	155.25	7.763	0.122			
SUB Acidity	20	163.50	8.175	0.251			
AGI Acidity	20	165.75	8.288	0.265			
ANOVA Result					**7.195**	**0.002**	**3.159**
DRY Flavor	20	151.75	7.588	0.133			
SUB Flavor	20	156.75	7.838	0.153			
AGI Flavor	20	156.50	7.825	0.106			
ANOVA Result					**3.034**	**0.056**	**3.159**
DRY Body	20	168.25	8.413	0.186			
SUB Body	20	157.50	7.875	0.194			
AGI Body	20	154.75	7.738	0.168			
ANOVA Result					**13.939**	**0.000**	**3.159**
DRY Aftertaste	20	148.50	7.425	0.060			
SUB Aftertaste	20	154.50	7.725	0.243			
AGI Aftertaste	20	155.25	7.763	0.187			
ANOVA Result					**4.190**	**0.020**	**3.159**
DRY Sweetness	20	165.00	8.250	0.178			
SUB Sweetness	20	164.00	8.200	0.195			
AGI Sweetness	20	163.50	8.175	0.211			
ANOVA Result					**0.150**	**0.861**	**3.159**
DRY Balance	20	159.75	7.988	0.332			
SUB Balance	20	167.25	8.363	0.227			
AGI Balance	20	168.00	8.400	0.233			
ANOVA Result					**3.943**	**0.025**	**3.159**
DRY Clean Cup	20	188.75	9.438	0.197			
SUB Clean Cup	20	193.00	9.650	0.266			
AGI Clean Cup	20	194.25	9.713	0.245			
ANOVA Result					**1.762**	**0.181**	**3.159**
DRY Uniformity	20	156.25	7.813	0.124			
SUB Uniformity	20	163.00	8.150	0.121			
AGI Uniformity	20	163.25	8.163	0.133			
ANOVA Result					**6.248**	**0.004**	**3.159**
DRY Overall	20	156.50	7.825	0.099			
SUB Overall	20	159.25	7.963	0.140			
AGI Overall	20	158.50	7.925	0.113			
ANOVA Result					**0.862**	**0.428**	**3.159**
DRY Cup Score	20	1606.25	80.313	7.512			
SUB Cup Score	20	1636.00	81.800	9.642			
AGI Cup Score	20	1629.50	81.475	9.466			
ANOVA Result					**1.378**	**0.260**	**3.159**

Appendix III. ANOVA tests results for cup scores from the highland site.

					df between groups		2
SUMMARY					df within group		57
Groups	***Count***	***Sum***	***Average***	***Var.***	***F***	***P-value***	***F crit.***
DRY Frag./Aroma	12	98.25	8.188	0.092			
SUB Frag./Aroma	12	97.25	8.104	0.062			
AGI Frag./Aroma	12	97.75	8.146	0.107			
ANOVA Result					**0.239**	**0.789**	**3.285**
DRY Acidity	12	99.25	8.271	0.119			
SUB Acidity	12	97.5	8.125	0.074			
AGI Acidity	12	102.5	8.542	0.134			
ANOVA Result					**4.919**	**0.013**	**3.285**
DRY Flavor	12	98.5	8.208	0.123			
SUB Flavor	12	97	8.083	0.038			
AGI Flavor	12	101.25	8.438	0.092			
ANOVA Result					**4.585**	**0.017**	**3.285**
DRY Body	12	97.5	8.125	0.051			
SUB Body	12	95	7.917	0.027			
AGI Body	12	94.5	7.875	0.051			
ANOVA Result					**5.015**	**0.013**	**3.285**
DRY Aftertaste	12	94	7.833	0.061			
SUB Aftertaste	12	97	8.083	0.152			
AGI Aftertaste	12	101	8.417	0.049			
ANOVA Result					**11.797**	**0.000**	**3.285**
DRY Sweetness	12	98	8.167	0.163			
SUB Sweetness	12	94.75	7.896	0.142			
AGI Sweetness	12	98.5	8.208	0.078			
ANOVA Result					**2.713**	**0.081**	**3.285**
DRY Balance	12	97	8.083	0.061			
SUB Balance	12	97.25	8.104	0.096			
AGI Balance	12	100.25	8.354	0.062			
ANOVA Result					**3.738**	**0.034**	**3.285**
DRY Clean Cup	12	116.75	9.729	0.039			
SUB Clean Cup	12	118.25	9.854	0.051			
AGI Clean Cup	12	119	9.917	0.038			
ANOVA Result					**2.567**	**0.092**	**3.285**
DRY Uniformity	12	96.5	8.042	0.044			
SUB Uniformity	12	96.75	8.063	0.047			
AGI Uniformity	12	99	8.250	0.068			
ANOVA Result					**2.988**	**0.064**	**3.285**
DRY Overall	12	96.25	8.021	0.039			
SUB Overall	12	94	7.833	0.049			
AGI Overall	12	96.75	8.063	0.070			
ANOVA Result					**3.392**	**0.046**	**3.285**
DRY Cup Score	12	992	82.667	1.958			
SUB Cup Score	12	984.75	82.063	2.479			
AGI Cup Score	12	1010.5	84.208	2.555			
ANOVA Result					**6.304**	**0.005**	**3.285**

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Appendix IV. T-test results comparing coffee cupping scores between the lowland and highland sites for each fermentation trial.

Dry Fermentation	Fragrance/ Aroma		Acidity		Body		Flavor		Aftertaste		Sweetness		Balance		Clean cup		Uniformity		Overall		Cup Score	
Mean	7.813	8.188	7.763	8.271	8.413	8.125	7.588	8.208	7.425	7.833	8.250	8.167	7.988	8.083	9.438	9.729	7.813	8.042	7.825	8.021	80.313	82.667
Variance	0.111	0.092	0.122	0.119	0.186	0.051	0.133	0.123	0.060	0.061	0.178	0.163	0.332	0.061	0.197	0.039	0.124	0.044	0.099	0.039	7.512	1.958
Observation(s)	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12
df	25		20		30		24		23		24		28		28		30		30		29	
	-		-				-		-				-		-		-		-			
t Stat	3.258		4.021		2.469		4.772		4.553		0.556		0.651		2.548		2.310		2.157		-3.207	
P(T<=t) one-tail	0.002		0.000		0.010		0.000		0.000		0.292		0.260		0.008		0.014		0.020		0.002	
t Critical one-tail	1.708		1.711		1.697		1.711		1.714		1.711		1.701		1.701		1.697		1.697		1.699	
P(T<=t) two-tail	0.003		0.000		0.019		0.000		0.000		0.583		0.520		0.017		0.028		0.039		0.003	
t Critical two-tail	2.060		2.064		2.042		2.064		2.069		2.064		2.048		2.048		2.042		2.042		2.045	

Sub Fermentation	Fragrance/ Aroma		Acidity		Body		Flavor		Aftertaste		Sweetness		Balance		Clean cup		Uniformity		Overall		Cup Score	
Mean	7.863	8.104	8.175	8.125	7.875	7.917	7.838	8.083	7.725	8.083	8.200	7.896	8.363	8.104	9.650	9.854	8.150	8.063	7.963	7.833	81.800	82.063
Variance	0.108	0.062	0.251	0.074	0.194	0.027	0.153	0.038	0.243	0.152	0.195	0.142	0.227	0.096	0.266	0.051	0.121	0.047	0.140	0.049	9.642	2.479
Observation(s)	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12
df	28		30		26		29		28		26		30		28		30		30		29	
	-				-		-		-						-							
t Stat	2.349		0.366		0.382		2.364		2.277		2.073		1.857		1.543		0.877		1.226		-0.316	
P(T<=t) one-tail	0.013		0.359		0.353		0.012		0.015		0.024		0.037		0.067		0.194		0.115		0.377	
t Critical one-tail	1.701		1.697		1.706		1.699		1.701		1.706		1.697		1.701		1.697		1.697		1.699	
P(T<=t) two-tail	0.026		0.717		0.706		0.025		0.031		0.048		0.073		0.134		0.388		0.230		0.754	
t Critical two-tail	2.048		2.042		2.056		2.045		2.048		2.056		2.042		2.048		2.042		2.042		2.045	

Agitated Fermentation	Fragrance/ Aroma		Acidity		Body		Flavor		Aftertaste		Sweetness		Balance		Clean cup		Uniformity		Overall		Cup Score	
Mean	7.850	8.146	8.288	8.542	7.738	7.864	7.825	8.438	7.763	8.417	8.175	8.208	8.400	8.354	9.713	9.917	8.163	8.250	7.925	8.063	81.475	84.208
Variance	0.128	0.107	0.265	0.134	0.168	0.055	0.106	0.092	0.187	0.049	0.211	0.078	0.233	0.062	0.245	0.038	0.133	0.068	0.113	0.070	9.466	2.555
Observation(s)	20	12	20	12	20	11	20	12	20	12	20	12	20	12	20	12	20	12	20	12	20	12
df	25		30		29		25		30		30		30		27		29		28		30	
	-		-		-		-		-		-				-		-		-			
t Stat	2.389		1.625		1.092		5.374		5.636		0.255		0.353		1.644		0.787		1.286		-3.300	
P(T<=t) one-tail	0.012		0.057		0.142		0.000		0.000		0.400		0.363		0.056		0.219		0.104		0.001	
t Critical one-tail	1.708		1.699		1.699		1.708		1.697		1.697		1.697		1.703		1.699		1.701		1.697	
P(T<=t) two-tail	0.025		0.115		0.284		0.000		0.000		0.800		0.726		0.112		0.437		0.209		0.003	
t Critical two-tail	2.060		2.045		2.045		2.060		2.042		2.042		2.042		2.052		2.045		2.048		2.042	